D4.2 – TeamMate HMI design, implementation and V&V results from 1st cycle

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Acronyms

ACC	Adaptive Cruise Control
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-everything
NCDC	Navigation-Centred Driving Cluster
TOR	Take Over Request
TTC	Time To Collision
RA	Roundabout
HUD	Head-Up Display
LKAS	Lane Keeping Assist System

Executive summary

The HMI design is a crucial element to model an effective overall interaction strategy between humans and highly automated vehicles. It is widespread opinion that the major challenges linked with the growth of the autonomous vehicle market are related to Human Factors issues.

A main topic covered in this document is the quality of the transition between manual and automatic state. One of the AutoMate project's purpose is to create HMI solutions that can provide an effective and safe interaction. It is therefore necessary to focus on the states of automation and on the modes in which they are displayed to the driver.

The HMI design process started from a review of the state of the art in the field of autonomous vehicles. The literature outline has been used to create a set of guidelines that can guide the design and avoid common mistakes in interaction design. The purpose of this phase was to go beyond the state of the art, creating innovative HMI solutions.

During the workshops, three scenarios have been identified, to create the field in which the concept can then be tested. A design thinking session was performed to identify the issues and related potential solutions. The scenarios have been enriched with six use cases for each of them. For the use cases, we identified the recovery strategy and the relationship between driver and automation (considered as teammate) behavior.

This phase has led to definition of the initial concepts for all the issues emerged in the use cases.

A crucial element in this phase was the definition of the possible automation state, and the expected driver behavior in each state.

Four stable automation modes have been identified: a full Automatic mode, a full Manual mode, the TeamMate mode (the cooperative driving solution) and an Emergency mode. Two more states, defined as Transition modes (Manual to Automatic and Automatic to Manual, respectively for the Handover and the Take Over) have been designed to ensure a smooth transition between the different modes. These elements were used to define the HMI information structure, adaptable to the different configurations, but able to ensure continuity between them.

At this stage, the concept of multimodal interaction has been defined to adapt the communication between the driver and the vehicle, based on the driver's degree of attention.

The initial concepts have then been merged into a general concept: the elements (channel selection, graphical features etc.) have been associated with the automation state, to ensure the presence of all the relevant elements in the HMI. A wireframe for all the visual displays in each automation state has been developed and the visual HMI has then been implemented.

Finally, a V&V process was carried out to verify the adherence of the product implemented to the requirements defined in task 1.3 during the first cycle.

1 Introduction

This document describes the process of design, implementation and V&V of the TeamMate HMI. The results from the Tasks 4.2, 4.3, 4.4 and 4.5 for the first cycle are specified. Partners involved are BIT, HMT, REL, ULM, VED.

The deliverable has the following structure:

- Chapter 1 (Introduction);
- Chapter 2 (HMI design issues for highly automated vehicles): a state of the art on the major issues related to Human-Machine Interaction in autonomous vehicle;
- Chapter 3 (Scenario description with a focus on Human-Machine Interaction and Cooperation): an extended description of scenarios and use cases;
- Chapter 4 (HMI design initial concepts): describes the results of the workshops for early design stage;
- Chapter 5 (General HMI features): in which are listed all the elements to be considered in the HMI design;
- Chapter 6 (Strategy for safe and robust transition for hand-over of vehicle control): describes the handover and take-over process, with a focus on fallback strategies;
- Chapter 7 (HMI modes): in which all the automation modes are defined, the information structure and the multimodal interaction concept are described in detail;
- Chapter 8 (HMI design and implementation): shows the current version of the HMI, designed and implemented according to the concepts discussed in the previous parts of the deliverable;

- Chapter 9 (Verification and Validation activities): describes the V&V results, in relation with the requirements defined in the Task 1.3;
- Chapter 10 (Conclusions and next steps): summarizes the results of the first cycle, introducing the activities for the next cycles.

2 HMI design issues for highly automated vehicles

The core of cooperative driving is the continuous exchange of information between the driver and the system. This exchange serves to make the system aware of the driver state and vice versa: the system should be able to detect driver conditions, and the driver should be able to understand the action and the intention of the automation.

One of the most important human conditions that automation must be able to recognize is driver's level of attention: distraction is described by NHTSA as "anything that diverts the driver's attention from the primary task of navigating the vehicle and responding to critical events" (NHTSA, 2013).

The challenges of vehicle automation are at least as much related to human factors as technical issues. Neale and Dingus stated that "the hardest problems associated with an Automated Highway System are "soft", that is, they are human factors issues of safety, usability and acceptance as well as institutional" (Neale, 1998).

Automation changes the nature of driving task from active operator to passive supervisor. Consequently, drivers experience an out-of-the-loop state characterized by reduced situation awareness, reduced direct feedback from vehicle controls, redistribution of mental workload, and overreliance on automation, among others (Endsley, 1995).

One of the most important issues related to human-automation interaction is the concept of transition of authority. When the system is not able to deal with a situation, due to reaching system boundaries or system failures, it must cede control to the human driver. The driver, in turn, must be able to take over manual control after receiving the information from the system when needed. An efficient human-automation interaction can be considered, in this sense, as a trade-off between driving comfort, a solid level of situation awareness and a steady and proper level of mental workload (Hancock, 2013).

An accurate mental model of the automation capabilities is built through the flow of information between the driver and the system. This mental model also helps the driver to trust in automation skills, making one aware of the automation state and intention. Trust can be defined as "the attitude that an agent will help achieve an individual's goal in a situation characterized by uncertainty and vulnerability" (Lee, 2004). In highly automated vehicles, an accurate level of trust in automation may improve the quality and safety of the human-machine interaction, which makes the measurement of trust indispensable in the design process of interaction systems.

In modern vehicles, the information flow between the driver and the system is continuous and bidirectional. The driver-to-vehicle interaction is achieved through vehicle commands and inputs given by driver to change the system state or to ask for an information. Vehicle-to-driver communication usually consists of a series of feedback to make the driver aware of the system state. In highly automated vehicles there are also other types of information, such as the takeover request issued by the system to the driver in certain situations in intermediate automation levels.

Both communication types (driver-to-vehicle and vehicle-to driver) can take place through different sensorial channels. Driving behaviour is mainly a visual task and visual channel is the most relevant one for driving-related information. Nowadays, due to a larger number of information on vehicle (navigation- or entertainment-oriented), new interaction modalities have emerged for vehicle-driver communication, to better respond to human factors needs.

An important current trend for in-vehicle communication is the rise of multimodal HMI, which can be defined as "those that process two or more combined user input modes, such as speech, pen, touch, manual gestures, gaze and head and body movements, in a coordinated manner with multimedia system output” (Oviatt, 2007).

Hence, multimodality in vehicle HMI can be considered from two different points of view, namely, multimodal input and multimodal output. A multimodal input describes the driver-to-vehicle information flux; whereas, a multimodal output describes vehicle-to-driver one. Multimodal elements help to reduce the complexity of car’s cockpit. Nonetheless, each single interaction modality has advantages and drawbacks. With respect to the input, individual modality is simple and can help to reduce the eyes-off time from the primary task. Otherwise, individual modality is often not enough adaptive and not optimized for the task to be performed. For example, when interacting with the system through speech command, the user needs to memorize and formulate a command that is valid for a particular system state. This can be demanding and induce high mental workload. The disadvantages of any single modality can often be overcome by combining them intelligently. There are different strategies to accomplish such combination:

- **Temporally cascaded modalities:** if two or more modalities are sequenced in a particular order such that partial information supplied by recognition of the earlier mode is able to constrain the interpretation of the later mode
- **Redundant modalities:** where each modality is available in each interaction step. In this type of interaction modality, the driver can decide how to give the input to the system, choosing between different sensorial channels and related command.

- **Fused modalities:** the most elaborate form of multimodality. It consists of simultaneous activation of different channels in order to give complex and elaborate commands (e.g. with the combination of speech commands and gesture recognition) (Muller, 2010).

One of the main goal of vehicle HMI design is to minimize driver distraction. However, each assistance system and infotainment function need a control command and a feedback signal that would make common display interfaces too complicated for an effective and comprehensible interaction. Thus, a continuous validation of the results on this aspect is crucial to design an effective series of control and feedback systems.

Also the combination of different integration strategies can be measured from the early design stages to the final product, to verify that the combination is the optimal one. Classical tests in automotive domain (e.g. Lane-Change task as a measure of driver distraction) and physiological measures to detect driver global state (e.g. heart rate and skin conductance) can be used in this type of validation. Actual challenges of multimodality in vehicle design are oriented to ensure good usability in the context of usage in the car. Current trends are trying to adapt general usability guidelines, which are traditionally stated for desktop systems, to vehicle HMI. Two of the main principles in these guidelines are learnability and visibility.

- **Learnability** refers to the degree to which a functionality and its HMI can be learned effectively and easily to achieve a maximal performance by a new user (Response 2, 2004). An example of this principle can be described as in the use of natural voice user (e.g. Dragon Drive), in which vocal commands can be given with natural language (without activation keys or codes).

- **Visibility** refers to the degree to which the user could see the options relevant for performing a certain task, but not the unnecessary alternatives in order to reduce distraction. This is particularly difficult for speech interfaces as there is not visual input and as a correct interaction can only be achieved via clear and consistent vocal feedback to optimize the bidirectional information flux.

The advantage of multimodal interaction is a debated theme in the domain of automotive user interface (UI) design. Research results show that there is a reduction in cognitive effort, deriving from the possibility of the driver to choose the most adapt channel to deal with a situation. Early research (Weinberg, 2010) also demonstrated how multimodal HMI can reduce temporal effort in addition to cognitive one. These results encourage multimodal approach for interface design, and suggest how the information mirroring on mobile devices is a promising strategy to minimize the effort, reinforcing driver's situation awareness and overall system safety. This theme and current design strategies will be described later in this paragraph.

HMI characteristics are important in the design of human-machine interaction, particularly in the case of a takeover request (TOR). In this respect, multimodal HMIs can be of help to the system reliability, effectiveness and safety. The information visualization of this kind of message is important due to the criticality of the action needed.

Takeover request can be described as follows:

- The system (in automatic mode) detects a situation that is not able to deal with;
- The system detects the driver's state (such as inattention, hands-off, use of another device);

- The system warns (or informs) the driver of the current state and the need to take over;
- The driver receives and understand the message;
- The driver executes the order (taking over) and communicates to the system the success of the interaction;

Basic forms of automation (i.e. adaptive cruise control and traffic jam) typically use an information system to make the driver aware of the system and driving state. In higher level of automation, the TOR design can have an impact on "how" and "in how much time" the takeover task is accomplished.

Traditionally, visual information about the vehicle state is provided on the dashboard. As stated by Bazilinskyy et al. "it is well established that the appropriate use of colour, saliency and spatial positioning according to the principles of moving part and proximity compatibility can make a visual display easy to understand" (Bazilinskyy, 2017).

