D4.4 – TeamMate HMI design, implementation and V&V results from 2nd cycle

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1 Introduction

The activities in the Automate project have been organized in 3 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 2 cycles are focused on the development and technical validation of the components (i.e. the enablers) performed in WP2, WP3 and 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 are planned to be integrated into the demonstrators in WP5, and the performances of the 1st version of the demonstrators are evaluated against their baseline in WP6.

In the 3rd cycle, WP2, WP3 and WP4 are fed with the results of this evaluation process to deliver the final version of the enablers. The 3rd cycle ends with the evaluation of the final version of the demonstrators.

This deliverable describes the current state of the enablers developed in WP4 in the first half of the 2nd cycle, as well as the experiments conducted and proposed to technically validate them according to the validation plan and the requirements and metrics defined in D4.3.

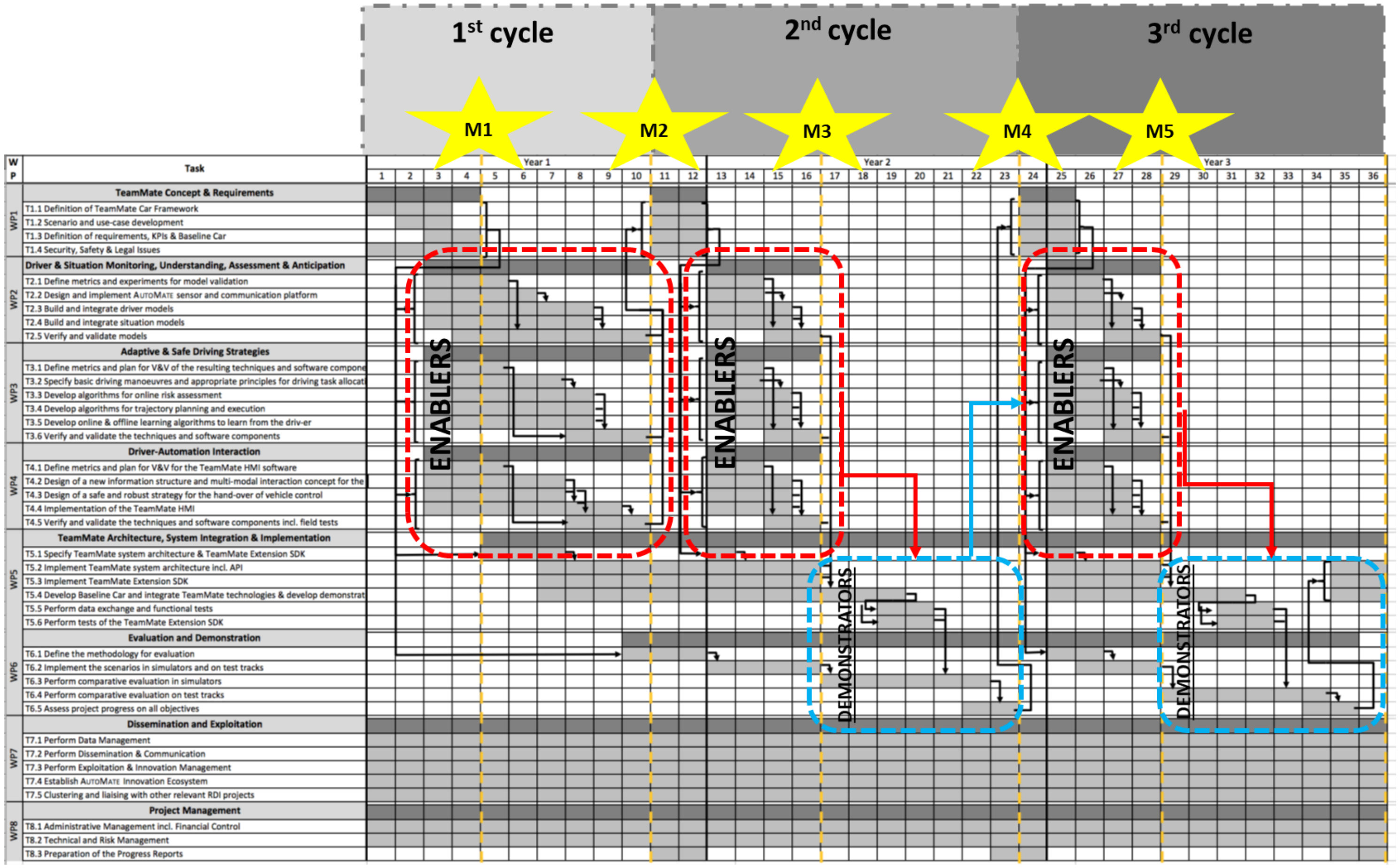


Figure 1: Project cycles, milestones and link between enablers (WP2, WP3 and WP4) and demonstrators (WP5 and WP6)

The development of all enablers follows the same process for WP2, WP3 and WP4. Therefore, the deliverable D2.4, D3.5 and D4.4 that describe the status of the development and validation of the enablers have been structured with the same chapters to reflect the common (parallel) process followed in WP2, WP3 and WP4 to deliver all enablers in time to be integrated into the demonstrators.

This deliverable includes 5 chapters:

- Chapter 1: Introduction
- Chapter 2: How the WP4 enablers contribute to the implementation of the concept of the project
- Chapter 3: Status of WP4 enablers in cycle 2
- Chapter 4: Validation
- Chapter 5: Conclusion

2 How the WP4 enablers contribute to the implementation of the concept of the project

The top-level objective of AutoMate is to develop, evaluate and demonstrate the “TeamMate Car” concept as a major enabler of highly automated vehicles.

This concept consists of considering the driver and the automation as members of one team that understand and support each other in pursuing cooperatively the goal of driving safely, efficiently and comfortably from A to B.

As a consequence, in order to show how the enablers contribute to the implementation of this concept, it is important to briefly explain why the cooperation is needed, and how the human and the automation can support each other to create a safe, efficient and comfortable driving experience.

As shown in Figure 2, both the human and the automation have **limits** that can negatively affect the safety as well as the efficiency, the comfort, the trust and the acceptance of the autonomous driving.

For the human, the limits are often related to his/her driving performance: they are likely to affect the safety, and cause accidents.

For the automation, the limits, mostly at perception and decision level, may affect the efficiency and the comfort of the trip, and then, in turn, the acceptance of the automation.

The AutoMate approach is based on the mutual complementarity between the driver and the automation: this support is achieved through the cooperation between the team members.

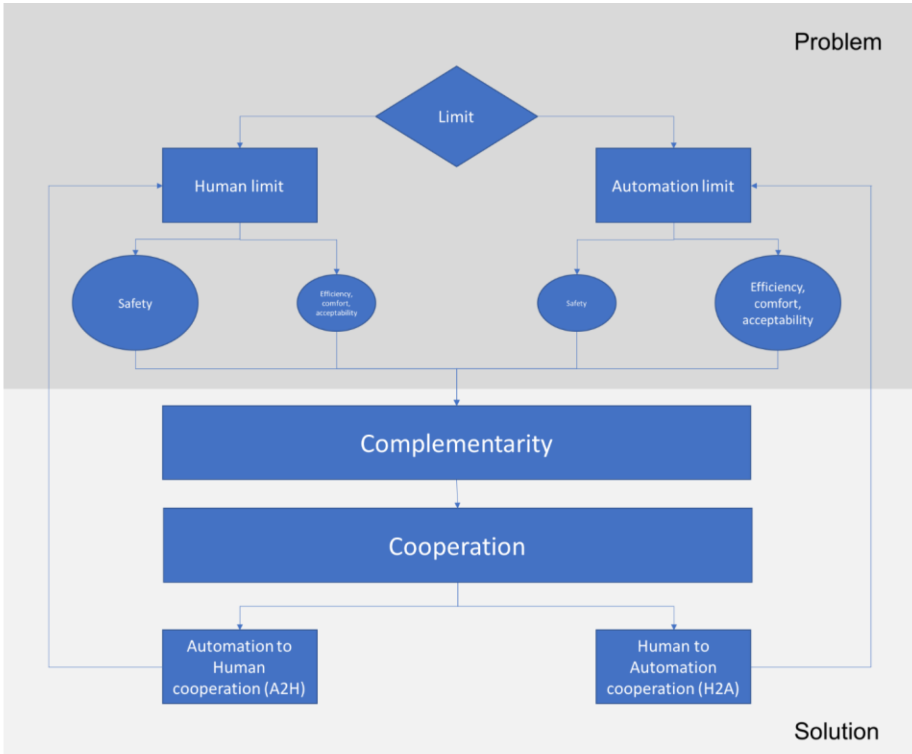


Figure 2: Schematic representation of the overall concept of the project

While the Automation to Human support (A2H) is used to complement the human limits, the Human to Automation (H2A) is implemented to allow the driver to support the automation to overcome its limits.

The complementarity between the driver and the automation is the conceptual solution to compensate the reciprocal limitations, while the cooperation is how the complementarity is implemented. Figure 3 shows how both the A2H and the H2A support can be implemented in perception (state A and B) and in action (state C and D).

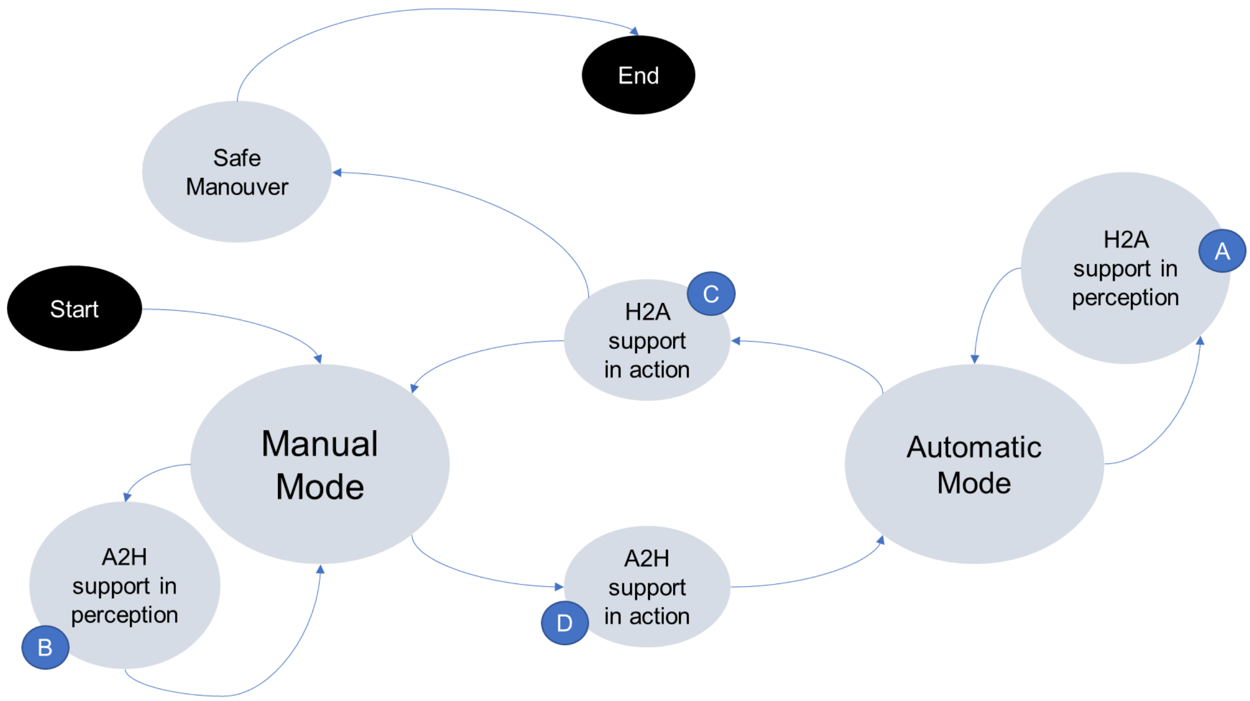


Figure 3: State machine that shows how the cooperation is implemented

The innovative solution developed in AutoMate is to provide, through the HMI, a support that doesn't not request a transition of control, but only a support in perception to compensate that specific limit.

The scenarios and use cases selected to demonstrate the relevance of each enabler are therefore representative and consistent with the direction of cooperation implemented by that enabler, as well as the modality of support (i.e. either in action or perception).

Since the cooperation is implemented through the enablers developed in the project,

Table 1 shows the role and relevance of each enabler in the cooperation.

WP	ID	Enabler	Enabler Owner	Aim of the enabler	Direction of support	
					Automation to Human	Human to Automation
WP4	**Enabler 6: HMI**					
	E6.1	Interaction modality	ULM	Define the best way to allow the driver to provide feedback to the HMI		**In perception and in action (negotiation-based HMI)** to allow the driver to answer the request of support of the automation
	E6.2	Instrument Cluster + audio	REL	Show information on driving-related features and request of support.	**In perception and in action (warning-based HMI)** either to inform the driver about a potential risk or to take the control of the vehicle	**In perception and in action (negotiation-based HMI)** to ask the driver either for support in perception or in action
	E6.3	Central Display	REL	Show information and allow interaction with non-driving-related features.	**In perception (warning-based HMI)** to inform the driver about a potential risk	**In perception and in action (negotiation-based HMI)** to ask the driver either for support in perception or in action
	E6.4	Ambient lights	ULM REL	Reinforce the awareness of an information.		**In perception and in action** to improve the

						communication of the expected support
	E6.5	Augmented Reality	HMT	Show information on the windshield to improve their comprehensibility (for simulators only).	**In perception (warning-based HMI)** to inform the driver about a potential risk	**In perception and in action (negotiation-based HMI)** to ask the driver either for support in perception or in action
	E6.6	HUD	REL	Show information on a small area in the windshield, to increase the "eyes-on-the-road" factor.	**In perception (warning-based HMI)** to inform the driver about a potential risk	**In perception and in action (negotiation-based HMI)** to ask the driver either for support in perception or in action

Table 1 How the enablers in WP4 support the cooperation

3 Status of WP4 enablers in cycle 2

In this chapter, the status of the HMI at the end of the 2nd cycle is described. In particular, the improvements compared to the first cycle are highlighted. Furthermore, in order to clarify how the enablers are able to support the cooperation and then to be consistent with the concept, the enablers have been linked to scenarios and use cases. For each enabler, a use case has been selected and the role of the module (part of enabler 6 – TeamMate HMI) has been described.