In the first attempts of take over request design, the information is showed with visual indicators, such as icons and colour changing in the visual display, and/or through acoustic warning. More advanced design strategies include: lighting up an icon/region on the dashboard, the information mirroring on head-up display (Kim, 2009) and nomadic devices.

Another promising approach is to use ambient TORs, by lighting up a led strip under the windshield or all around the cabin (Kelsch, 2015).

Visual channel is not the only one used for the takeover request. The use of multimodal HMIs can improve the takeover quality and accuracy: for example, auditory channel is one of the most important to effectively catch the driver's attention. Auditory displays are widely used in cars, for warning about hazards in the driving environment, to support the driver during the parking task and as an advice on a collision path (Bazilinskyy, 2017).

Another important strategy involves the use of vibrotactile information, from the seat or from nomadic devices. All these strategies can be combined into a multimodal display. In this case, there is a multimodal output that can improve the understanding of the takeover message for the driver. The efficacy of a multimodal HMI depends on whether or not the different parts are congruent with each other.

It is important, in this phase, to emphasize the final user's trust and acceptance of the different types of information. It has been argued that multimodal TORs are a preferable option in high urgency scenarios; auditory messages are the most referred in low urgency scenarios and as confirmation message.

Another finding shows that the information on the visual display is perceived as more urgent than vibrotactile one in low criticality conditions (Bazilinskyy, 2017). All these findings highlight the effectiveness of an adaptive strategy for information visualization for a takeover request. Currently, the strategy for designing takeover information is not standardized. Some attempts described in literature show that there are some solid and recurring elements in visual displays (Flemisch, 2011):

- Automation Scale: shows the active degree of automation in a scale that represents possible degrees. It serves to make the driver aware about the system state and avoid mode errors.
- Automation monitor: a representation of driving state, such as position in the lane and detection of obstacles.
- Message field: a space on the HMI to indicate a TOR by means of an icon, the use of iconic colours and a written message, often in combination with other types of information.

Simulator studies revealed that drivers pay great deal of attention to the aforementioned elements, such as the colour coding and a clean interface, in their interactions with the vehicle. It has been argued that the use of these design features can improve the quality of takeover, both for accuracy and time of response (Larsson, 2015).

Traditionally, visual in-car displays are positioned through a consistent code that keep different types of information separate in order to ensure a high level of usability. Driving-related univocal information, that is, from vehicle to driver, such as speed, RPM or fuel consumption, is usually presented on the dashboard. Bidirectional information, on the other hand, is generally presented on the central stack and the driver can interact with this interface through touchscreens, buttons, joystick or knobs). Such bidirectional information is mostly "in-vehicle information systems (IVIS)", including infotainment functions. A promising approach of in-vehicle information visualization resides in the use of Head-up display (HUD) on the windscreen. Usually navigation information is showed on this type of visual display. Solid general design principles, such as legibility, visibility, frequency of usage and location expectancy, can be applied in the design effective HMI for highly automated vehicles.

Class	Guidelines	Reference
Human-automation interaction	Avoid as possible supervisory task in the interaction with highly automated vehicles	Endlsey (1995)
	Develop an efficient interaction for authority transition, considered as a trade-off between SA, driving comfort and workload level	Hancock (2013)
	Build a coherent mental model between human and automation	Lee (2004)
	Measure "Trust in automation" as key factor for an efficient driving performance	
Multimodal HMI	Combine in an accurate way the multimodality	Muller (2010)

	strategies (temporally cascaded, redundant, fused)	
	Multimodal HMI can reduce temporal effort, but add cognitive one: evaluate the use of multimodality due to the need	Weinberg (2010)
	Combine different evaluation strategies to evaluate multimodality and adapt general usability guidelines for in-vehicle HMI	
	Use of “information mirroring” (e.g. on HUD or mobile device) can improve global performance	
	Ensure learnability and visibility of the interfaces	
Takeover request (TOR)	TOR can be mirrored on HUD	Kim (2009)
	The use of ambient lights signals can improve the takeover performance	Kelsch (2015)
	Develop a flexible and adaptive strategy for information visualization of TOR	Flemisch (2011)
	Develop accurate graphical features (e.g. recognizable icon and solid colour coding) can improve the takeover performance	Larsson (2015)
	Haptic feedback (e.g. vibrotactile seat) can help the driver to come back into the loop)	Bazilinskyy (2017)
	Use of other multimodal approach (e.g. visual and audio) can improve the takeover performance	

Table 1. Summary of the state of the art

2.1 Explanation of the concept of concurred abbreviation

The term of "*concurred abbreviations*" denotes a set of human-like, bidirectional, personized multi-modal messages.

These personalized abbreviated messages can be used to

1) notify the driver
2) train automation.

The goals of the messages in the first group are to explain a past event (feedback information), to explain a current event and to provide information on what will happen in the near future (e.g., alerts of upcoming event - feedforward notification).

The goals of the messages in the second group are to provide short explanations about how the driver solved complex situations and why the driver took over control so that the vehicle can learn how to handle the same situation in the future.

Koo and colleagues (Koo, 2014) categorize the bidirectional feedback and feedforward messages in three groups:

1) ***how message****:* information about how the car is acting, announcing the automated action the car is initiating, such as "*Taking over is in progress..*".
2) ***why message****:* situational information explaining the reason for engaging automation, such as "*Obstacle ahead*".
3) ***how & why message****:* information on how the car is acting and why the car is making those actions, such as "*Cancelling take over manoeuvre due to obstacle ahead*."

The HMI designed in AutoMate provides intuitive, bidirectional communication via different modalities between driver and automation. For example, the HMI retrieves the manoeuvre plans from the vehicle and suggests these to the driver. While doing so, it chooses a communication strategy that relies on stored personalized, multimodal communication preferences of the driver (including "How and Why" message). In the context of complex, dynamic driving environment, several events are likely to take place simultaneously. This, in return, implies concurrent messages on the past, present, and planned events. The main challenge lies in displaying the driver accurate and pertinent information in a way that the driver is able to interpret appropriately.

3 Scenario description with a focus on Human-Machine Interaction and Cooperation

Three main scenarios have been considered within the frame of the AutoMate project, and a number of use cases have been identified for each scenario. These use cases are depicted as flowcharts in order to describe the cooperation between driver and TeamMate Car and to locate the interaction strategies. The vertical axis of the flowchart consisted of the three possible driving modes, namely, automatic mode, cooperation/information mode and manual mode. The horizontal axis, on the other hand, consisted of different driving states, namely, safe driving situation before the manoeuvre, the critical manoeuvre and safe driving situation after the manoeuvre. A consistent symbols in the form of rectangle, ellipse and diamond have been used to describe the possible situations and behaviours. Finally, a summary table has been prepared to describe the relevance of the three pillars described in the description of work (DOW) (NCDC, Multimodal HMI, Concurred Abbreviation).

3.1 Scenario 1 (Peter) and use case description

In the Peter scenario, the TeamMate car is driving on a rural road. A slow, large vehicle, which in this scenario is a truck or a tractor, reduces the capturing capabilities of different sensors of the car. TeamMate could overtake the slow vehicle and drive off. Nonetheless, information from the sensors are needed in order to decide if it is safe to overtake. The driver is capable to extract this information, therefore, the TeamMate car needs to cooperate with the driver. The driver can fill in the missing information of the oncoming traffic and the manoeuvre can be finished in a cooperative and efficient way.

The interface in this scenario should provide the necessary information to the driver and support an interaction in which the car and the driver can cooperate.

Use case 1

The driver indicates that he wants to overtake. As the current situation and the sensor confidence allow, the TeamMate car overtakes (as shown in Figure 1).

Use case 2

The indication from the driver is that an overtake is possible. However, the confidence level of the sensor data is not in the safe threshold due to bad road or weather conditions. Thus, the system needs driver's full attention and could possibly need the help of the driver. During the manoeuvre, TeamMate needs the drivers support for the lateral control and communicates this to the driver (Figure 2).

Use case 3

The indication from the driver to overtake is in contradiction with the Highway Code because of a "No passing" road sign. So the system initially refuses to start the manoeuvre. However, the situation affords an overtaking manoeuvre because a truck is blocking the road. Therefore, the driver has to communicate to the system that it is necessary to overtake (Figure 3).

Use case 4

The indication from the driver to overtake cannot be safely assured as it is in contradiction with the road (e.g. curvy road) or weather conditions. The system refuses to overtake and communicates the reasons to the driver (Figure 4).

Use case 5

The driver does not know if an overtaking manoeuvre is possible because s/he is not sure if the opposite lane is wide enough. The confidence level of the sensor data of the system is high enough to confirm that an overtaking manoeuvre is safe, thus, the TeamMate car offers the driver to overtake (Figure 5).

Use case 6

The indication from the driver to overtake is in contradiction with the traffic situation. Because of oncoming traffic on the opposite lane, the car is not able to carry out a safe overtaking manoeuvre. In the moment the sensors detect that the oncoming traffic is too close, the manoeuvre is aborted (Figure 6).

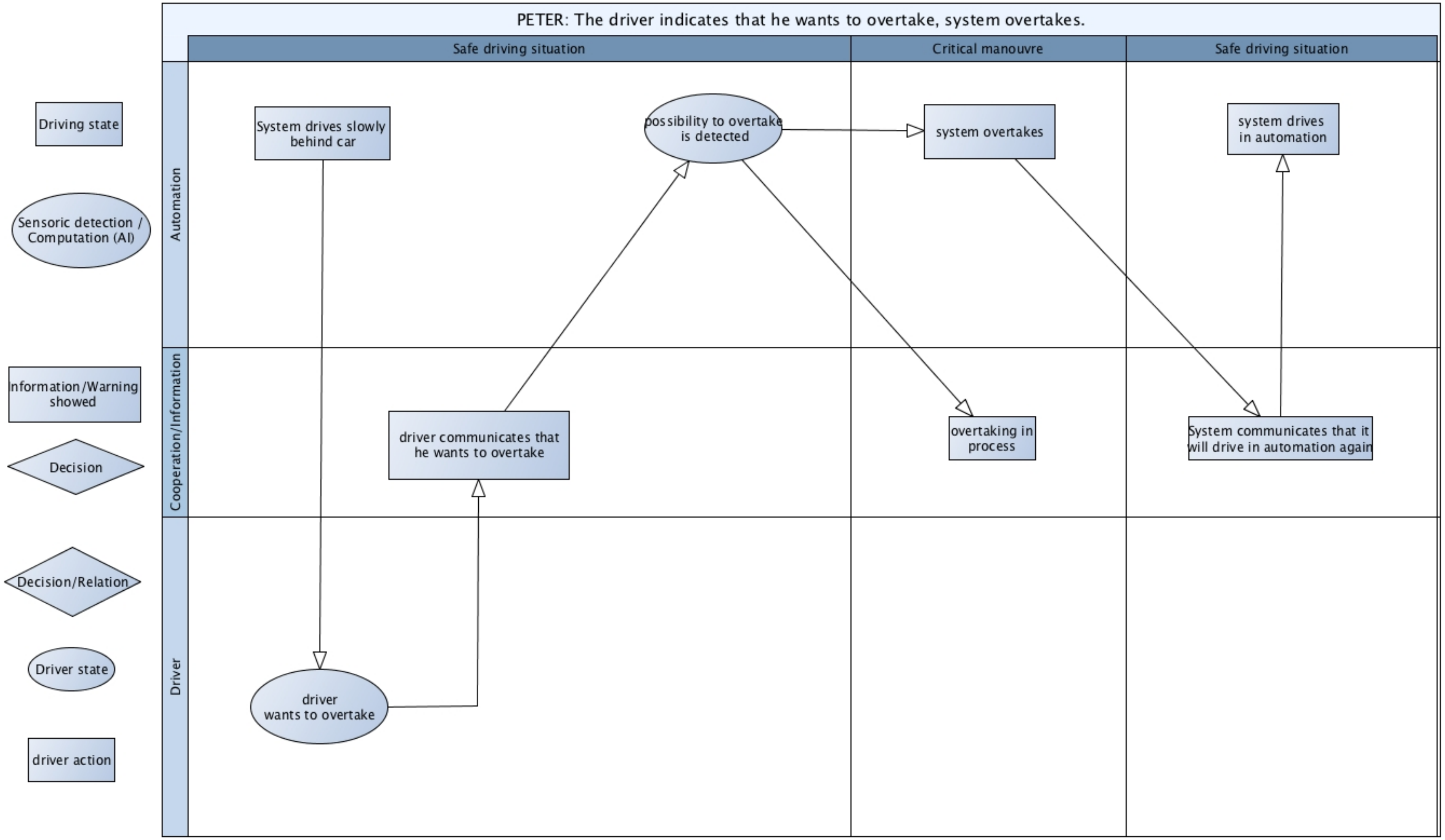


Figure 1. Peter - Use case 1

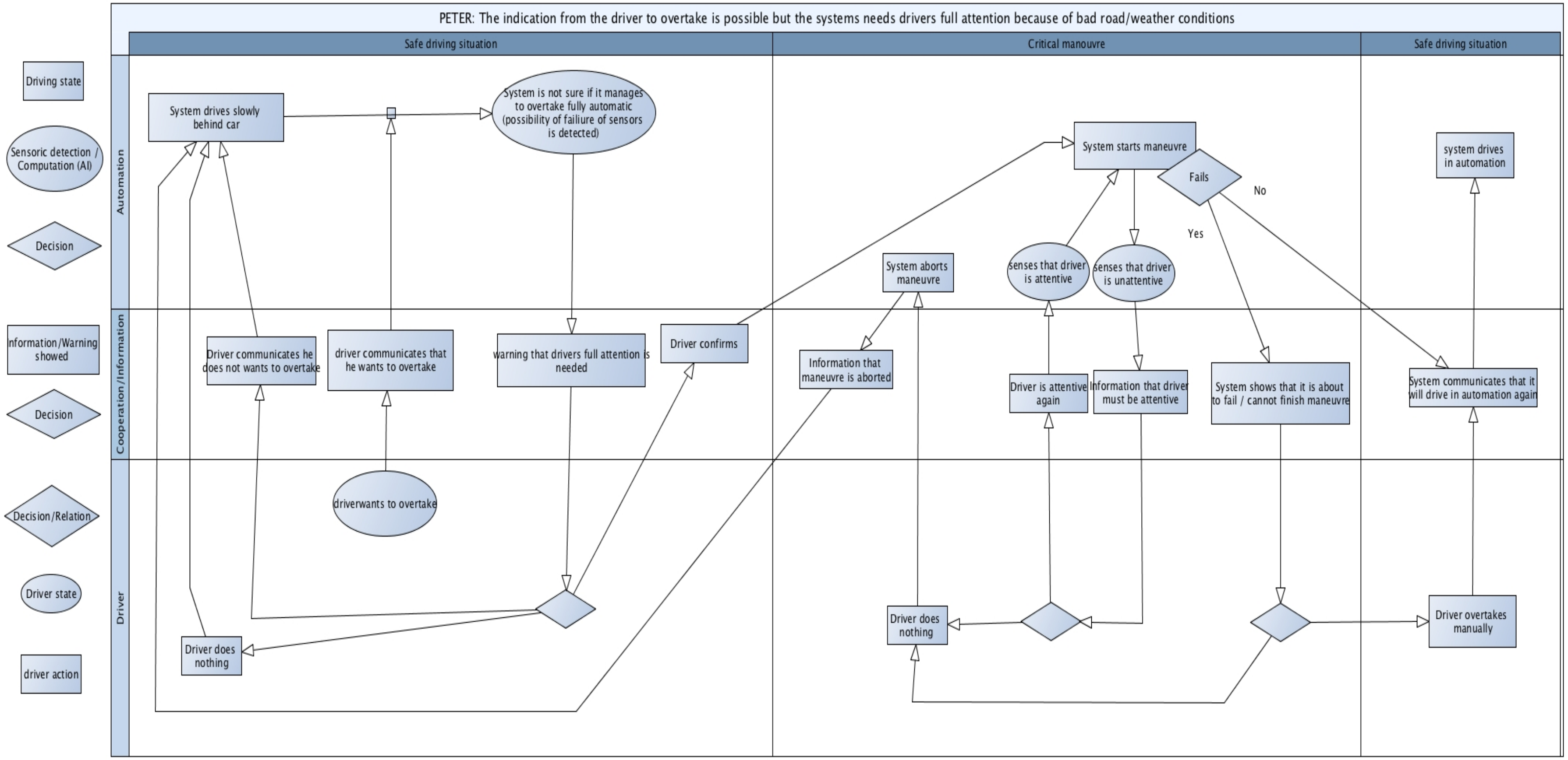


Figure 2. Peter - Use case 2

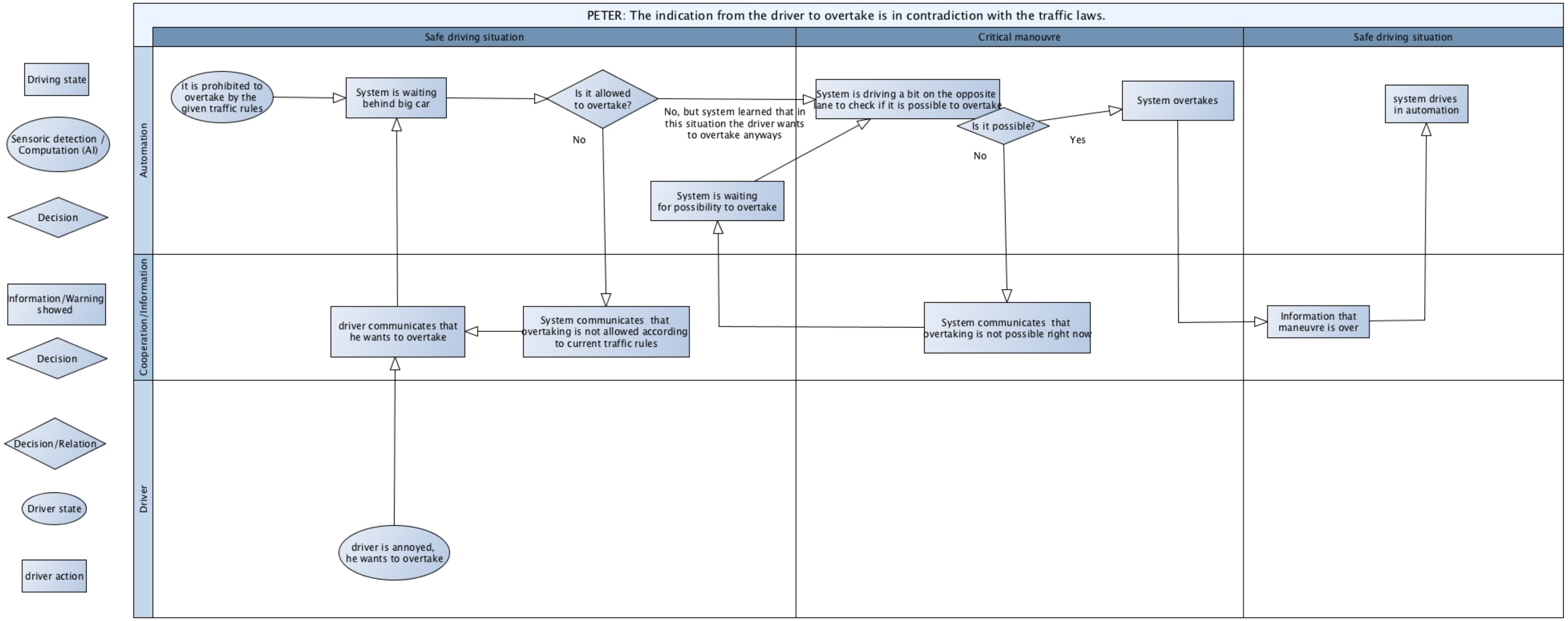


Figure 3. Peter - Use case 3

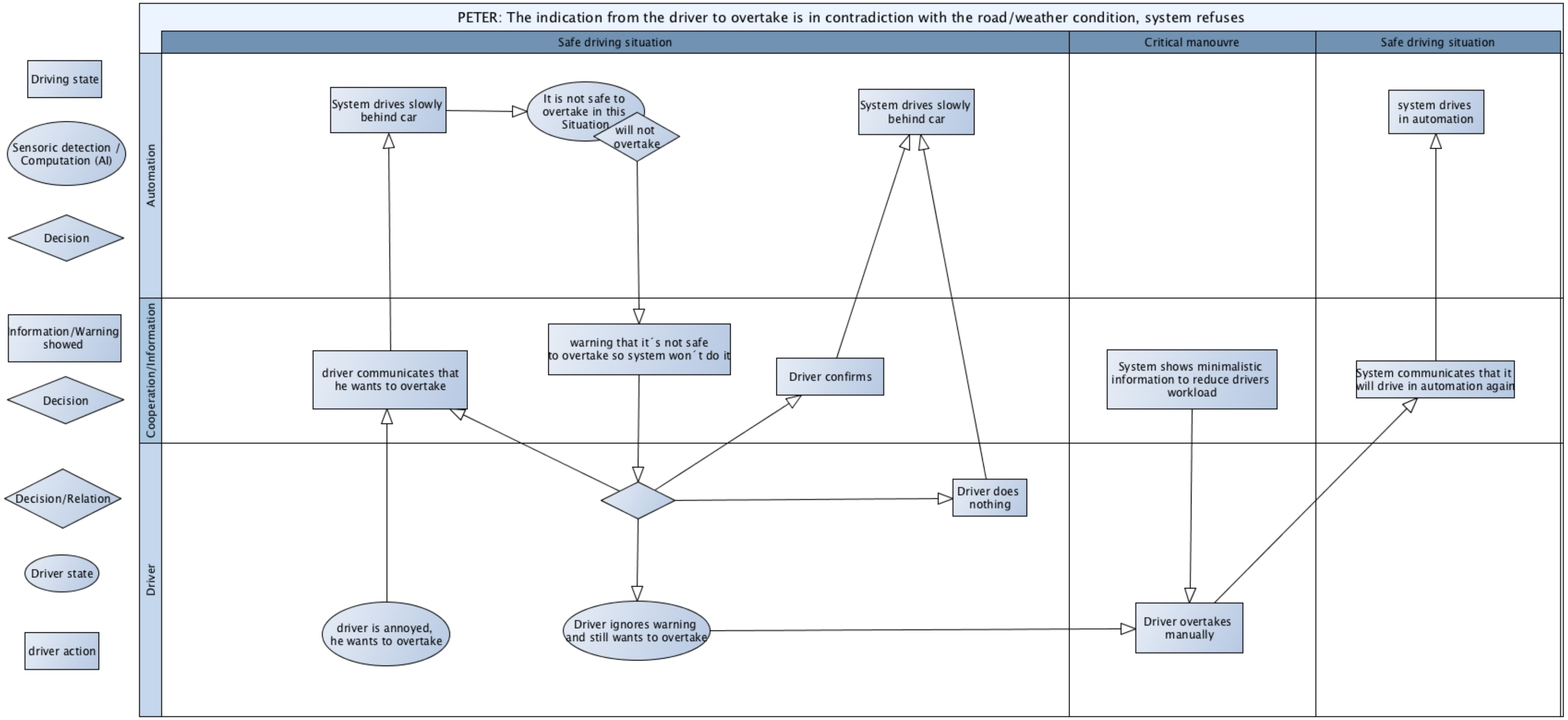


Figure 4. Peter - Use case 4

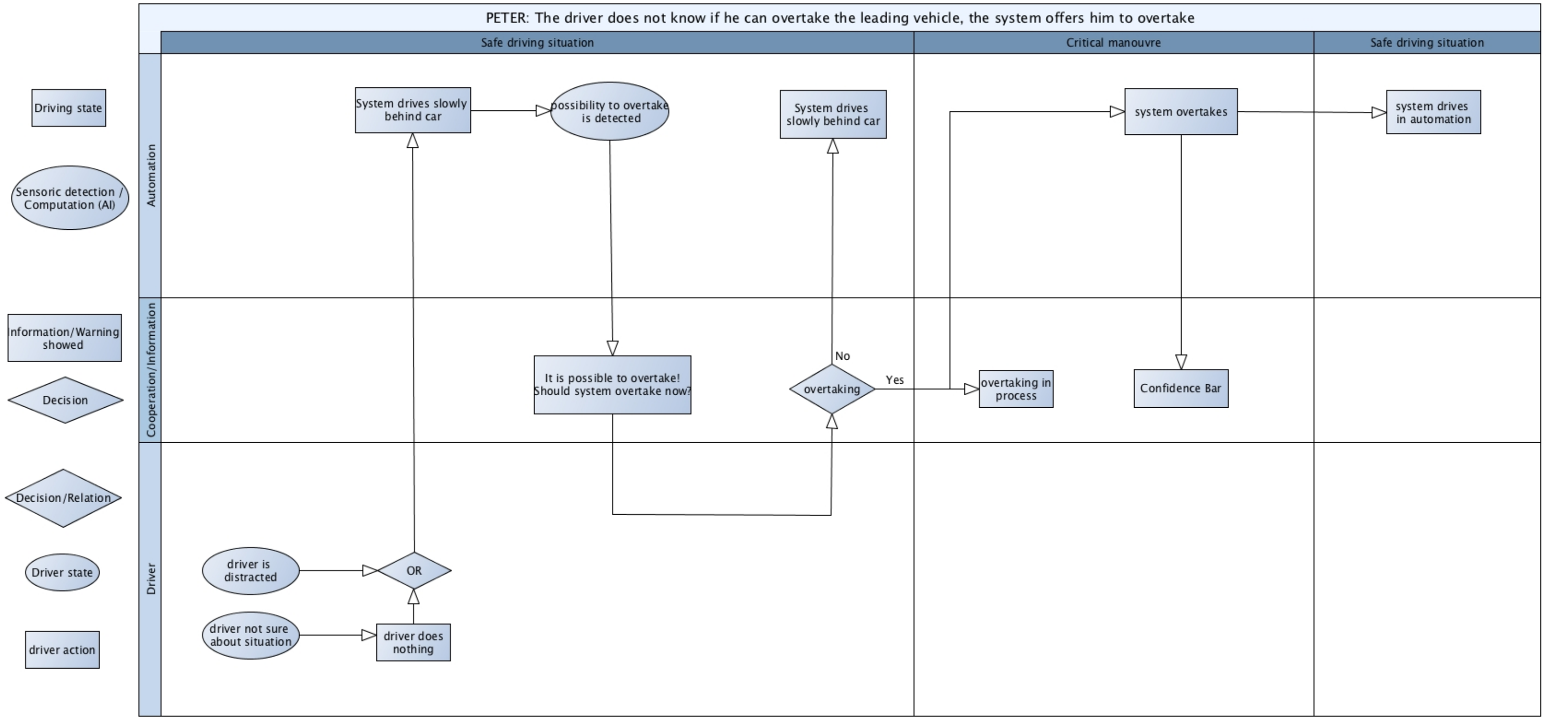


Figure 5. Peter - Use case 5

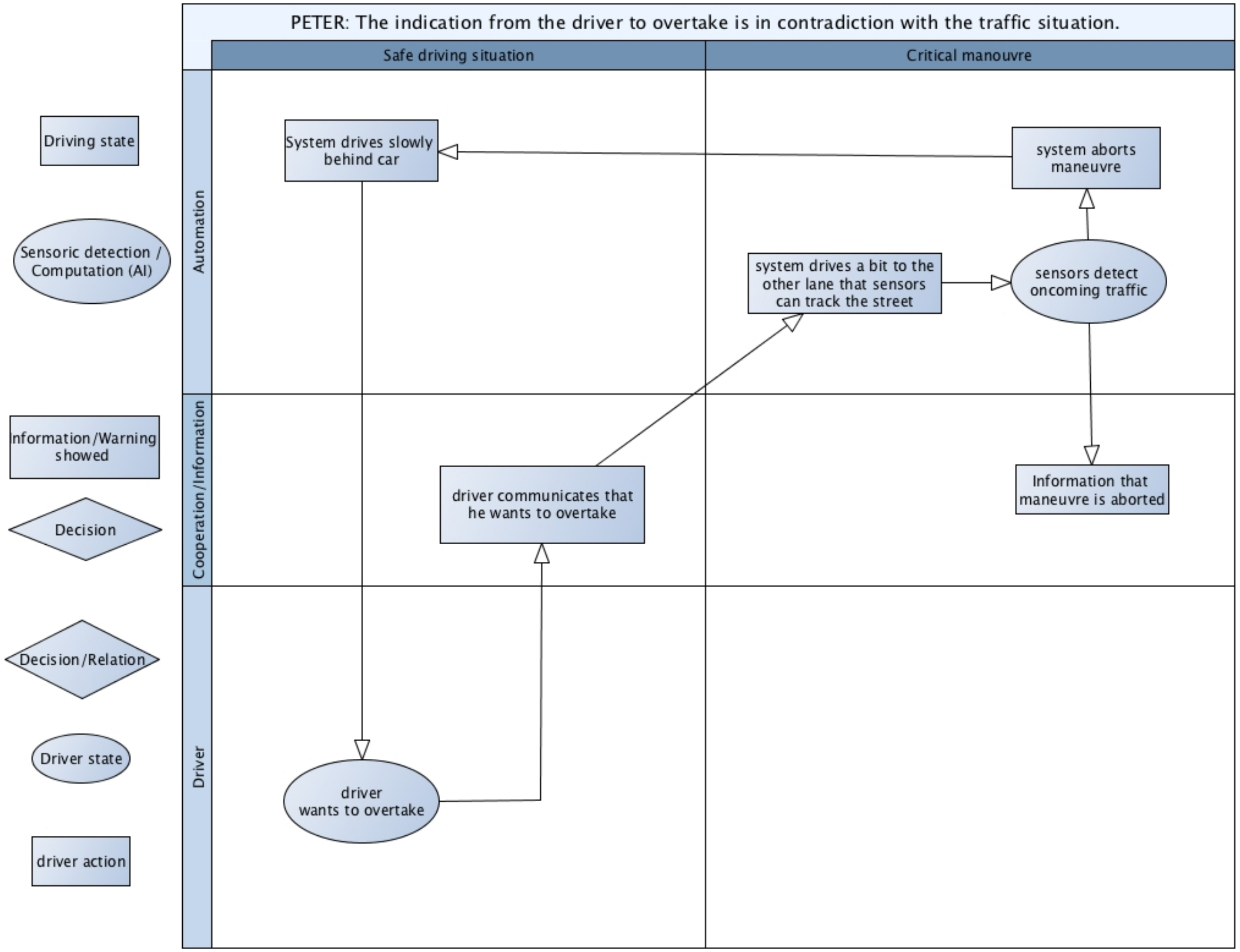


Figure 6. Peter - Use case 6

3.2 Scenario 2 (Martha) and use case description

Martha scenario will be realized by the VEDECOM demonstrator vehicle. In this scenario, the TeamMate Car is driven in manual mode by the driver on an urban road. The driver, Martha, receives a text message and starts reading through. TeamMate detects that the driver is distracted and not attentive to the forward roadway anymore, thus, proposes the driver to activate automated mode.

Six use cases have been identified.

Use case 1

In the first use case, Martha immediately confirms TeamMate’s suggestion and activates the automated mode. After a while, TeamMate detects that the end of automated driving zone is approaching via GPS. TeamMate sends a takeover request to Martha informing her that the end of the automated driving zone is approaching sufficiently in advance. Martha takes over manual control of the vehicle (Figure 7).

Use case 2

In the second use case, Martha initially refuses TeamMate's suggestion to activate the automated mode. TeamMAte detects via connectivity that there is a dangerous zone (roadwork) ahead. Thus, it repeats its suggestion to activate the automated mode with an explanation of the upcoming situation. Martha activates the automated mode (Figure 8).

Use case 3

In the third use case, similar to the second use case, Martha rejects TeamMate’s proposition to activate the automated mode and remains busy with her mobile phone. TeamMate has learned Martha’s habitual driving behavior throughout her vehicle use. Eventually, it detects that Martha's driving behavior deviates from her normative driving style, such as driving close to the lane line and varying speed maintenance. Therefore, it proposes to switch to automated driving mode for a second time. Martha rejects TeamMate’s suggestion for a second time and remains in manual control of the vehicle. TeamMate registers this response and does not make further proposal (Figure 9).