Since the concept affects the overall information structure and the HMI strategy, next section describes the new information structure updated in the 2nd cycle to be consistent with the states described in the state machine.

3.1 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 2nd 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	Possible Monitoring	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 A2H support in action (in manual driving)	Monitoring	Handle the current speed
		Be aware of the RPM
		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

The major improvement of the information structure has been to make it consistent with the updated HMI state machine. The HMI state machine represented in chapter 2 foresees the introduction of new states (according to the direction and the type of cooperation) and the removal of some of the previous states (i.e. the emergency mode). Moreover, a new state, the Safe Mode has been introduced, when the driver is not able to handle the take-over request and the car activates a recovery action, i.e. a minimum risk manoeuvre.

For the information structure, only the elements useful to increase the driver's awareness and to enable the cooperation have been selected.

3.2 HMI Strategy

On the basis of the information structure created to ensure the correct distribution of information to the driver (according to the different tasks he/she is expected to perform in each state), a HMI strategy has been defined. For each driving mode, the driver's macro-tasks and subtasks have been related to an HMI element, aimed at explaining the requested or offered support.

The main objective of the HMI strategy was to deploy the concept of the project on each enabler, i.e. to use the HMI as a means to enable the cooperation between the driver and the automation.

Since, as stated in the concept, the cooperation is bidirectional, two levels of communication were defined:

- When the direction of the support is **from the automation to human**, the communication is **warning-based**;
- When the direction of the support is **from the human to the automation**, the communication is **negotiation-based**.

As a consequence, two very different HMIs have been conceptualized, designed and implemented.
Through the warning-based HMI the automation **offers a support to the driver** (in perception or in action). This interface has a more typical structure, since the automation-to-human support is the archetypal paradigm used in automotive HMI industry and research.
Trough the negotiation-based HMI the automation **requests a support from the driver,** in particular when the request of support is in perception. This interface is used when the automation, detecting its own limits, asks a sensorial help to the driver to compensate them; the HMI state that represents this request is the state A - human to automation support in perception. In order to adapt the information to the complexity of the situation, different elements (instrument cluster, audio messages, ambient lights) have been combined into an integrated HMI designed to make the driver aware of five levels of information:

1. The **current state** of the automation;
2. Which of the two agents (the human or the automation) has a limit, in order to be aware of the **direction of the cooperation**;
3. What is the **"meta-message",** i.e. if the vehicle needs support in action or in perception;
4. What is the **message**, i.e. what is the requested/offered support;

5. What will be the **next HMI state** after the support.

To cover all these levels of information and to ensure an effective cooperation, different elements was designed.

Each element has been placed on the most suitable device. As a general approach, the driving related information (and, in particular, the information related to the cooperation) have been placed on the instrument cluster, non-driving related information have been placed on the central display (or on a separated device, i.e. on a nomadic display like a tablet).

Other elements of information were used as a means to improve the comprehension of the message or to reduce the cognitive workload requested to the driver:

- the ambient lights have been used as a tool to reinforce the comprehension of the cooperation and to discriminate the type of cooperation (in perception or in action).
- the Augmented Reality (AR) functionalities have been used to inform the driver about the vehicle’s intention (e.g. the intention to overtake)
- the Head-Up Display (HUD), as alternative to AR, was used to inform the driver about a possible danger or a disengagement.

The following tables show the HMI strategy defined for the 2nd cycle.

Manual Mode

Main driver task	Subtask	Information / HMI element	Device / Display
Driving	Handle the current speed	Speedometer	Cluster, HUD
	Be aware of the RPM	RPM	Cluster, HUD
	Check the vehicle state	Icons, telltales	Cluster
	Be aware of the automation state	Automation State Label	Cluster
Monitoring	Be aware of the long-term surrounding situation	Map	Cluster, HUD
	Be aware of the estimated time to arrival	ETA	Cluster
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

In Manual Mode the driver resources are focused on driving. In order to avoid possible distractions, in the HMI are placed only elements useful for the primary task.

The focus of the driver should be on the vehicle state and on the road. Since the most useful information for the driver in Manual Mode is the map, this element has a central role in the instrument cluster: this topic, the Navigation Centered Display Cluster, has been confirmed from the 1st cycle being one of the pillars for the HMI development, as defined also in the Description of Work.

In Manual Mode the driver will be able to manage only basic functions, i.e. only entertainment features and phone calls: other functionalities are not achievable in this mode. As shown in the state machine, from the Manual Mode (a stable mode) the driver can receive two different types of support from the Automation: if the driver's limit is in perception, the HMI activates the support in perception (state B), if the limit is in action, with possible consequences on safety, the HMI offers a support in action (state D).

Automated Mode

Main driver task	Subtask	Information	Device / Display: Driver attentive	Device / Display: Driver distracted
Possible Monitoring	Be aware of the current speed	Resized Speedometer	Cluster	Cluster
	Check the vehicle state	Icons, telltales	Cluster	Cluster
	Be aware of the possible events for disengagement	Trip representation	Cluster	Cluster
	Check the estimated time to arrival	ETA	Cluster	Cluster
	Be aware of the automation state	Automation State Label	Cluster	Cluster
Entertainment	Manage phone calls	Phone icon and label	Central display	Central display
	Manage multimedia entertainment	Radio and multimedia functions	Central display	Central display
	Select menu settings	Menu settings labels	Central display	Central display

Table 4 HMI strategy: Automated Mode

When the automation is in charge of the vehicle control, the driver is asked to stay in the loop only when a support is needed. In this modality, the driving related information are limited to basic functions such as speed and telltales. The driver should be aware only on the predictable conditions that can lead to a request of support from the vehicle.

Consistently with what has been defined in the 1st cycle, in this Mode all the entertainment functionalities are achievable since the management of these functions is the primary task for the driver.

H2A Support in perception (A)

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

Table 5 HMI strategy: H2A support in perception

The “H2A support in perception” state starts in Automated Mode, when the automation has a limit in perception and recognize not to be able to handle the situation in the most effective way. Since the driver could be distracted, an integrated HMI strategy was designed: this means that the enablers for the HMI are combined with each other, to improve the comprehension of the expected support. In this mode, the message should be complex enough to match the complexity of real driving scenarios.

In addition to the information given to be aware about the vehicle state, since in this mode a cooperation (in the form of negotiation) is needed, an explanation of the automation’s limit and a suggestion about the requested support are presented to the driver.

The HMI strategy described in Table 5 represents only the information given by the vehicle to the driver. One of the tasks of this 2nd cycle was to design and validate the most effective interaction modality to enable the communication in the opposite direction, i.e. from the driver to the automation. The design suggestions and the validation results are described in the next chapters of this deliverable. These results will serve as a basis to design the interaction in the opposite direction, i.e. how the driver should give his/her feedback and inputs to the automation.

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
	Be aware of the automation state	Automation State Label	Cluster
Receive a support from the automation	Understand the meaning of the support from the automation	Support representation	Cluster, separated device (e.g. tablet)
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

When the automation detects a human limit, it offers a support in perception to the driver. In this case the cooperation is not based on negotiation, but it is warning-based. The objective of the communication is to make the driver aware about the support given by the automation, and to exploit the support to overcome his/her limits. In addition to the information presented in Manual Mode (the stable state from which this state starts) a representation of the content of support is shown on the instrument cluster to inform the driver about the support. Entertainment functionalities, shown on the central stack display, are the same as those of Manual Mode state.

H2A Support in action (C)

Main driver task	Subtask	Information	Device / Display: Driver attentive	Device / Display: 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	Cluster
Understand the expected support, i.e. the transition	Receive the explanation of the expected support	Message about support	Cluster + audio, HUD	Cluster + audio, HUD
	Be aware of the expected behaviour	Message about expected behavior	Cluster + Ambient lights	Cluster + Ambient lights

Table 7 HMI strategy: H2A support in action

This state replaces the "Take-over state" described in D4.2. When the TeamMate car is driving in Automated Mode and notes that is not able to handle a situation, a cooperation in action in the form of take-over request is shown. In order to improve the effectiveness of the transition of control the car should be able to explain the situation that conducted to the transition, explaining implicitly the limit which led to the request of support.
Since this is a potentially critical situation, entertainment functions and information not directly linked to the transition are minimized to reduce driver's distraction.
In this mode, the comprehension of the expected support is reinforced by the ambient lights. The ambient lights have a double goal:

(i) reduce the mental demand for the detection of the support needed by the automation (perception or action);

(ii) distinguish the type of support needed by the automation, in order to adapt his/her behavior. In this case, since the ambient lights in addition to the other information is used to inform the driver about a possible critical situation (i.e. a support in perception is not enough and a transition of control is needed), a color which indicates a potential danger (yellow) is used.

A2H Support in action (D)

Main driver task	Subtask	Information / HMI element	Device / Display
Monitoring	Handle the current speed	Speedometer	Cluster
	Be aware of the RPM	RPM	Cluster
	Check the vehicle state	Icons, telltales	Cluster
	Be aware of the automation state	Automation State Label	Cluster
Understand the support, i.e. the handover	Be aware of the support received	Support representation	Cluster + audio
	Be aware of the cause of the support needed	Message about support	Cluster + audio
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

The Automation to Human support in action occurs when the automation, detecting a human limit, takes the control of the car. In this state the HMI, coming from Manual Mode, has the same structure with the addition of the information of the ongoing transition.

Due to the relevance of this kind of information, a multimodal strategy has been designed: the message and the representation in the instrument cluster is reinforced and explained by a vocal message in natural language. The message about the transition ongoing has a central role in the HMI: other information (e.g. entertainment functions) can be reached and handled with limitations.

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
	Be aware of the RPM	RPM	Cluster
	Check the vehicle state	Icons, telltales	Cluster
	Check the automation state	Automation State Label	Cluster
	Be aware of the safe manouver	Warning (safe manouver activated)	Cluster

Table 9 HMI strategy: Safe Mode

As represented in the state machine (see Chapter 2) the Safe Mode is activated when the automation is not able to handle a situation (limits in action) and a transition of control from the automation to the driver fails. In order to avoid possible consequences on safety, this state has the goal of conducting smoothly the car into a safe stop, for example with a minimum risk manouver. Since the Safe Mode is generated by a failure of the transition, i.e. an alignment of automation and human limits, the driver is expected to be out of the loop: the role of the HMI is to show information that the driver could need in case he/she'll be able to come back into the loop and react.

3.3 E6.1 - Interaction modality

3.3.1 Scenario and use case where E6.1 is relevant

As shown in
Table 1, Enabler E6.1 is needed to implement a support from the driver to the automation in perception and in action to allow the driver to answer the request of support of the automation.
One of the use cases of PETER scenario has been revised to highlight and clarify the role of E6.1 to implement the H2A support.

Peter is driving in a narrow rural road in Automated Mode. The car, arriving behind a tractor, detects that it obstructs the view. Therefore, the vehicle is not confident of the available space sideways to overtake the tractor, due to a limit in perception. Since the vehicle is not sure about the possibility to overtake, it would follow the tractor for several kms (it knows they are several kms because of the map) performing an "over-safe" manouver, until the road is wider. The TeamMate car asks Peter to check if there is enough spae to overtake. When Peter confirms there is enough space, the TeamMate car performs the overtake in Automated Mode.

3.3.2 Implementation

During the 1st cycle, the concept of a multimodal interface with different input modalities was designed in WP4. To test the different input modalities, the PETER scenario was implemented into the ULM driving simulator. Three input modalities were chosen to be tested against each other concerning their Usability and the safe assurance by the driver.
The first input modality is the natural way of initiating the overtaking maneuver. The driver has to press the indicator to the other lane and turn the steering wheel a bit into the same direction. These are the actions that

also have to be taken while driving and manual mode and starting an overtaking maneuver.

The second interaction method is the central touch display. This should represent the most common way of interacting with the car in current state of the art vehicles.

The last interaction style, is a gesture that the driver must perform with the right hand somewhere in the middle of the car. This interaction style is implemented as a wizard-of-Oz action where the researcher has to initiate the overtaking on runtime on the operating computer of the simulation.

3.3.3 Driver Modelling and Experimental Analysis with DriveGOMS

In order to gain a detailed understanding of the drivers' behaviour, and explain possible differences in the experimental outcome, the driver behaviour is modelled with a task analytical approach. Conducting empirical studies can uncover very well effects between different ADAS design variants, but the deeper reason behind these effects can remain hidden from the researcher.

DriveGOMS is a task analytical method which uses an established goal-operator-approach to model the driving task (Käthner, Andree, Ihme & Drewitz, 2015). The basic approach is to describe the driving task and any other task executed in parallel using a set of operators applied by the user to achieve specific goals. These operators are assigned to a cognitive, perceptual and manual level. To give an impression what such a model can look like, Figure 4 depicts a very simple model showing how a minimum brake reaction time could be calculated.

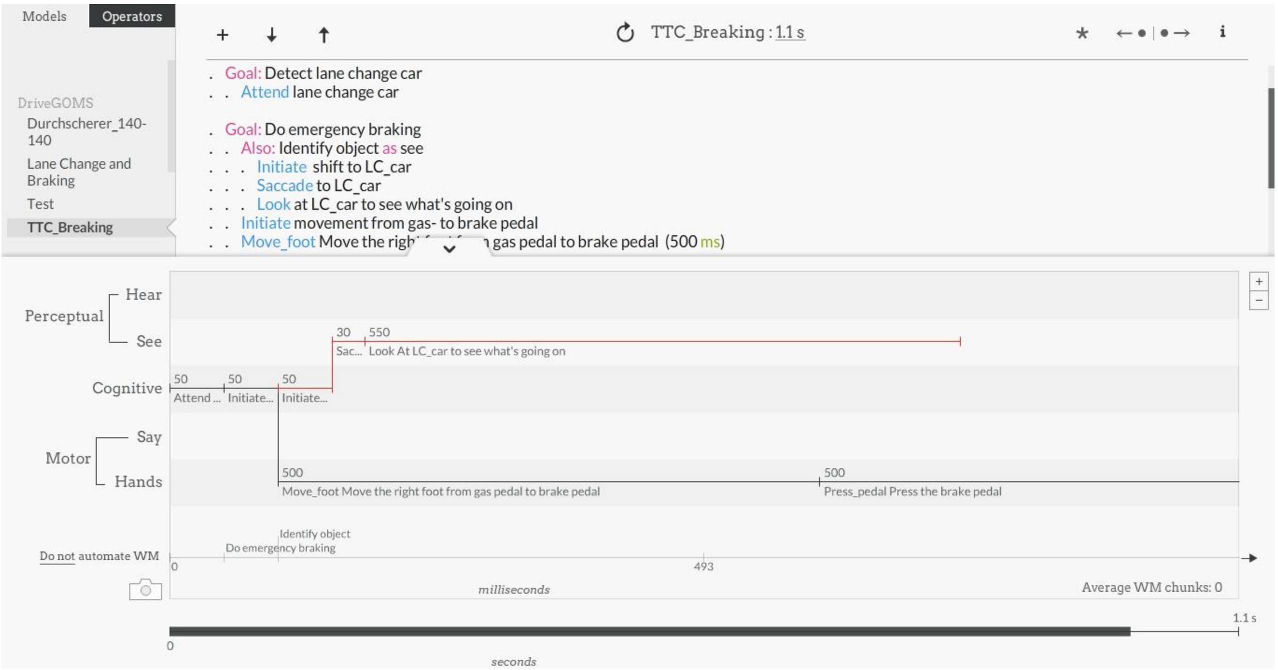


Figure 4: Example DriveGOMS-model.

The use of this method will support the choice of the best interaction strategy. To build the required models, dedicated trials have been conducted with the original experiment as a basis. Five subjects drove parts of the course, while concurrently saying out loud what they were doing, and why. This "Thinking Aloud" method (Käthner, Bühring & Ihme, 2017) is an effective yet easy way to understand drivers' motivations and cognitive processes. The resulting protocols serve to model the cognitive operators as well as provide context to the perceptual operators.

We are currently in the process of preparing the data for analysis and constructing the models. The results will be available early next year, in order to support the decision for or against certain design alternatives.

3.4 E6.2 - Cluster + audio (visual and audio interaction)

3.4.1 Scenario and use case where E6.2 is relevant

As shown in

Table 1, Enabler E6.2 is needed to implement both directions of support:

- from the human to the automation (H2A) to allow the automation to request the driver either for support in perception or in action
- from the automation to the driver (A2H) to offer a support either in perception or in action

One of the use cases of EVA scenario has been revised to highlight and clarify the role of E6.2 to implement the H2A support.

The TeamMate car is driving in Automated Mode. When it approaches a roundabout, it detects high traffic flows that can affect the efficiency (i.e. the TeamMate car evaluates that it may take some time to enter the roundabout in Automated Mode). To speed up the manouver, the TeamMate car requests a cooperation in perception, asking EVA to check the available space and to provide a trigger to start the manouver. Eva checks the traffic and gives the confirmation to enter the roundabout. The TeamMate car understands the feedback and performs the manouver in Automated Mode.

One of the use cases of PETER scenario has been revised to highlight and clarify the role of E6.2 to implement the A2H support.

Peter is driving in a narrow rural road in Manual Mode. He approaches a tractor, that causes limited visibility or the road. The TeamMate car detects a car approaching from the opposite lane. Since Peter is not aware of the car, he decides to overtake, and the TeamMate car detects his intention. In order *to avoid an imminent collision, the TeamMate car informs Peter about the approaching vehicle and warns him about the risky manoeuvre. Peter suddenly becomes aware of the risk, and he does not perform the overtake until it is safe.*

3.4.2 Improvements

Since the instrument cluster has been selected as the principal means to enable the cooperation, the major improvements from the 1st cycle concerned this tool.

The most important adjustments of the cluster design have covered its alignment to the concept and the resulting HMI strategy. The HMI modes defined in the 1st cycle have been updated to be in line with the different types and directions of support.

A more complex and detailed description of the support offered or requested by the automation was integrated in the 2nd cycle, including the addition of a "why-layer" in the negotiation-based HMI to explain the motivations (i.e. the limit) that conducted to the need of support.

In Manual Mode the driver should be aware of the long-term situation. Only minor changes have been applied, since in this state there is no need for cooperation.

Figure 5: Instrument cluster in Manual Mode

In A2H support in perception (i.e. when the automation detects a human limit and offers a support in perception), a warning-based HMI was designed. Starting from Manual Mode a warning is shown to the driver to make the driver aware about the potential dangerous situation caused by his/her distraction.

The instrument cluster for this state (state B) is shown in Figure 6.

Figure 6: Instrument cluster in A2H support in perception (state B)

When a support in perception is not enough to overcome the human limit and a transition of control is necessary (A2H in action), the state D is activated. In this state the HMI is only intended to inform the driver about the incoming transition. In order to avoid possible consequences on safety, the automation takes over autonomously, and the driver is not asked to give any confirmation to the user.

The instrument cluster of state D is shown in Figure **7**.

Figure 7: Instrument cluster in A2H support in action (state D)

The instrument cluster for Automated Mode had important modifications compared to the 1st cycle. Since the driving is totally automated, the driver should not be in the loop and the primary task is represented by entertainment functions. The only relevant element in the cluster is, in this cycle, the representation of the trip: it serves to make the driver aware of the possible expected situation in which a support is needed.

This representation, placed in the middle of the cluster, describes the path making clear the situation and the causes of possible requests (including disengagements).

The instrument cluster for Automated Mode is shown in Figure 8.

Figure 8: Instrument cluster in Automated Mode

When the automation detects a limit in perception (state A) a more complex HMI is needed. The instrument cluster shows a representation of the expected support and the cause that leads to the request, i.e. the limit. The type of limit is represented with an animated icon; the cause of the limit and the expected behavior is explained through an animated representation of the situation. The request of support is also reinforced with an audio and written message.

In Figure 9 is shown the instrument cluster in state A with a representation of a roundabout from Eva scenario.

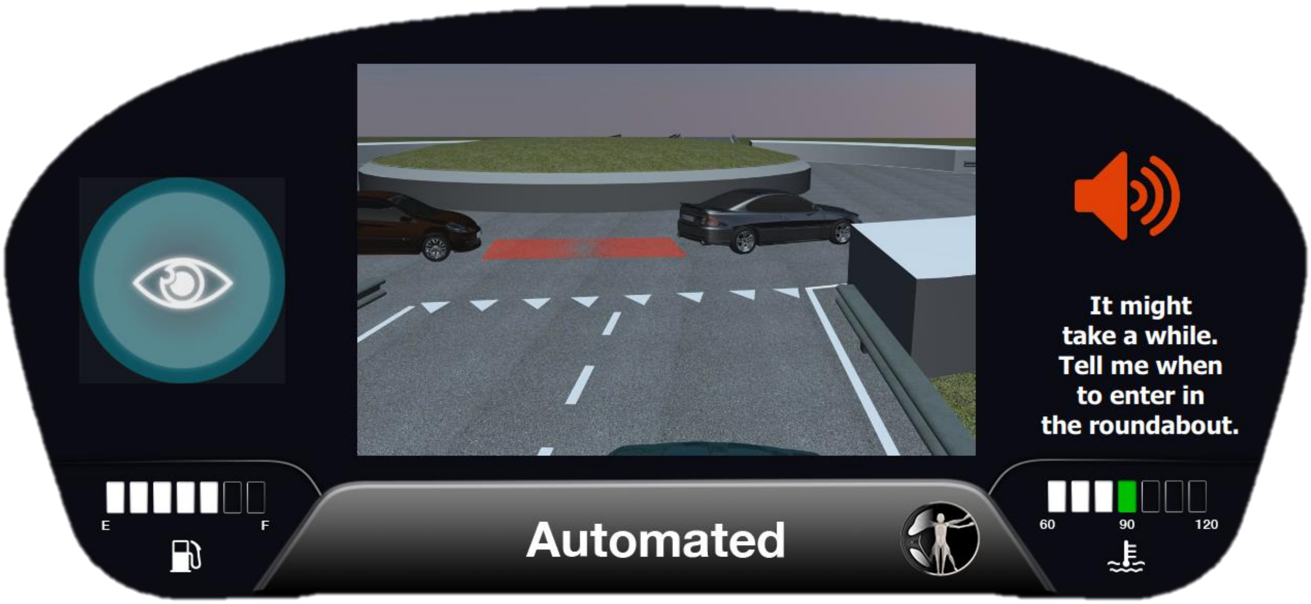


Figure 9: Instrument cluster in H2A support in perception (state A)

When the limit of the automation is in action and a transition of control is needed, the takeover is shown in the instrument cluster with a combination of audio, icons and written messages.
The main difference compared to the request of support in perception is in the type and color of the icon and the content of the message.

The instrument cluster of state C is shown in Figure 10.

When the transition of control from the automation to the driver fails, the Safe Mode is activated. Since this mode take into account that the driver was not able to regain control following a request, the only purpose of this state is to be active in case the driver is able to come back into the control loop.

Figure 10: Instrument cluster in H2A support in action

Figure 11: instrument cluster f in Safe Mode

In the 1st cycle, multimodal elements in the interface were hypothesized. In this cycle, **audio features** have been implemented to improve the effectiveness of the communication. For this element it has been decided to use a natural and informal language style. The messages were implemented in the HMI and synchronized with the visual messages.

From the representations shown in this chapter it is clear how the HMI has two very different approaches: **negotiation-based** when the cooperation is from the human to the automation, **warning-based** when the cooperation is from the automation to the human.

Figure **12** shows the difference between the HMIs by placing the different layouts of the cluster on the state machine.

Figure 12: State machine with instrument clusters

By starting from the state machine and the new layouts, the HMI has been developed as a software for an embedded system (industrial display) to be installed in the different demonstrators.

Figure 13 shows the state machine implemented in the software developed with Qt.

```
Connections {
    target: screen
    onStatusChanged: {
        // set cluster visibility according to Status(Mode)
        switch (screen.status) {
        case Status.MANUAL:
            manual_cluster.visible = true
            automatic_cluster.visible = false
            perception_A2H_cluster.visible = false
            takeover_cluster.visible = false
            handover_cluster.visible = false
            perception_H2A_cluster.visible = false
            safe_cluster.visible = false
            keyEvent.focus = true
            break
        case Status.AUTOMATIC:
            manual_cluster.visible = false
            automatic_cluster.visible = true
            perception_A2H_cluster.visible = false
            takeover_cluster.visible = false
            handover_cluster.visible = false
            perception_H2A_cluster.visible = false
            safe_cluster.visible = false
            keyEvent.focus = true
            break
        case Status.A2H_PERCEPTION:
            manual_cluster.visible = false
            automatic_cluster.visible = false
            perception_A2H_cluster.visible = true
            takeover_cluster.visible = false
            handover_cluster.visible = false
            perception_H2A_cluster.visible = false
            safe_cluster.visible = false
            keyEvent.focus = true
            break
        case Status.TAKEOVER:
            manual_cluster.visible = false
            automatic_cluster.visible = false
            perception_A2H_cluster.visible = false
            takeover_cluster.visible = true
            handover_cluster.visible = false
            perception_H2A_cluster.visible = false
            safe_cluster.visible = false
```

Figure 13: State machine implemented in the HMI software

3.5 E6.3 - Central stack display (visual interaction)

3.5.1 Scenario and use case where E6.3 is relevant

As shown in
Table 1, Enabler E6.3 is needed to implement both directions of support:

- from the human to the automation (H2A) to allow the automation to ask the driver either for support in perception or in action
- from the automation to the driver (A2H) to offer a support either in perception or in action

One of the use cases of EVA scenario has been revised to highlight and clarify the role of E6.3 to implement the H2A support.

The TeamMate car is driving in Automated Mode. When it approaches a roundabout, it detects high traffic flows that can affect the efficiency (i.e. the TeamMate car evaluates that it may take some time to enter the roundabout in Automated Mode). To speed up the manouver, the TeamMate car asks Eva a cooperation in perception, asking her to check the available space and to provide a trigger to start the manouver. Eva checks the traffic and gives the confirmation to enter the roundabout. The TeamMate car understands the feedback and performs the manouver in Automated Mode.

One of the use cases of PETER scenario has been revised to highlight and clarify the role of E6.3 to implement the A2H support.