Use case 4

The fourth use case is a variation of the third use case by the final decision of Martha. After refusing TM's proposition to switch to automated mode, Martha continues her text message and starts deviating from her habitual driving style. TeamMate repeats its proposition for a second time. Martha then complies with TeamMate’s suggestion, activates automated driving mode, and carries out her side activity. Upon finishing her side activity, she communicates to TeamMate that she wants to take over manual control. TeamMate verifies that the distracting situation is over and that Martha is attentive to the forward roadway again. TeamMate gives control back to Martha (Figure 10).

Use case 5

The fifth use case is a variation of the first use case. TeamMate issues a takeover request as it approaches the end of automated driving zone. However, it detects via the driver monitoring system that Martha is not attentive to the forward roadway. It, then, issues a warning indicating that she is distracted to drive safely in manual mode and proposes relevant information (Figure 11).

Use case 6

The sixth use case is about a minimum risk maneuver (MRM). Martha activates the automated mode while she is busy replying her text message and remains in automated mode afterwards. TeamMate detects via GPS that the end of the automated driving zone is approaching, thus, issues a takeover request to Martha sufficiently in advance. Martha does not take over manual control for a certain time (to be decided). The vehicle, thus, initiates an MRM and informs Martha about its decision (Figure 12).

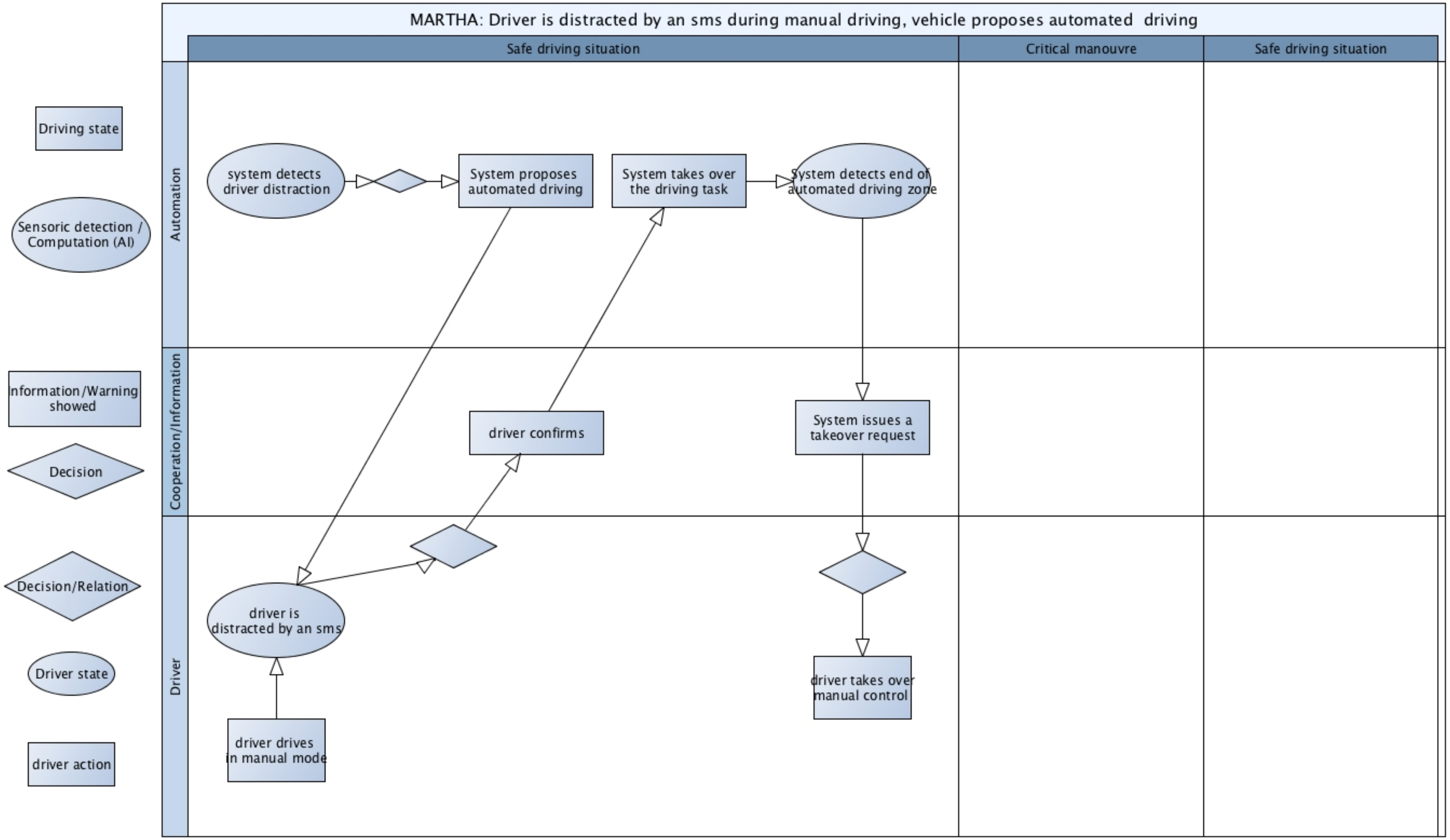


Figure 7. Martha - Use case 1

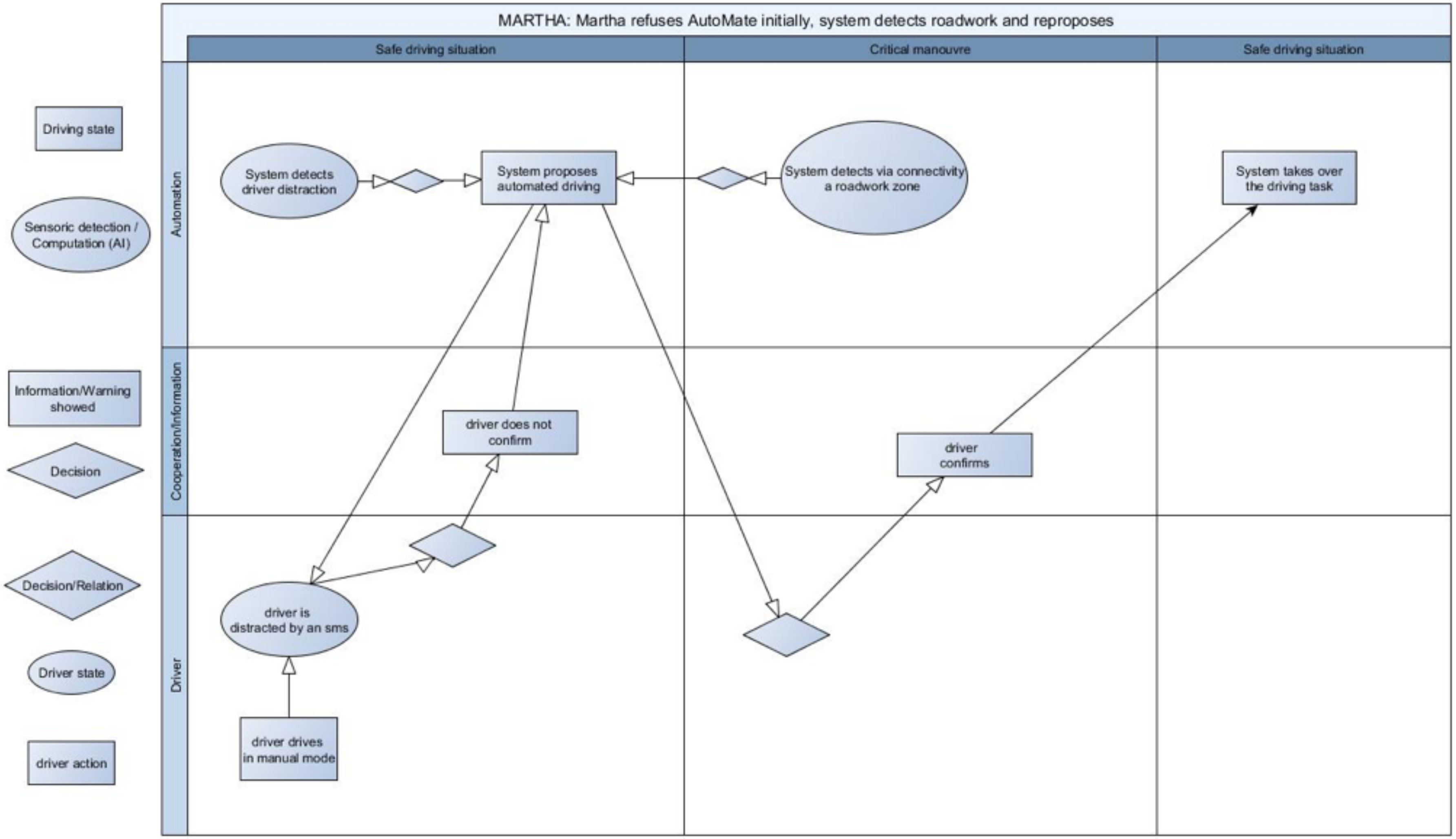


Figure 8. Martha - Use case 2

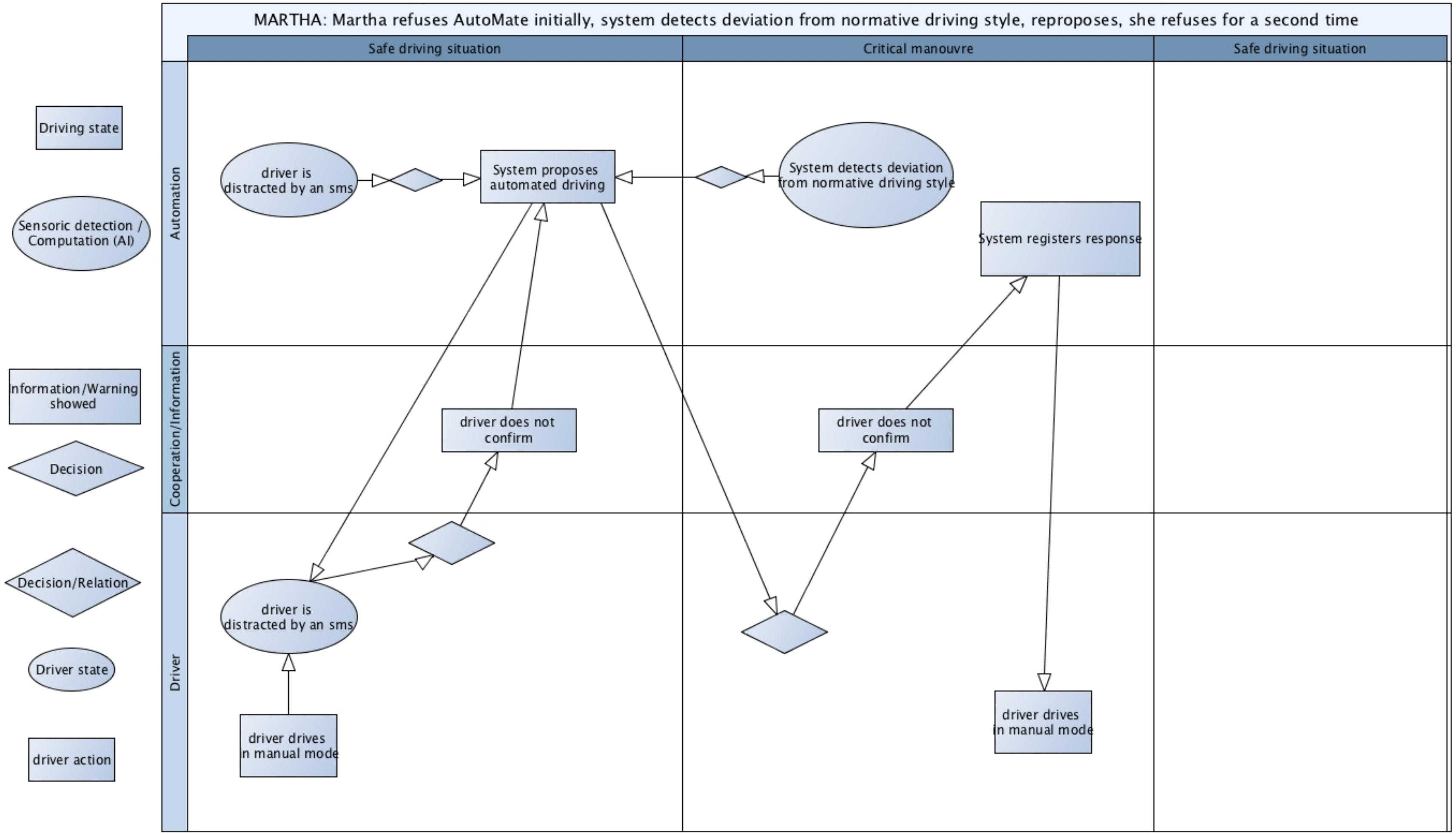


Figure 9. Martha - Use case 3

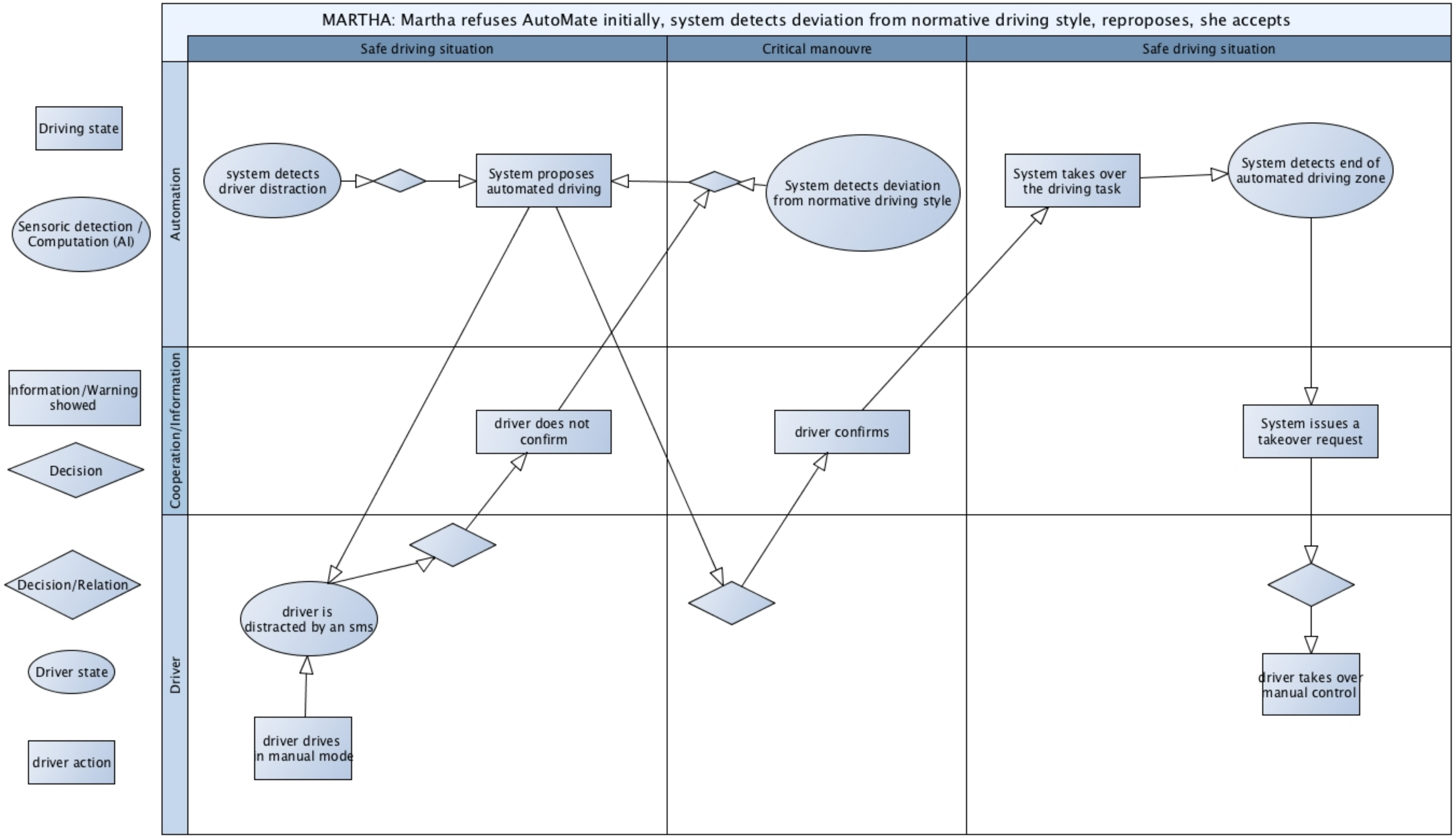


Figure 10. Martha - Use case 4

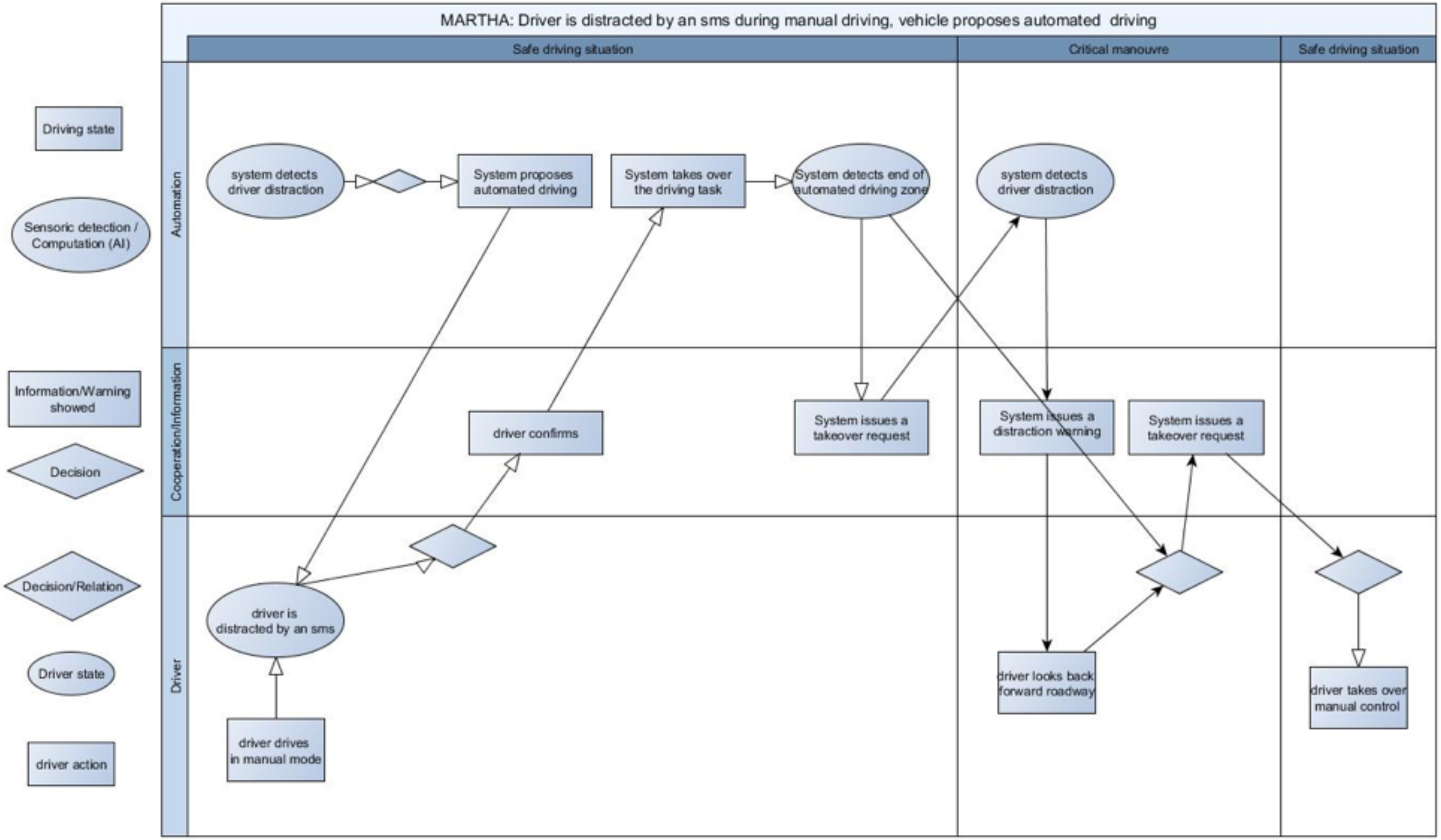


Figure 11. Martha - Use case 5

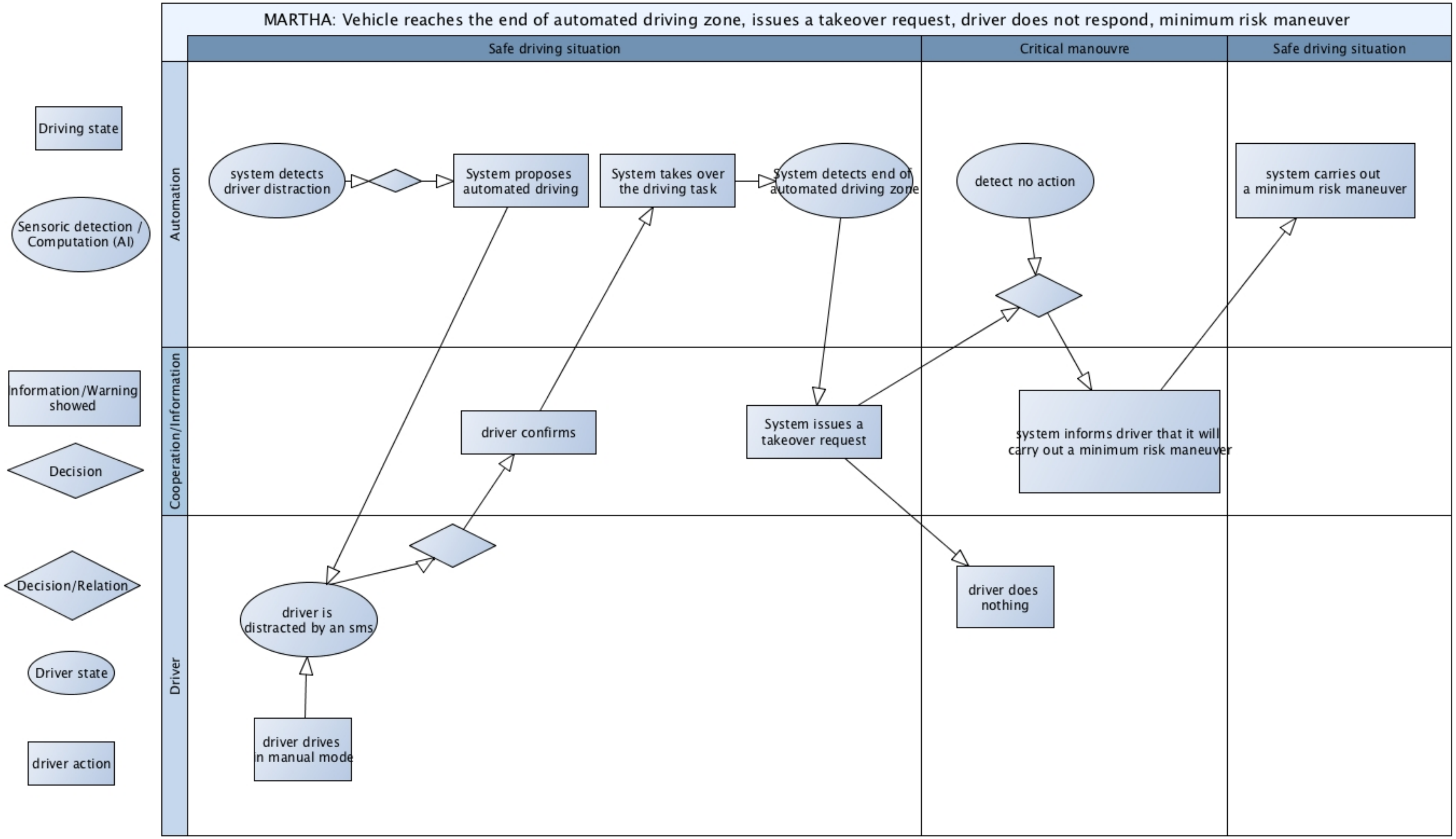


Figure 12. Martha - Use case 6

3.3 Scenario 3 (Eva) and use case description

In the Eva scenario, the TeamMate Car is driving through a complex roundabout with different traffic and driving status conditions (e.g. risky driving situation , such as hidden pedestrian crossing, and high/low driver workload).

By driving through a complex roundabout several times, the system learns from the driver how to deal with it and how to manage hand-over situation between human and automated system efficiently.