Peter is driving in a narrow rural road in Manual Mode. He approaches a tractor, that causes limited visibility or the road. The TeamMate car detects a car approaching from the opposite lane. Since Peter is not aware of the car, *he decides to overtake, and the TeamMate car detects his intention. In order to avoid an imminent collision, the TeamMate car informs Peter about the approaching vehicle and warns him about the risky manoeuvre. Peter suddenly becomes aware of the risk, and he does not perform the overtake until it is safe.*

3.5.2 Improvements

The use of additional displays to improve the effectiveness of the interaction between the vehicle and the driver has been hypothesized in this 2nd cycle. As described in Martha scenario in which this enabler is relevant, the possibility to mirror some critical information on mobile devices can represent an added value to help the driver in handling potential critical situations such as the takeover.

Minor changes have been implemented on the central stack display. In order to avoid useless information and reduce the overload, the short-term information about the navigation (i.e. the surround view) have been deleted.

Consistently with what was defined in D4.2, in the central stack display some functions can be activated only when the TeamMate system is in Automated Mode: for example, the driver can handle settings and all the functionalities that involve text input only when the vehicle is driving autonomously.

An example of central display HMI is shown in Figure 14.

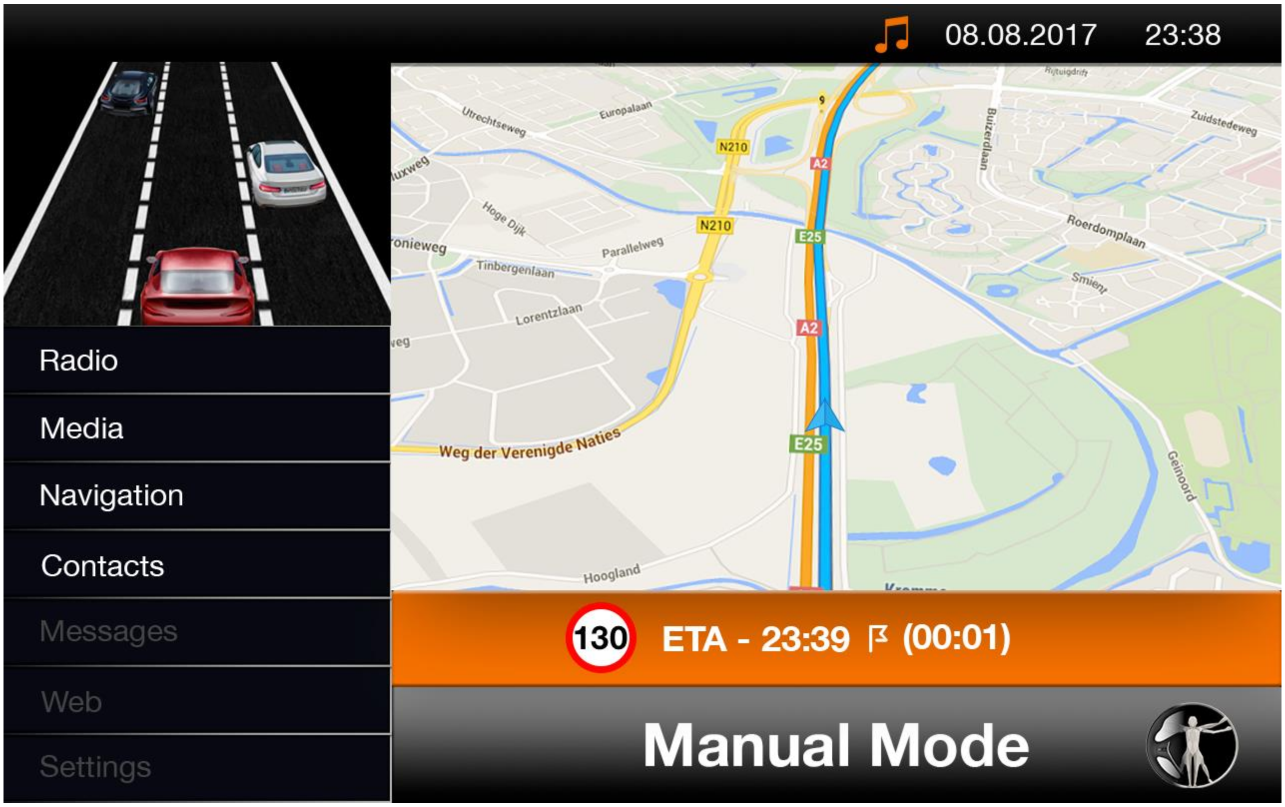


Figure 14: Central stack display in Manual mode

The aim of the 3rd cycle is to implement the communication of driving-related data between the vehicle and nomadic device. In particular, information such as the request of cooperation from the vehicle can improve the effectiveness of this kind of message when the driver is using a tablet or a smartphone.

This activity is also related to the app development through specific SDKs in WP5, which can allow the driver to be aware about incoming situations also when he/she is interacting with another device.

3.6 E6.4 - Ambient lights

3.6.1 Scenario and use case where E6.4 is relevant

As shown in

Table 1, Enabler E6.4 is needed to implement a support from the driver to the automation in perception and in action to improve the communication of the expected support.

One of the use cases of PETER scenario has been revised to highlight and clarify the role of E6.4 to implement the H2A support.

Peter is driving in a narrow rural road in Automated Mode. The car, arriving behind a tractor, detects that it obstructs the view. Therefore, the vehicle is not confident of the available space sideways to overtake the tractor, due to a limit in perception. Since the vehicle is not sure about the possibility to overtake, it would follow the tractor for several kms (it knows they are several kms because of the map) performing an "over-safe" manouver, until the road is wider. The TeamMate car asks Peter to check by also using a blue ambient light. Peter understands the request of support (in perception) and confirms there is enough space, so the TeamMate car can perform the overtake in Automated Mode.

3.6.2 Improvements

While in the 1st cycle the ambient lights were hypothesized as a means to recognize the automation state, in this 2nd cycle, they have been used as a means to improve the comprehension of the type of support needed by the automation (either perception or action).

The ambient lights have been used only when the cooperation is from the human to the automation, since their objective is to reduce the effort requested to understand the support required to the human agent.

An ambient light was planned also for the Safe Mode, with a different goal, i.e. to increase the driver awareness of the failure of the transition of control and of the activation of a safe manouver.

Three colors have been selected for the ambient lights implementation: blue for H2A support in perception, yellow for H2A support in action, red for Safe Mode.

Direction of the cooperation	Type of support	HMI state	Ambient light colour
H2A	Support in perception	H2A support in perception (A)	Blue
	Support in action	H2A support in action (C)	Yellow

Table 10: Ambient lights strategy for H2A support

In comparison to the 1st cycle, in which the ambient lights were only hypothesized, in this cycle a prototype of this enabler has been developed and tested.

The validation of this tool is described in chapter 4.

3.7 E6.5 - Augmented reality

3.7.1 Scenario and use case where E6.5 is relevant

As shown in
Table 1, Enabler E6.5 is needed to implement both directions of support:

- from the human to the automation (H2A) to allow the automation to ask the driver either for support in perception or in action
- from the automation to the driver (A2H) to offer a support either in perception or in action

One of the use cases of EVA scenario has been revised to highlight and clarify the role of E6.5 to implement the H2A support.

The TeamMate car is driving in Automated Mode. When it approaches a roundabout, it detects high traffic flows that can affect the efficiency (i.e. the TeamMate car evaluates that it may take some time to enter the roundabout in Automated Mode). To speed up the manouver, the TeamMate car asks Eva a cooperation in perception, asking her to check the available space and to provide a trigger to start the manouver. Eva checks the traffic and gives the confirmation to enter the roundabout. The TeamMate car understands the feedback and performs the manouver in Automated Mode.

One of the use cases of PETER scenario has been revised to highlight and clarify the role of E6.2 to implement the A2H support.

Peter is driving in a narrow rural road in Manual Mode. He approaches a tractor, that causes limited visibility or the road. The TeamMate car detects a car approaching from the opposite lane. Since Peter is not aware of the car, he decides to overtake, and the TeamMate car detects his intention. In order *to avoid an imminent collision, the TeamMate car informs Peter about the approaching vehicle and warns him about the risky manoeuvre. Peter suddenly becomes aware of the risk, and he does not perform the overtake until it is safe.*

3.7.2 Implementation

To follow the TeamMate approach, it is necessary that the system provides a shared understanding of the current situation between the driver and the automation. The main objective of the Augmented Reality HMI is to improve the cooperation between the automation and the driver. As described in Deliverable 4.3, this means that the Augmented Reality HMI should provide a better situation understanding to understand the behavior of the automation. The information of the HMI helps the driver to understand the current situation and the behavior of the car.

In this 2nd cycle, the Augmented Reality (AR) HMI works while the car drives autonomously. Though the Augmented HMI could assist the driver in manual mode to assess the risk of a situation (for example a planned overtaking manouver) as well, the focus is on autonomous driving to understand the actions taken by the automation. The AR HMI will only be visible if a car – in this approach a truck – is in front of the ego-car. In the next cycle, the scope of the Augmented Reality HMI can be extended e.g. integration with enabler 6.6 or integration in manual mode.

The AR HMI is dealing with the intention of the driver and the potential risk of an overtaking manoeuvre. The consideration of the intention of the driver is an important part for a shared understanding of the current situation between the driver and the automation. With the use of the Driver Intention Recognition (developed in WP2) it is possible to recognize the intention of the driver without an active driving task of the driver. The Driver Intention Recognition most commonly addresses the problem of anticipating driving maneuvers that a driver is likely to perform in the next few seconds. Autonomous systems may gain a currently unused value from knowing whether a driver would have the intention to overtake, if he was in control, such as to enable the autonomous system to comply to the usual behavior of the driver and communicate when such compliance cannot be achieved. The Driver Intention Recognition uses surrounding information e.g. vehicles in the vicinity, distances to the recognized vehicles and current speed limits, provided by camera systems or derived from GPS and digital maps.

Based on this traffic information, the Driver Intention Recognition derived the intentions of the driver prior to their execution. All in all, the AR HMI visualizes the combined results of the Risk Assessment (enabler 5.1) and the Driver Intention Recognition (enabler 4.2).

The Augmented Reality HMI contains two underlying visualization components. First a safety corridor and second an intention arrow.

The safety corridor visualizes potential upcoming driving manoeuvres of the automation like lane holding or overtaking inclusive a risk analyze of the manoeuvre. A potential upcoming driving manoeuvre is based on the intention of the driver. If the automation recognizes an overtaking intention, the automation predicts an overtaking trajectory. The Risk Assessment checks this trajectory. The color of the safety corridor shows the risk of the visualized manoeuvre: green means safe manoeuvre, red means unsafe manoeuvre. The intention arrow visualizes intentions of the driver like lane holding or overtaking. The color is always blue.

As described above, in this approach the ego-car follows a truck. The challenge for the HMI is to visualize the current situation and upcoming manoeuvres, that the driver is not surprised of the actions by the system.

While the ego-car follows a truck, the view of the driver is highly limited. If the Augmented Reality HMI shows the intention of driver, the driver recognizes that the automation knows what s/he want to do, if s/he would drive. In combination with the safety corridor, the driver understands the situation. S/he understands why the automation acts in a certain manner in an understandable way.

Dependent on the output of the Risk Assessment (overtaking trajectory safe/unsafe) and on the Driver Intention Recognition, the Augmented Reality HMI can show three different layouts.

The first one is the lane-holding use case (see Figure 15). In this case, the driver has the intention to hold the lane and the automation follows the truck in front of the ego-car. Therefore, the intention arrow shows ahead and the safety corridor visualizes the lane-holding manoeuvre. The green color of the safety corridor signals the driver the recognized lane holding intention and, that the upcoming manoeuvre is safe.

Figure 15 - Augmented Reality HMI scenario 1: Car following

The second use case is the first of two overtaking scenarios (see Figure 16). In this case, the driver has the intention to change the lane and to overtake the truck in front of the ego-car while the automation is driving. For this reason, the intention arrow changes its orientation to the left side. The automation calculates an overtaking trajectory. The Risk Assessment assesses the predicted overtaking trajectory as safe and the safety corridor changes its layout. The green color of the safety corridor signals the driver the recognized overtaking intention and, that the upcoming manoeuvre is safe.

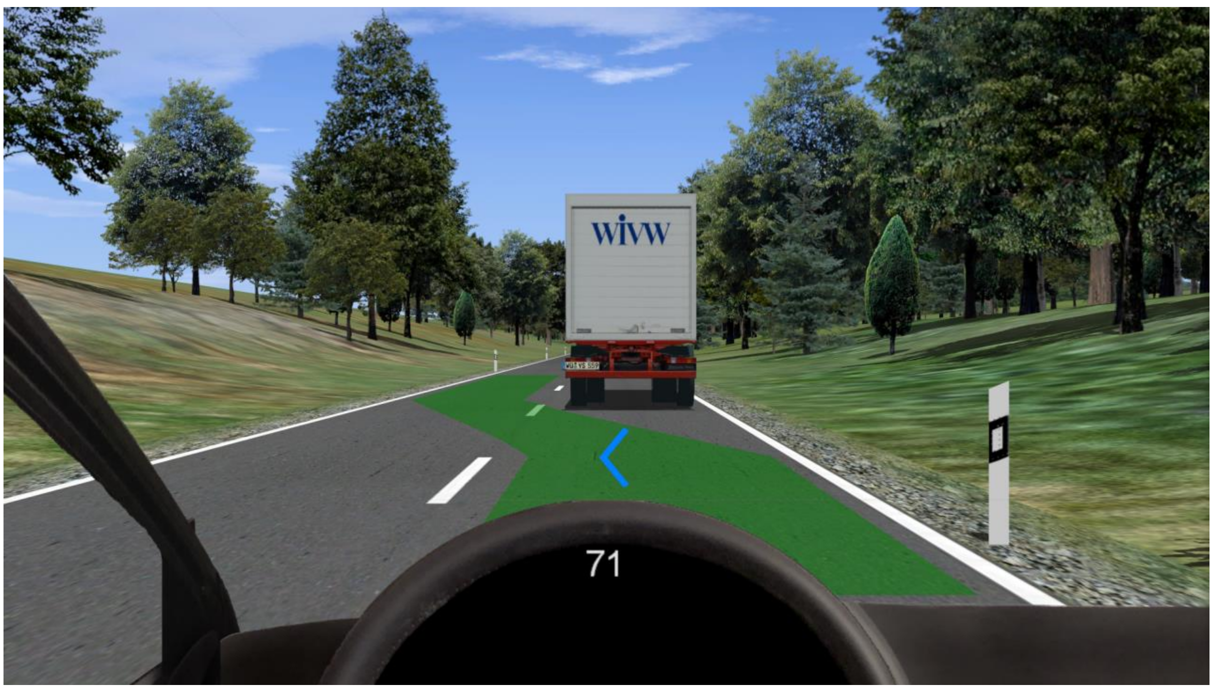


Figure 16 - Augmented Reality HMI scenario 2: Overtaking

The third use case is the second of the two overtaking scenarios (see Figure 17). In this case, the driver also has the intention to overtake the truck in front of the ego-car while the automation is driving. For this reason, the orientation of intention arrow is to the left side. The automation calculates an overtaking trajectory. The Risk Assessment assesses the predicted overtaking trajectory as unsafe and the safety corridor changes its layout.

The green color on the right lane signals the driver, that this lane is safe. The red color on the left lane signals the driver, that this lane and this manoeuvre is unsafe. The reason for the unsafe assessed overtaking manoeuvre is oncoming traffic that is not visible for the driver yet.

The automation has much more information about the environment as the driver. Especially in the car following situation behind a truck, the view of the driver is highly limited. Therefore, the Augmented Reality HMI expands the perception of the driver and helps the driver to assess specific situations and to understand the behavior of the automation. Through the visualization of the intention of the driver, the driver recognizes that the automation knows what s/he wants to do and that this manoeuvre is not safe.

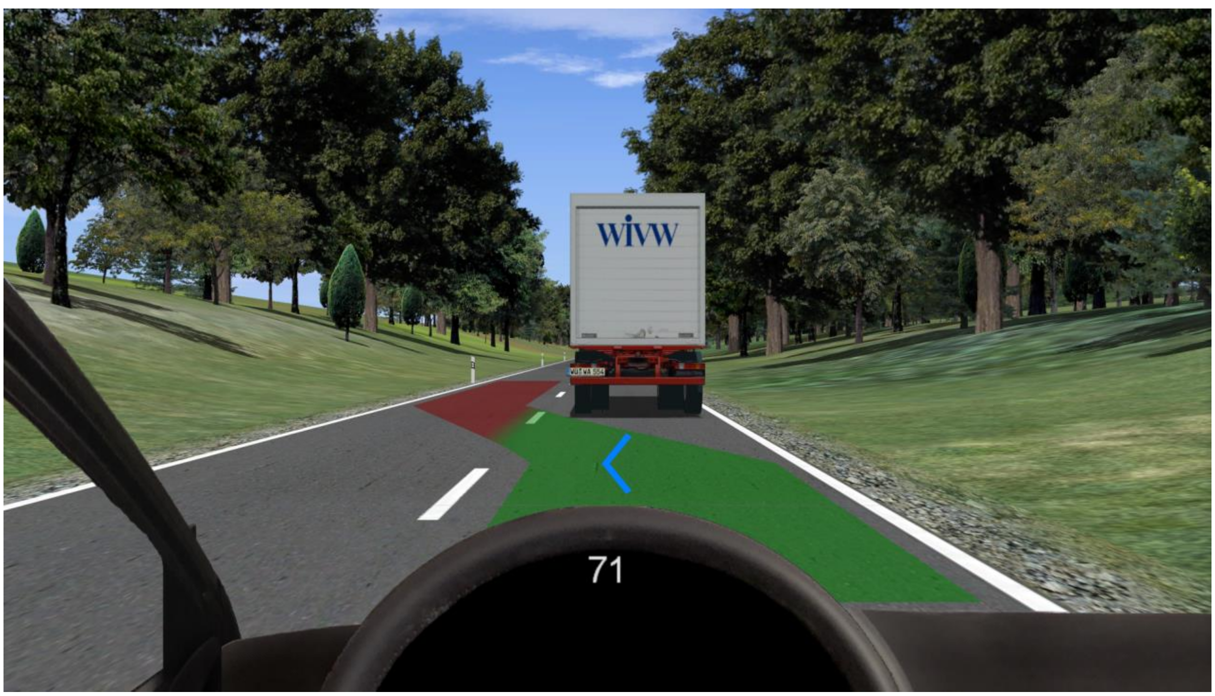


Figure 17 - Augmented Reality HMI scenario 3: Overtaking forbidden

3.8 E6.6 - HUD

3.8.1 Scenario and use case where E6.6 is relevant

As shown in
Table 1, Enabler E6.6 is needed to implement both directions of support:

- from the human to the automation (H2A) to allow the automation to ask the driver either for support in perception or in action
- from the automation to the driver (A2H) to offer a support either in perception or in action

One of the use cases of EVA scenario has been revised to highlight and clarify the role of E6.6 to implement the H2A support.

The TeamMate car is driving in Automated Mode. When it approaches a roundabout, it detects high traffic flows that can affect the efficiency (i.e. the TeamMate car evaluates that it may take some time to enter the roundabout in Automated Mode). To speed up the manouver, the TeamMate car asks Eva a cooperation in perception, asking her to check the available space and to provide a trigger to start the manouver. Eva checks the traffic and gives the confirmation to enter the roundabout. The TeamMate car understands the feedback and performs the manouver in Automated Mode.

One of the use cases of PETER scenario has been revised to highlight and clarify the role of E6.2 to implement the A2H support.

Peter is driving in a narrow rural road in Manual Mode. He approaches a tractor, that causes limited visibility or the road. The TeamMate car detects a car approaching from the opposite lane. Since Peter is not aware of the car, *he decides to overtake, and the TeamMate car detects his intention. In order to avoid an imminent collision, the TeamMate car informs Peter about the approaching vehicle and warns him about the risky manoeuvre. Peter suddenly becomes aware of the risk, and he does not perform the overtake until it is safe.*

3.8.2 Improvements

The Head-up display (HUD) has been previewed for both the directions of cooperation.

When the automation needs a support from the driver, the Head-up display is used to reinforce the message presented on the instrument cluster: for example, the take-over request is mirrored on the HUD trough an icon.

When the automation offers a support to the driver, the HUD is used to propose additional information avoiding that the driver (that is in Manual Mode) is forced to keep the eyes off the road.

The HUD is used as an alternative means to the Augmented Reality HMI.

Minor changes have been implemented from the design point of view. An example of HUD HMI is shown in Figure 18.

Figure 18: HUD in Manual Mode

4 Validation

4.1 Overall approach to validation

As stated in D4.3, in the 2nd cycle, the focus of the V&V process is placed on validation. The overall objective of the HMI is to provide a means to request a support from the driver to the automation and vice versa.

Therefore, the validation, in this 2nd cycle, is twofold, since twofold is the approach at the HMI defined in the concept.

In the validation of the Human to Automation support (i.e. when the automation requests a support to the human), the main goal is to assess the comprehensibility of the request of cooperation, since the driver should be aware about the need of the TeamMate car: the objective is to improve the level of understanding of the communication.

In the validation of the Automation to Human support (i.e. when the automation supports the driver), the main goal is to improve the effectiveness of the suggestion: since this direction of cooperation derives from a human limit, it is very important to measure how the human reacts to the action/message of the automation.

In general, the validation process will highlight how the HMI encourages the level of understanding of the TeamMate concept, i.e. the cooperation. For this reason, the validation of the HMI will be performed considering all enablers: the assessment process will involve also the test on the single modules that are part of the enabler 6 (i.e. the TeamMate HMI), but the focus will be on how the modules, combined with each other, are able to improve:

- The overall level of understanding of the cooperation and the communication;

- The capability of the user to predict the near future, i.e. the consequences of the requests of the automation and the expected behavior and action, including the changes in the HMI (and vehicle) state;

The overall validation process, that is consistent with D1.3 and D4.3, will consider the requirements defined at the beginning of the second cycle (cfr. D4.3) as well as new requirements recently created to ensure a depth comprehension of the interaction process.

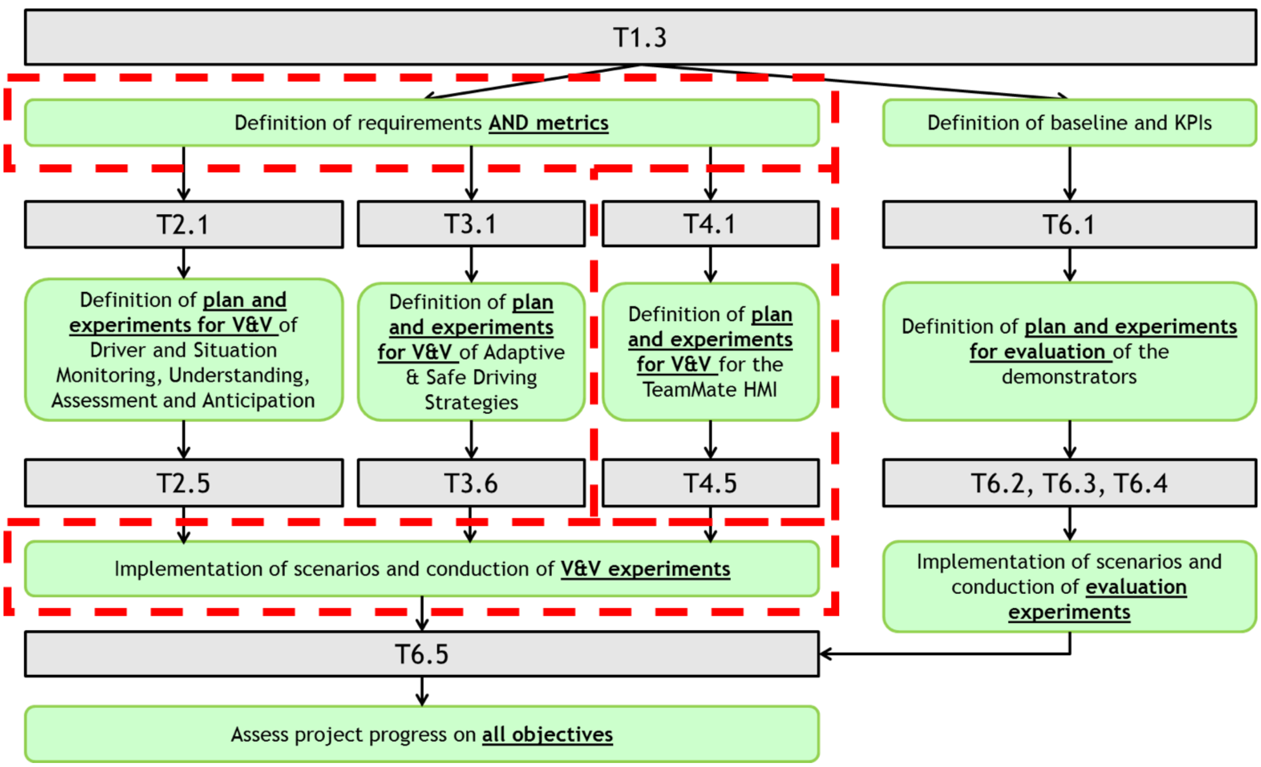


Figure 19: overall validation process described in D1.3

In order to measure these aspects in the following paragraphs, the tests and the results of the validation phase will be described for each direction of cooperation.

The Human-vehicle interaction has been validated paying attention on how the different enablers that are part of the HMI, combined with each other, are able to ensure an effective interaction.

For example, in order to validate the comprehensibility of the expected cooperation represented on the instrument cluster, it was fundamental to assess the combination of this kind of information with multimodal information such as audio and vocal interaction. For this reason, the HMI has been validated as an integrated enabler, with 3 exceptions:

- The **E6.1 – Interaction Modality**, since it has the objective of measuring the effectiveness of the input and the feedbacks given by the driver back to the automation.
- The **E6.6 - Augmented Reality**, since it is an additional information finalized to reduce the eyes-off-the-road factor of the HMI.
- The **E6.7 - Ambient lights**, since this information has been used as an additional way of communication to increase the awareness and reduce the user's cognitive involvement and the temporal demand, improving the communication through an abbreviated message based on the common understanding between the driver and the automation (i.e. a concurred abbreviation).

4.1.1 Human to Automation (H2A) Support

As stated before, the main objective of the validation process is to measure the level of comprehensibility of the HMI when a cooperation is expected.

When the direction of the cooperation is from the driver to the vehicle, since the request of cooperation is always initiated by the automation, the driver is expected to understand what kind of limit the automation has, what kind of help the automation needs and what is the expected behaviour that he/she should have.

The validation of H2A support has therefore considered the five levels of information already used to design the HMI strategy:

1. The **current state** of the automation;
2. Which of the two agents (the human or the automation) has a limit, in order to be aware of the **direction of the cooperation**;
3. What is the **"meta-message",** i.e. if the vehicle needs support in action or in perception;
4. What is the **message**, i.e. what is the requested support;
5. What will be the **next HMI state** after the support.