Six different use-cases have been identified.

Use Case 1

TM car is approaching a roundabout and the system is able to deal with the situation. Eva does not need to intervene.

In this scenario, the driving task is assigned to the automation part. No problem is detected by vehicle sensors while approaching the roundabout, thereby, system is able to deal with the situation and the manoeuvre is executed in automated mode. The system communicates the current state to Eva, indicating that no supervision is needed and that she can decide to take over (and perform the manoeuvre in manual mode) or to leave the control to the system (doing nothing). In this second case, the system executes the manoeuvre in automated mode, and Eva continues the path in "passenger mode" (Figure 13).

Use case 2

TM car is approaching a roundabout, but the system is not able to deal with the situation. It requires Eva's intervention.

In the second use case, TeamMate car is not able to perform the manoeuvre in automated mode. The system decides to cede control to the driver, advising her with a warning. Eva is attentive, so she can decide to do nothing (i.e. because she does not understand the message or she is not able to take over) or to take over. In the first case, a safety procedure is activated by the system to minimize the risk. In the second case, the manoeuvre is executed in manual mode. In this event Eva can correctly perform the manoeuvre (deciding later if she wishes to continue in manual mode or to switch back to automated mode) or fail the execution (the system activates the safety procedure). In either case, a communication between system and driver is needed to make them aware of mutual intentions (Figure 14).

Use Case 3

TeamMate car is approaching a roundabout and is able to deal with it. However, Eva is reading, thus inattentive, and the system asks for supervision due to complexity of scenario.

In this scenario the system is confident in the execution of the manoeuvre but, due to complexity of the scenario, it asks driver's supervision. TeamMate detects via its sensors that Eva is inattentive (she is reading) and warns her in order to get her back in the control loop. If Eva pays attention in response to the warning, the system will be able to perform the manoeuvre. If she remains inattentive, the system will warn her again (i.e. using a different strategy or another sensory channel) (Figure 15).

Use case 4

TeamMate car is approaching a roundabout, but there are roadblocks and it requires Eva to intervene. She starts changing lane, system drives to left lane and sees that it is not safe now, so it drives back into initial lane.

In this scenario TeamMate car detects roadblocks on the path while driving in automated mode. It decides to ask Eva's intervention, warning her to take over. Eva is attentive, so she decides to take over and perform the manoeuvre in manual mode. The system is informed about driver's intention. Nonetheless, detecting that left lane is not safe, TeamMate decides to intervene to avoid risks, driving back into initial lane in automatic mode. The system informs Eva about the decision and, after the manoeuvre, a collaborative decision for safe driving situation is taken (whether to continue in automated mode or in manual mode) (Figure 16).

Use case 5

TeamMate car is approaching a roundabout, but there are roadblocks and it requires Eva to intervene. However, she is distracted and the system needs a recovery action to get her back in the control loop.

Use case 5 is a complex scenario. The system detects road-blocks while approaching a roundabout in automated mode. It, thus, requires driver's intervention, warning Eva to take over. TeamMate detects that Eva is inattentive and decides to activate a recovery action to get her back in the control loop. The system warns Eva (i.e. via visual or/and acoustic warnings). If she is back in the control loop, she can take over and execute the manoeuvre in manual mode. If she remains inattentive, the manoeuvre is executed by the system with the activation of a safety procedure to minimize the risk (i.e. gradually adjusting speed and position or with the activation of flashing red lights to report the danger to other drivers) (Figure 17).

Use case 6

Driver is in "manual" mode and approaches a round-about. She receives an incoming call and answers. TeamMate car can deal with the situation and offers to take the control.

In use case 6, the driving state in the safe driving situation is manual mode. Eva receives an incoming call, which is detected by the system. TeamMate car communicates to Eva the opportunity to take over. Eva, whose attention level is low due to the call, has to decide whether to give the control to the system or to perform the manoeuvre manually. In the first case, she accepts to cede the control, and the manoeuvre is performed by the system. In the second case, she refuses and the performs the manoeuvre in manual mode in a dual-task situation (Figure 18).