As represented in the state machine, the Human to Automation support occurs when the car is in Automated Mode. In order to ensure an effective support, the vehicle should be able to explain its limit and make the driver aware of the support needed.

The validation of this direction of cooperation will be therefore oriented to measure the comprehension of the suggestion, that is in this case a real negotiation of the upcoming manouver. The HMI to enable the H2A support will be validated in the "H2A support in perception" modality, since this mode is potentially the most disruptive way because it reduces the number of disengagements (i.e. when the cars unexpectedly takes over the control to the driver, that represents a well-known safety critical condition) with a minimum effort of the driver.

4.1.2 Automation to Human (A2H) Support

The Automation to Human support occurs starting from Manual Mode. When the cooperation happens in this direction, the vehicle to human communication approach is warning-based.

Since the aim of the communication is to inform the driver about a support given by the automation, the main objective of the validation is to assess that the driver is able to understand this support and adapt his behavior according to the needs.

As defined before, when the cooperation is in this direction the emphasis should not be placed on the explanation of the manouver, but on the possible consequences of the human limits: from this point, it derives that for the different directions of the support, two different representations of the HMI are needed.

4.2 Integrated HMI Validation

4.2.1 Validation method

The integrated HMI validation has been performed through a test with users by REL. The experiment, called Test 1, was designed as a repeated measures design, meaning that each participant drove every condition.

In order to ensure a depth analysis of the results, the experimental requirements to:

- Validate the HMI in each scenario (Peter, Martha, Eva);
- Validate the HMI in both the direction of the cooperation,
- Validate the HMI in both the types of cooperation (in perception and in action).

Since, according to the HMI strategy, the HMI in which the cooperation is shown is mainly the instrument cluster, the test was performed on this enabler. The participants were asked to see the HMI in the instrument cluster, and then to answer some questions to measure the level of comprehension of the message. Since the aim of the HMI concept is to use multimodal features to adapt the communication to the complexity of the scenario and use cases, the message was reinforced with audio, i.e. vocal communication in natural language from the vehicle to the driver.

The HMI has been validated in 3 representative use cases: in Peter and Eva scenario, it has been tested for H2A support in perception; in Martha scenario, it has been tested for A2H support in action.

Since, as stated before, the HMI (especially when the cooperation is from the human to the vehicle) has five levels of information, the following levels of comprehension were measured with a customized questionnaire:

- The **current state** of the car before the request (or offer) of support;
- The **direction** of the support, i.e. who has the limit to be compensated;
- The **meta-message**, i.e. the type of support needed (in perception or in action);
- The content of the **message**;
- The **next state**, i.e. if there is or not a transition of control.

	Per scenario					
User ID	**Current state** In which Mode is the HMI before the cooperation?	**Direction** In this representation, who needs the support? The automation or the driver?	**Meta-message** What kind of support the HMI shows? In perception or in support?	**Message** What is the content of the message?	**Next state** What will be the next state? Automated or Manual	**Comments**
1						
2						
…						

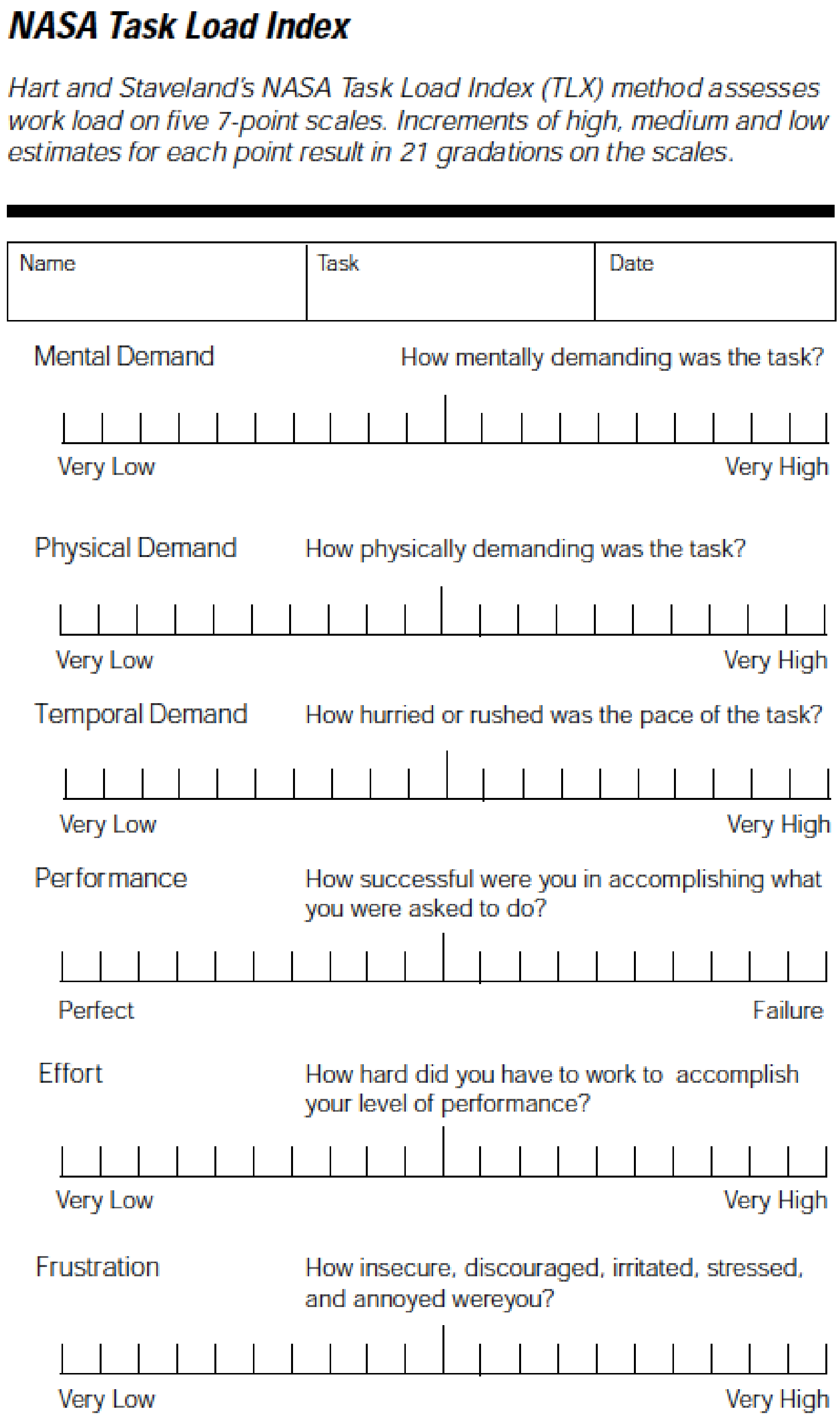
Table 11 Template of integrated HMI validation questionnaire

Qualitative data on the comprehension of the support have been collected during the experiment.

Moreover, the NASA-TLX questionnaire for workload measurement was administered after each part of the experimental scenario.

The hypothesis is that the support in perception is perceived as less demanding then the support in action: it would mean that, by introducing the H2A support in perception, we can achieve the benefit of reducing the takeover requests (i.e. the disengagement) with a lower workload of the driver (compared to the request of support in action).

The NASA-TLX was also used to assess the overall workload level generated by the HMI.



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Figure 20 NASA TLX questionnaire

Table **12** shows the requirements and the metrics used to validate the integrated HMI.

REQ ID	Description	Metrics (success criteria)	How to validate it
R_EN6_tool1.42	The user should always be aware of the automation state	Correct rate: X > 90%	Customized questionnaire
R_EN6_tool1.43	When a limit occurs, the user should be aware of the agent that has a limit	Correct rate: X > 90%	
R_EN6_tool1.44	When a support is needed, the user should be aware of the type of expected cooperation	Correct rate: X > 90%	
R_EN6_tool1.45	The user should be able to understand the message communicated by the driver	Correct rate: X > 90%	
R_EN6_tool1.46	The user should be able to predict in which HMI mode will be after the support	Correct rate: X > 90%	
R_EN6_tool1.47	The H2A support in perception should be less demanding then the H2A support in action	NASA TLX Support in perception < support in action	NASA TLX survey

Table 12 Requirements for integrated HMI validation

In order to select the most effective representation of the cooperation in the HMI, different suggestions were tested. For example, in Peter scenario, two different solutions of Automation to Human request in perception were tested: the design solution considered as the most effective was then implemented in the HMI.

4.2.2 Participants

The test was performed in REL facilities. The software with the HMI was installed on a laptop and the subjects were asked to answer the questions after viewing each part of the experimental scenario; an experimenter supported the subjects for every clarification and was in charge of administering the questions and collect real-time subjective data.
The experimental setup is shown in Figure 21.

Figure 21 Integrated HMI experimental setup

The number of participants selected for the validation was 9. The gender of the subjects was balanced in order to avoid possible bias: 5 males and 4 females were recruited.
The average age of participants was 29,44 years.

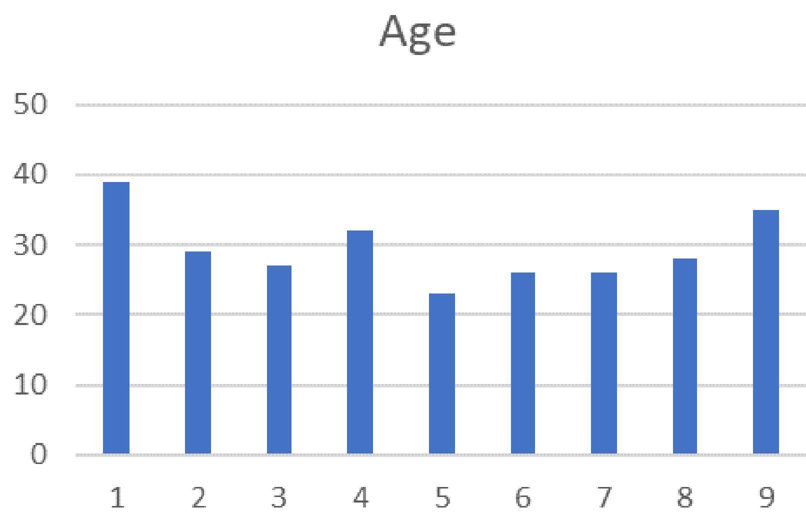


Figure 22: Age of participants

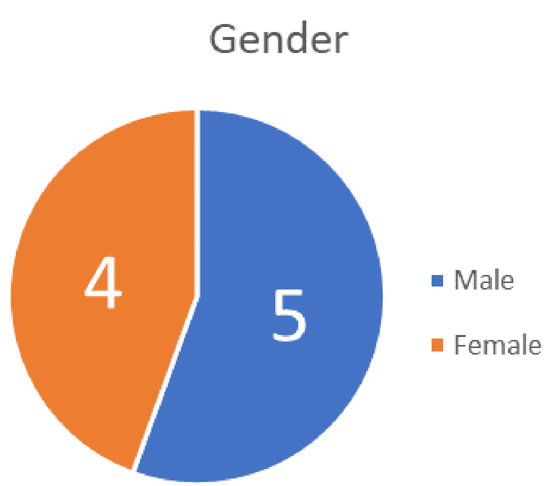


Figure 23: Gender of participants

Only participants with valid driving licence were considered for the test. They have driving license from 10,77 years and they travel for 18.200 kms/years on average.

All the users were asked to sign an informed consent form to participate in the test. No other user requirements were used for the validation.

Before the test, the experimenter briefly introduced the project to the subjects and showed a video to introduce the project's concept.

4.2.3 Results

4.2.3.1 Requirements validation

REQ ID	Description	Metrics (success criteria)	Result	Has the req. been met?
R_EN6_tool1.42	The user should always be aware of the automation state	Correct rate: X > 90%	100%	Yes
R_EN6_tool1.43	When a limit occurs, the user should be aware of the agent that has a limit	Correct rate: X > 90%	100%	Yes
R_EN6_tool1.44	When a support is needed, the user should be aware of the type of expected cooperation	Correct rate: X > 90%	96,30 %	Yes
R_EN6_tool1.45	The user should be able to understand the message communicated by the driver	Correct rate: X > 90%	96,30 %	Yes
R_EN6_tool1.46	The user should be able to predict in which HMI mode will be after the support	Correct rate: X > 90%	100%	Yes
R_EN6_tool1.47	The H2A support in perception should be less demanding then the H2A support in action	Overall WL in perception < overall WL in action	Workload in perception = **3,82** Workload in action = **4,55** Difference (Δ) =**0,73**	Yes

Table 13: Integrated HMI Requirements Validation

As stated before, the integrated HMI validation concerned the five levels of information offered to ensure an effective communication between the driver and the automation.

All the requirements defined in the previous paragraphs have been successfully validated; the users were able to understand the meaning of the cooperation, i.e. to understand the state from which the support starts, the agent which has a limit, the difference between cooperation in perception and in action, and the message explained through the HMI.

Since the radical innovation of the approach used in AutoMate is to enable the support from the human to the automation, the deep research question in this cycle was to evaluate if the support in perception is less demanding then the support in action, i.e. if the support without the transition of control can help to reduce the driver’s workload.

The results of the NASA TLX questionnaire show that the support in perception is less demanding then the support in action, confirming the hypothesis and giving strength to the approach established in the concept.

In particular, the support in perception proved to be effective in improving the perceived performance (Δ = 1,05), reduce the effort (Δ = 0,88), and reduce the frustration (Δ = 1,25).

The overall results of the NASA TLX is shown in Figure 24.

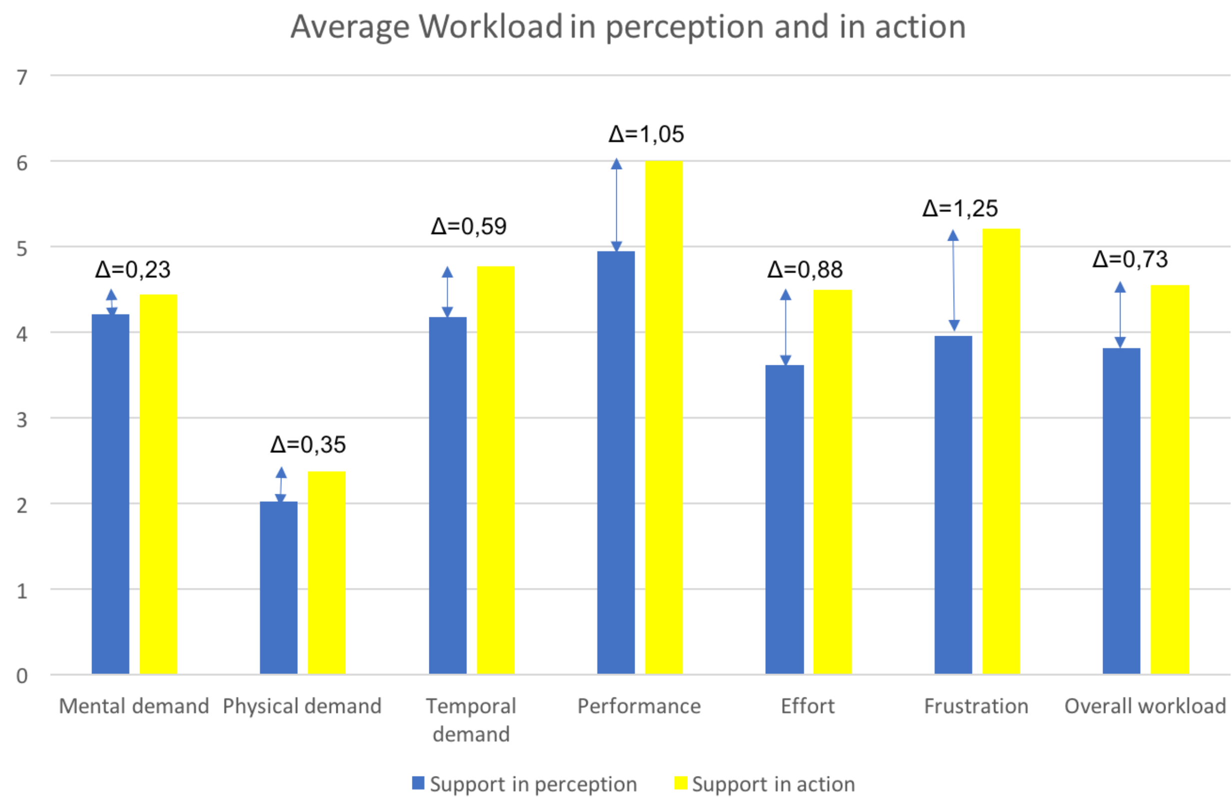


Figure 24: Average workload in perception and in action

Although the HMI for H2A support in perception (negotiation-based) is more complex than the warning-based HMI (to adapt the amount of information to the complexity of the situation), the users perceive less effort when the cause of the need (i.e. the limit) of cooperation is explained.

4.2.3.2 Qualitative results

As shown by the results of the requirements validation, the integrated HMI has a high level of comprehensibility and was well accepted by the users.
The comments collected through a think aloud protocol highlight that the cooperation is well understood, and the elements designed on the instrument cluster are visible and don’t require too much attention to be interpreted.

Several comments on the interaction style was collected. Some users considered the messages too peremptory (*"I don't want that car tell me that I'm distracted, I'd rather prefer that it tells me that it's better than me in doing something and can help me")* or too informal (*"I would prefer a more formal communication"*).

One user felt that it might take a bit of training to learn the expected cooperation and to discriminate the different types of cooperation.

Moreover, for some of the representations, two alternative versions were shown to select the most comprehensible: the top-rated designs were used for the real validation.

These comments will be used as cues to drive the design in the 3rd cycle.

4.3 E6.1 - Interaction modality

The three different input modalities, described in 3.1, are tested in the ULM driving simulator. The Peter scenario was implemented in the driving simulator. The course includes six overtaking manoeuvres, where the participants are requested to decide if it is safe to overtake.

About 30 participants will test all interaction modalities and will drive through a baseline course without automation. All the participants will start by driving the track manually in order to collect eye tracking data of the participants' natural safety assurance. Afterwards they will drive the same, but randomized track, with all the interaction modalities. The order of the interaction modalities is also randomized for every participant. The result should show which of the interaction modalities is the safest according to the safety assurance measured with the eye tracker and the driving data.

Additionally, a thinking-aloud experiment will be conducted in cooperation with DLR. In this experiment four to six subjects will drive through the PETER scenario while they initiate the overtaking manoeuvre with the different input modalities. In the experiment, the test subjects will be recorded from different angles of the driving simulator to collect data of their actions taken in the simulator.

The eye tracking system Smarteye will track the driver's eye gaze and the fixation of following areas of interest: the cluster, the central HMI, the left, rear and back mirror and the front display of the simulator where the forward track is displayed. Around 5 people will participate in the experiment and drive through the course in about 10 minutes per interaction modality. The data will be than analyzed by DLR to model the driving task.

4.4 E6.5 - Augmented reality

To follow the TeamMate approach, it is necessary that the system provides a shared understanding of the current situation between the driver and the automation. To realize that objective it is important to learn if and how the users understand and interpret the developed AR HMI components in different situations. Therefore, the objective of the experiment is the validation of the Augmented Reality (AR) HMI.

The subject of the experiment should be able to recognize and understand the meaning of the different AR HMI scenarios, which are described in chapter 3.7

For the verification of the AR HMI, the requirements R_EN6_tool1.20, R_EN6_tool1.33 and R_EN6_tool1.34 must be met. To validate the AR HMI, the requirements R_EN6_tool1.35, R_EN6_tool1.41 and R_EN6_tool1.42 must be met.

The validation requirement R_EN6_tool1.35 contains the comprehensibility of the performed manoeuvres for the driver in the automated mode. The requirement R_EN6_tool1.41 and R_EN6_tool1.42 describes the understandability of the automations behavior and of the overtaking corridor visualized through the Augmented Reality HMI.

REQ ID	Description	Metrics	How to test it
R_EN6_tool1.20	The HMI must show safe driving corridors and constraints on these corridors using graphical means	Check: Y/N	Online questionnaire with a driving scenario video
R_EN6_tool1.33	In manual mode, augmented reality (AR) elements should be reduced to a minimum and not distract the driver.	Check: Y/N	Online questionnaire with a driving scenario video
R_EN6_tool1.34	In automated mode, augmented reality elements can be used to enhance the situation awareness.	Check: Y/N	Online questionnaire with a driving scenario video
R_EN6_tool1.35	In automated mode, the manoeuvres performed by the vehicle must be comprehensible for the driver through graphical visualizations.	CR for understanding level >90%	Online questionnaire with a driving scenario video
R_EN6_tool1.41	The HMI should communicate to the driver why the automation is acting in a certain manner	CR for understanding level >90%	Online questionnaire with a driving scenario video

	in an understandable way.		
R_EN6_tool1.42	The driver needs to understand the meaning of the overtaking corridor visualized through AR.	CR for understanding level >90%	Online questionnaire with a driving scenario video

Table 14 - Requirements to be met

In the 2nd cycle experiment, a video will be shown to different users. The video contains the three above-described scenarios.

In the video, each scenario is shown one after the other and several times. Due to the repetition of the scenarios in the video, a "learning effect" of the different HMI components and their meanings should arise. It is not possible to recognize the real intention of the participant in the video. Therefore, the intention of the driver – in this case the participant – was set manually.

Before a scenario in the video changes (all scenarios were described in section chapter 3.7) the users get the message "*Imagine, you have the intention to follow/overtake*". This should generate specific intentions e.g. an overtaking or a lane holding intention.

After the video, each user has to fill up a questionnaire, which contains several sections. A subject number of at least ten participants with different ages and automotive knowledge is required to generate a meaningful experiment.

The detailed structure of the questionnaire is as follows: The first questions are personal questions like age and yearly kilometres. The next section shows the above-described video. All questions in this section are fully "open" e.g. "*What do you see in this picture?*" and for some questions the users get a picture of a specific situation of the video. Open questions are useful to get fully free answers without any influence of the formulation of the question. The disadvantage of open questions is the difficult interpretation of the answers. It is possible, that some users' answers are very short or describe only the meaning of one part of the visualizations (safety corridor or intention arrow).

After the open questions, in the next section the users assess the overall Augmented Reality HMI based on a System Usability Scale questionnaire and several more questions.

The questionnaire is created with Google Forms. Google provides an extensive questionnaire tool with the possibility for open questions, drop-down lists, multiple choices or scales. One advantage is the easy distribution of the online questionnaire. Another advantage is the result handling with Google Forms. All results will be processed by google and visualized e.g. if the questions are multiple choice or scales.

4.4.1 Results

The questionnaire took around 20 minutes. In total, 14 people took part in the experiment. Ten (71.4%) of the participants was male four (28.6%) was female. The minimum age was 25 years, the maximum age was 58 years and the average age was 32.6 years. In average, the participants own their driver license since 13.4 years with a minimum of five years and a maximum of 28 years. In average, the yearly driven kilometres were 10017 with a minimum of 50 and a maximum of 25000 kilometres per year.

Three of the 14 participants had advanced driver assistance systems (ADAS) in their own vehicle. For example, an adaptive cruise control (ACC) or a lane departure warning (LDW).

With a range of 33 years in the age of the participants and a range of 24050 yearly driven kilometres, the experiment includes a spectrum of different people with different automotive knowledge.

In the second section of the questionnaire, the users saw the video that contains all three Augmented Reality scenarios. Each scenario was shown one after the other and several times. After the video, each user got a set of questions. One part of the questionnaire was to describe the meaning of the displayed visualizations (safety corridor **and** intention arrow) at a specific situation based on a picture of this situation. Another part of the questionnaire was to describe the general meaning of only one part of the visualizations (safety corridor **or** intention arrow) without a specific situation or a picture. Primarily the metric for the validation of the Augmented Reality HMI is the correct rate (see deliverable 4.3). For this, the answers of the participants must be interpreted because the questions are open.

First, the meaning of the combined displayed visualizations at a specific situation based on a picture of this situation should be analyzed by the users. The Figure 15, Figure 16 and Figure 17 show the different situations and pictures. The associated questions were

- "*What do you think is the meaning of the shown visualizations in the picture?*".

Because the questions were open, it was hard to interpret the answers of the participants. The answers are often short or contains only the meaning of one visualization (safety corridor **or** intention arrow). Because of that, for this answers it is not possible to create a meaningful correct rate.

In the next section, the questions contain only one part of the visualizations (safety corridor **or** intention arrow). The interpretation of answers of the users for only one singular visualization was more precise and easier. That is helpful to identify the correct meanings of the participants for each singular visualization. The correct rate (CR) of the safety corridor, based on the question

- "*What do you think, which information the green and / or red corridor contains?*",

was 0.86. The CR of the intention arrow, based on the question

- "*What do you think, which information the blue arrow contains?*",

was 0.42. Much more people reported the correct meaning of the safety corridor than of the intention arrow. For the evaluation, the answers of the participants was evaluated in detail and would only be marked as "correct" if the users understood the complete safety corridor inclusive the colors and the intention arrow.

In the next section of the questionnaire, the users should evaluate the overall visualization based on a System Usability Scale (SUS) (*Bangor et al., 2008*). The SUS is a quantitative questionnaire to analyze the usability of a specific system. The System Usability Scale is based on a likert scale and contains five positive and five negative formulated questions. The result of the questionnaire is in range between 0 and 100 points. Four different quartiles organize the resulting points.

In this experiment, the result of the SUS was in total 82.5 points. In the SUS classification, that was the fourth quartile. A total number of points greater than 80 indicates a system with a "good" usability.

To understand the problems in the interpretation of the visualizations, in the last section the users should describe the advantages and disadvantages of the overall Augmented Reality HMI. There was three different questions to cover the needs of the users regarding to the visualizations.

- "Are *there visualizations that we did not covered? Which ones?*"
- "*What do you particularly like about the visualizations?*"
- "*What are the disadvantages about the visualizations?*"

These questions resulted in many different answers. For this reason, the answers were grouped. The most referred answer (3 of 14 users) is the needlessness of the intention arrow. At this point, it is important to remember, that the correct rate of the intention arrow was 0.42. Maybe the needlessness of the intention arrow is based on the unintelligibility of the intention arrow itself.

The next group of users (3 of 14 users) desires a more dynamic/animated/adaptive intention arrow e.g. like a dynamic indicator of a new modern Audi (running light). Five more users want better-looking (modern) textures. A majority of the users (8 of 14) praise the comprehensibility and the clarity of the overall visualization. Two users stated safety critical theses: First, that the visualizations may distract the driver from the driving task in manual mode and second, that a color-blind user or a user with red-green color blindness does not distinguish between a red and a green corridor. Especially the second thesis is significant in manual mode and must be considered. In case of an unsafe overtaking scenario a possible solution could be a thick line/bar between the right and the left lane.

To follow the TeamMate approach, the quality of co-operation and communication will strongly determine the driver's trust in the automated systems. In order to leverage the introduction of highly automated vehicles to the market and to fully exploit the automation's potential to improve traffic safety and efficiency these systems need to be trusted by the driver appropriately. Because of that, the last question was

- "*Do you think the presented visualizations would be helpful in gaining confidence in the actions of autonomous vehicles?*".

Nine (64.3%) users confirm this question and five (35.7%) users answered "maybe".

4.4.2 Conclusion of this experiment

The objective of this experiment was the validation of the Augmented Reality HMI and the fulfillment of the validation requirements R_EN6_tool1.35, R_EN6_tool1.41 and R_EN6_tool1.42. The requirement R_EN6_tool1.35 validates the comprehensibility of the performed manoeuvres through graphical visualizations and needs a correct rate greater than 90%. The comprehensibility of the performed manoeuvres in automated mode can be checked if the participants understand the meaning of the safety corridor. The safety corridor visualizes the driver the potential upcoming driving manoeuvres of the automation like lane holding or overtaking inclusive a risk analyze of the manoeuvre based on the intention of the driver. The resulted CR for R_EN6_tool1.35 is 86%. This is the above-described CR for the safety corridor. The answers of the participants were evaluated in detail and would only be marked as "correct" if the users understood the complete safety corridor and the meaning of the colors. Therefore, the requirement R_EN6_tool1.35 has not been met.

The requirement R_EN6_tool1.41 and R_EN6_tool1.42 describes the understandability of the automations behavior and of the overtaking corridor visualized through the Augmented Reality HMI. To validate the requirements R_EN6_tool1.41 and R_EN6_tool1.42, the correct rate for the safety corridor is also used. For R_EN6_tool1.41 especially the red part of the corridor is important because this part contains the information "why" the automation did not overtake and why the automation acting in a certain manner in an understandable way. Therefore, the requirements R_EN6_tool1.41 and R_EN6_tool1.42 for a CR greater than 90% have not been met.

A validation requirement for the intention arrow did not exists. Nevertheless, the CR for the intention arrow is important for future developments. The same applies for the other questions in the questionnaire. The results are not used to check requirements but they are important for future developments and changes of the Augmented Reality HMI.

Table 15 - Requirements results

REQ ID	Metrics	Fulfilled	Description
R_EN6_tool1.20	The HMI must show safe driving corridors and constraints on these corridors using graphical means	Yes	Safe driving corridors and constraints on these corridors (colors) are used.
R_EN6_tool1.33	In manual mode, augmented reality (AR) elements should be reduced to a minimum and not distract the driver.	No	Manual mode not proofed.
R_EN6_tool1.34	In automated mode, augmented reality elements can be used to enhance the situation awareness.	Yes	The Augmented Reality elements enhance the situation awareness based on the safety corridor and the intention arrow.
R_EN6_tool1.35	CR for understanding level >90%	No	CR < 90% Reached CR: 86%
R_EN6_tool1.41	CR for	No	CR < 90%

	understanding level >90%		Reached CR: 86%
R_EN6_tool1.42	CR for understanding level >90%	No	CR < 90% Reached CR: 86%

In this experiment, the above-described validation requirements have not been met. It is important to consider that all generated results are only based on a video and pictures.

For this video and the overall experiment, the real intention of the driver were not recognized. Without a fully implemented intention recognition, it is hard for the participant to understand the meaning of the intention arrow. Additionally, the safety corridor is also based on the real intention of the driver. It is not easy to generate a specific intention through a driving video. In a real driving experiment in a simulator with a connected Driver Intention Recognition, the correct rates are expected to increase. Then the users learn that their intentions trigger the safety corridor and the intention arrow.

Through the safety corridor and the intention arrow, the verification requirements R_EN6_tool1.20 and R_EN6_tool1.34 can be met. R_EN6_tool1.33 cannot be met because a manual mode was not tested.

All in all, the correct rate of the corridor was high and the corridor was accepted by the participants of the experiment but not high enough to met the requirements. The usefulness and the acceptance of the intention arrow must be re-tested in a real driving scenario in a simulator with a connected Driver Intention Recognition. However, the intention arrow was also accepted by almost 50% of the users. Eight of 14 participants praised the comprehensibility and the clarity of the overall visualization.

Nevertheless, it may be enough to show the safety corridor without the intention arrow because the corridor itself are also based on the intention of the driver. Another possible way is only to show the safety corridor (and the intention arrow), if the driver has the intention to overtake.

In line to the overall objective of the AutoMate project, nine (64.3%) users confirm the increasing confidence in the actions of autonomous vehicles through the presented visualizations. That underlines the benefits and the importance of the Augmented Reality HMI.

4.5 E6.7 – Ambient lights

The ambient lights, as a means of concurred abbreviation, have been validated in REL facilities as second part of the integrated HMI validation test (Test 1); the same users sample used in that Test 1 was invited to validate this enabler (Test 2).

4.5.1 Validation method

This phase of the experiment (Test 2) was performed to validate two different categories of requirements:

- The most effective **color** of the ambient lights;
- The usefulness of this means of concurred abbreviation, i.e. if this HMI is able to **improve the comprehension of the cooperation** reducing the user's workload.

The users were asked to see two scenarios with ambient lights, and to express their opinion on the color selected to communicate the cooperation. The ambient lights, in fact, have been used to improve the **request of support** from the automation; therefore, they have been used only when the direction of the support is H2A.
The colors selected to suggest the cooperation are:

- Blue, for H2A support in perception;
- Yellow, for H2A support in action.

The experimental setup of the Ambient lights validation is shown in Figure **25**.

Figure 25 Experimental setup of ambient lights validation

In order to measure how this HMI is able to improve the effectiveness of the communication, the NASA-TLX questionnaire was repeated on scenario and use cases with the addition of the ambient lights.

The **H2A support in perception** was measured with **blue ambient lights**, comparing the results with the score of Test 1.

The **H2A support in action** was measured with **yellow ambient lights**, to assess how this enabler can improve the effectiveness of the take-over request's comprehension.

The requirements defined in this section should not be considered as functional requirements, but user requirements: as stated in the PMBOK guide, they should "highlight that the product/service/project is designed well" contrary to functional requirements that "highlight that the product/service/project is well designed". Therefore, the objective of these requirements is to witness that the user-centered design approach has achieved its purpose.

The requirements used to validate this enabler are reported in Table 16.

REQ ID	Description	Metrics (success criteria)	How to validate it
R_EN6_tool1.48	In H2A support in action, the yellow should be considered the most suitable color for the ambient light	Positive answer X > 80%	Questionnaire
R_EN6_tool1.49	In H2A support in perception, the blue should be considered the most suitable color for the ambient light	Positive answer X > 90%	
R_EN6_tool1.50	The ambient lights should increase the comprehension of the expected cooperation	**NASA TLX** Workload with ambient lights < without ambient lights	NASA TLX survey

Table 16 Requirements for ambient lights validation

4.5.2 Results

4.5.2.1 Requirements validation

REQ ID	Description	Metrics (success criteria)	Results	The requirement has been met?
R_EN6_tool1.48	In H2A support in action, the yellow should be considered the most	Positive answer X > 80%	55%	No

	suitable color for the ambient light			
R_EN6_tool1.49	In H2A support in perception, the blue should be considered the most suitable color for the ambient light	Positive answer X > 80%	55%	No
R_EN6_tool1.50	The ambient lights should reduce the effort requested for the cooperation	Workload with ambient lights < without ambient lights	Overall WL without AL: **4,21** Overall WL with AL: **3,59** Δ: **0,62**	Yes

Table 17: Ambient lights validation results

The ambient light colours selected for this validation phase didn't met the user requirements, i.e. the results are below the success criteria. Other colours will be considered in the next cycle, also according the comments collected in this experiment.

The important result collected in the experiment was to highlight that the ambient lights have been considered a useful means to improve the effectiveness of the communication when the support needed is from the human to the automation.

This factor is confirmed by the comments of the users, and above all by the objective results of the NASA TLX. These results shows how the HMI, with the addition of the ambient lights, is able to reduce the driver's workload, improving the comprehension of the expected cooperation.

The results of NASA TLX repeated on the same scenario without the ambient lights and then with ambient lights are shown in Figure 26.

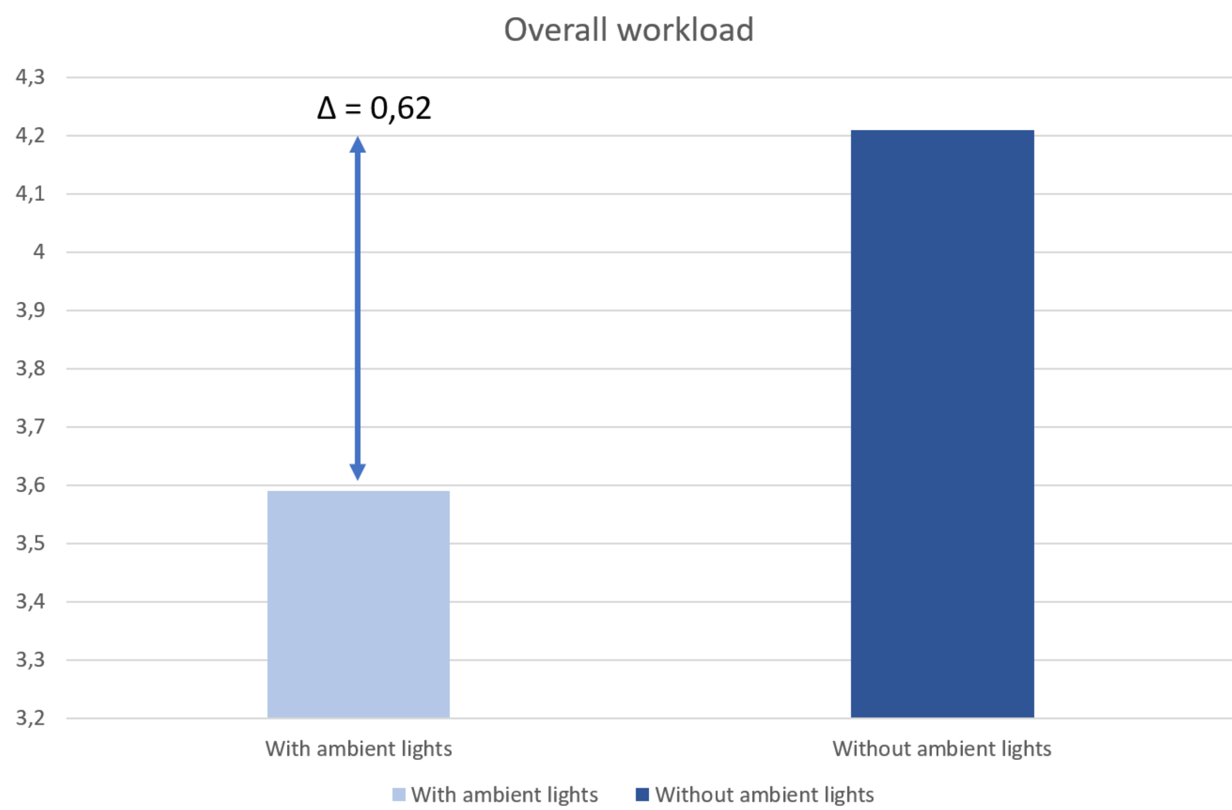


Figure 26: Comparison of overall workload with and without ambient lights

4.5.2.2 Qualitative results

In addition to the validation of the requirements, qualitative data was collected also for Test 2.

The ambient lights were well accepted and considered as a useful support to simplify information comprehension.

The color of the ambient lights has been object of discussion: the blue was selected as the color for H2A support in perception since this color was considered neutral enough to avoid confusion in the driver. From the comments of the users it emerges that for some of them the color was too neutral and therefore not useful for attracting attention.

Also for H2A support in action some of the users felt that yellow ambient light was not clear enough to explain the expected cooperation. While not necessarily implying a safety related situation, the disengagement has been considered a critical event, and two users would have preferred a more intense color (e.g. *"since I have to take control, and I could be out of the loop, I would have preferred an orange blinking light").*

These comments while be used as a basis for discussion in the next project's cycle.

5 Conclusion

The enablers in WP4, i.e. the modules that make up the HMI, have been developed to implement the cooperation in both directions.
E6.2, E6.3, E6.5 and E6.6 are designed to allow the support from the Human to the Automation and vice versa. Only E6.1 (Interaction Modality) and E6.4 (Ambient Lights) have been developed to provide the support only from the human to the automation (H2A).

Compared to the 1st cycle, at this stage of WP4 several improvements have been made: the modules have been implemented at a much more mature level, and some of them, which had only been hypothesized in the first cycle (e.g. audio, augmented reality and ambient lights) have been developed and implemented in this cycle.
Furthermore, the modules have been validated in tests with real users.
In order to be consistent with what has been defined in the project's concept, the HMI has been validated as an integrated enabler, to measure the different levels and directions of support.

The results of the validation show that the most innovative direction (i.e. H2A, when the automation requests a support to the driver) is well understood and accepted by the users.
Moreover, the H2A support in perception has been measured to be less demanding then the support in action (the transition of control). This factor can be considered one of the most relevant concept emerged during the project.
In fact, although the HMI for H2A support in perception (negotiation-based) is more complex than the A2H warning-based HMI (i.e. the archetypal paradigm used in automotive HMI industry and research), the users are able

to understand it and correctly perceive the reduced requested effort compared to the H2A support in action (i.e. the request of takeover).

In fact, the H2A support in perception has highlighted a reduction of perceived mental workload and frustration, and an increase of perceived performance compared to a support in action. This is of particular interest, since this type of cooperation is able to reduce the disengagement and potentially to improve the relationship between the driver and the automation (i.e. the trust and acceptance), as the driver is aware of the minimum effort requested to effectively support the automation.

6 References

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