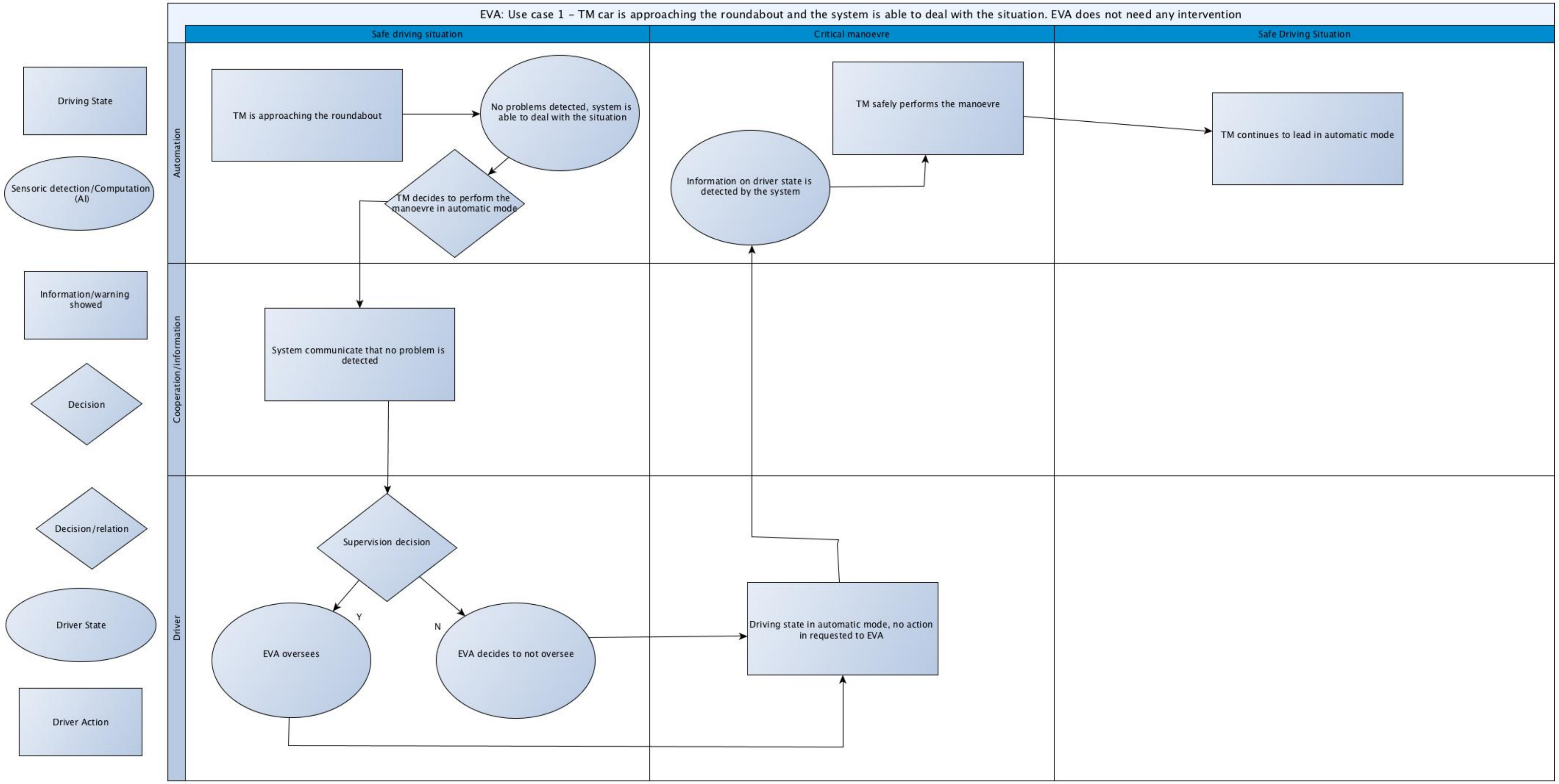


Figure 13. Eva - Use case 1

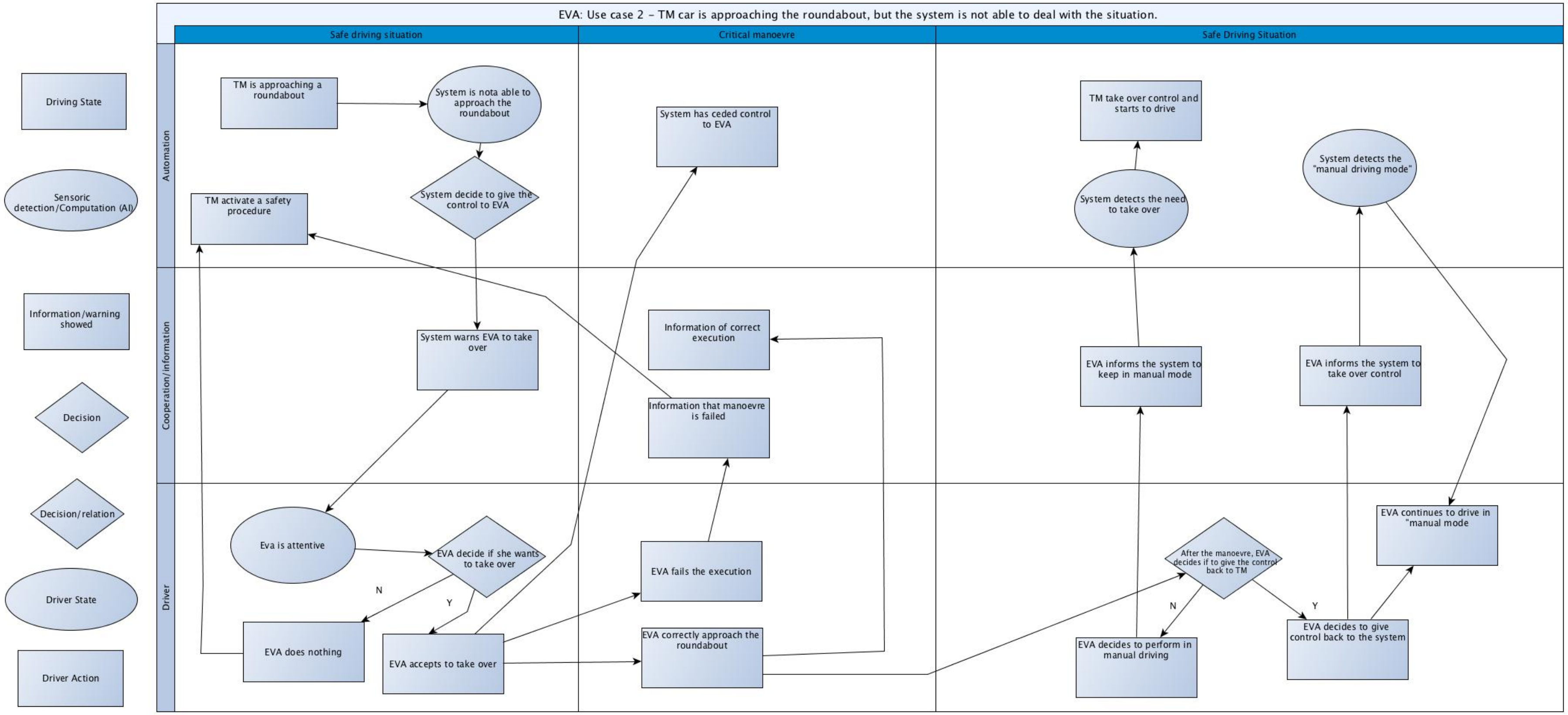


Figure 14. Eva - use case 2

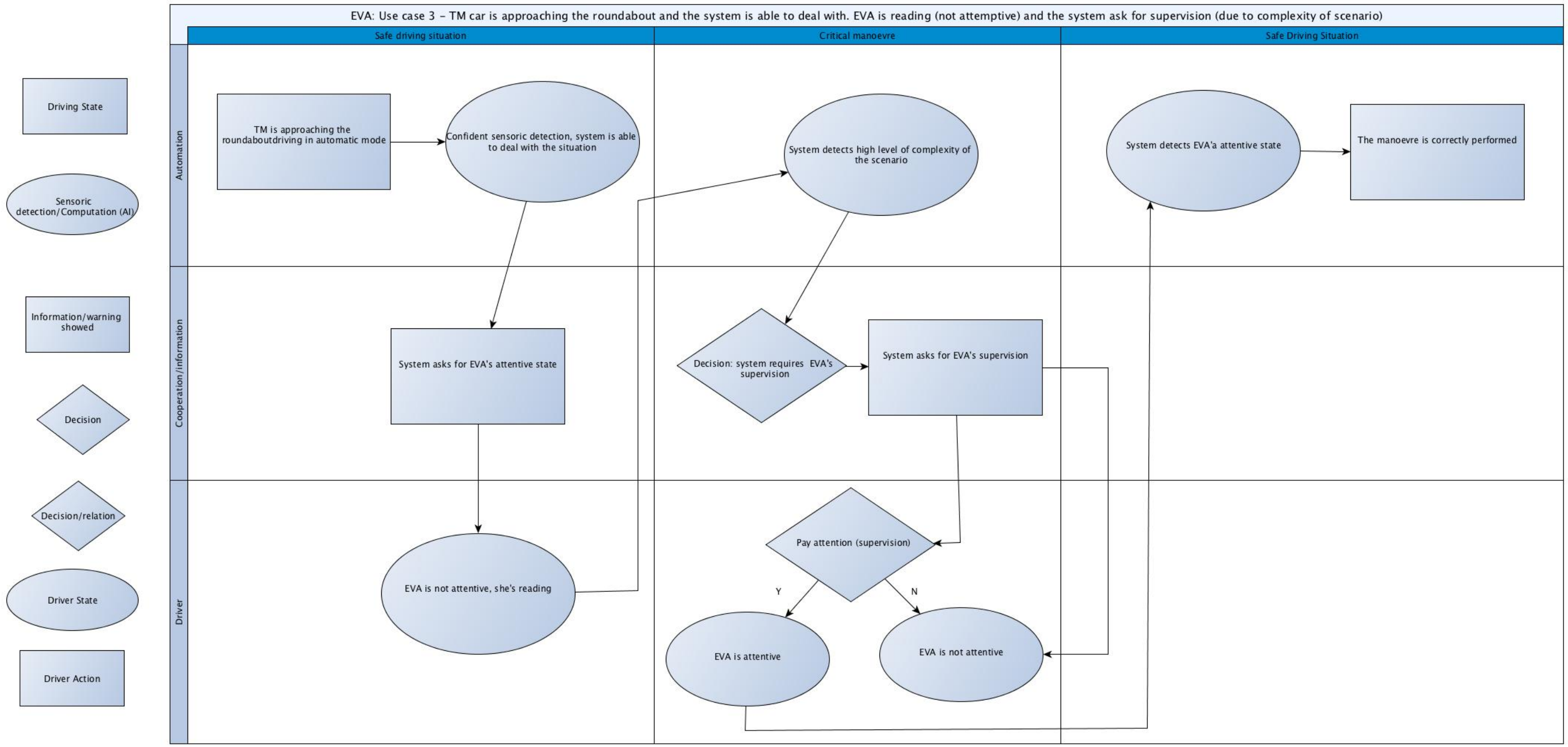


Figure 15. Eva - Use case 3

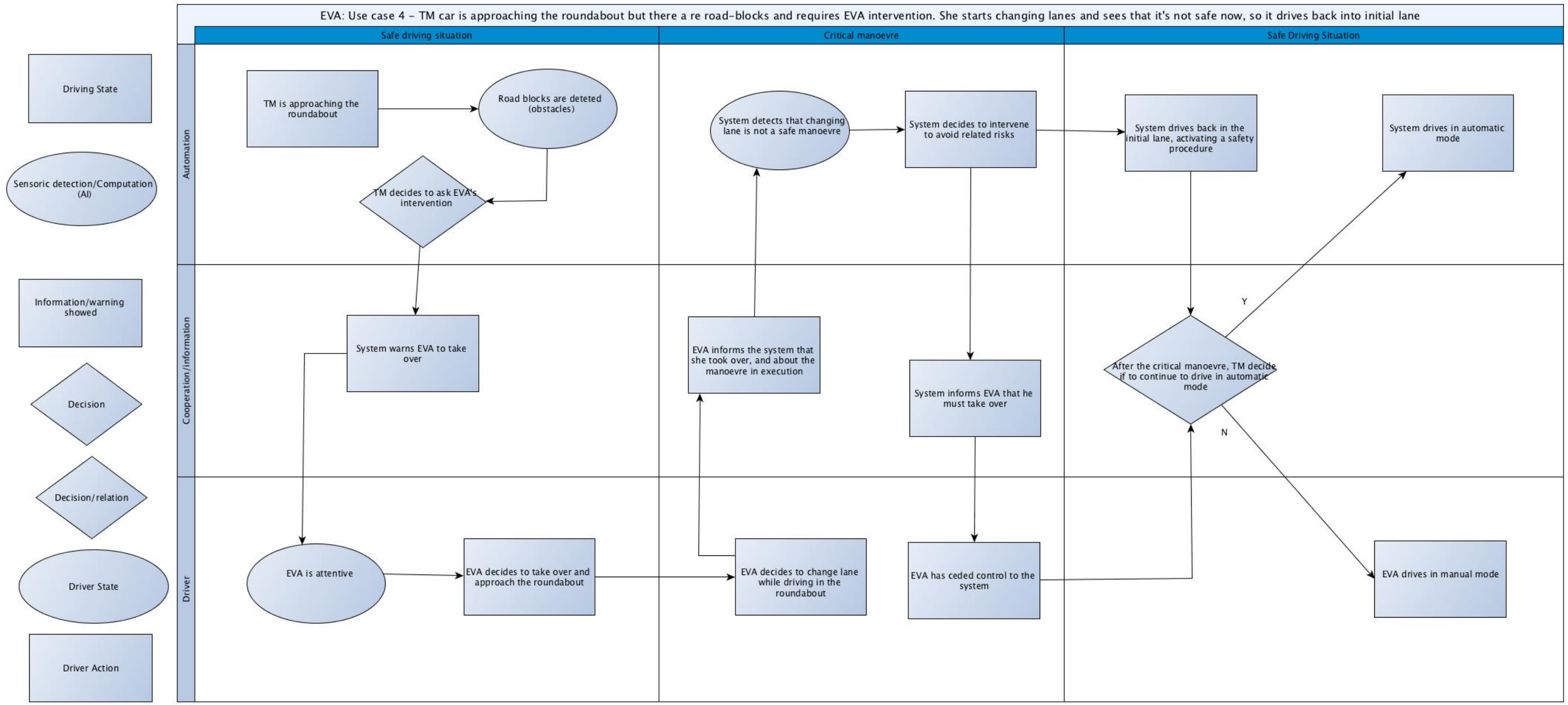


Figure 16. Eva - Use case 4

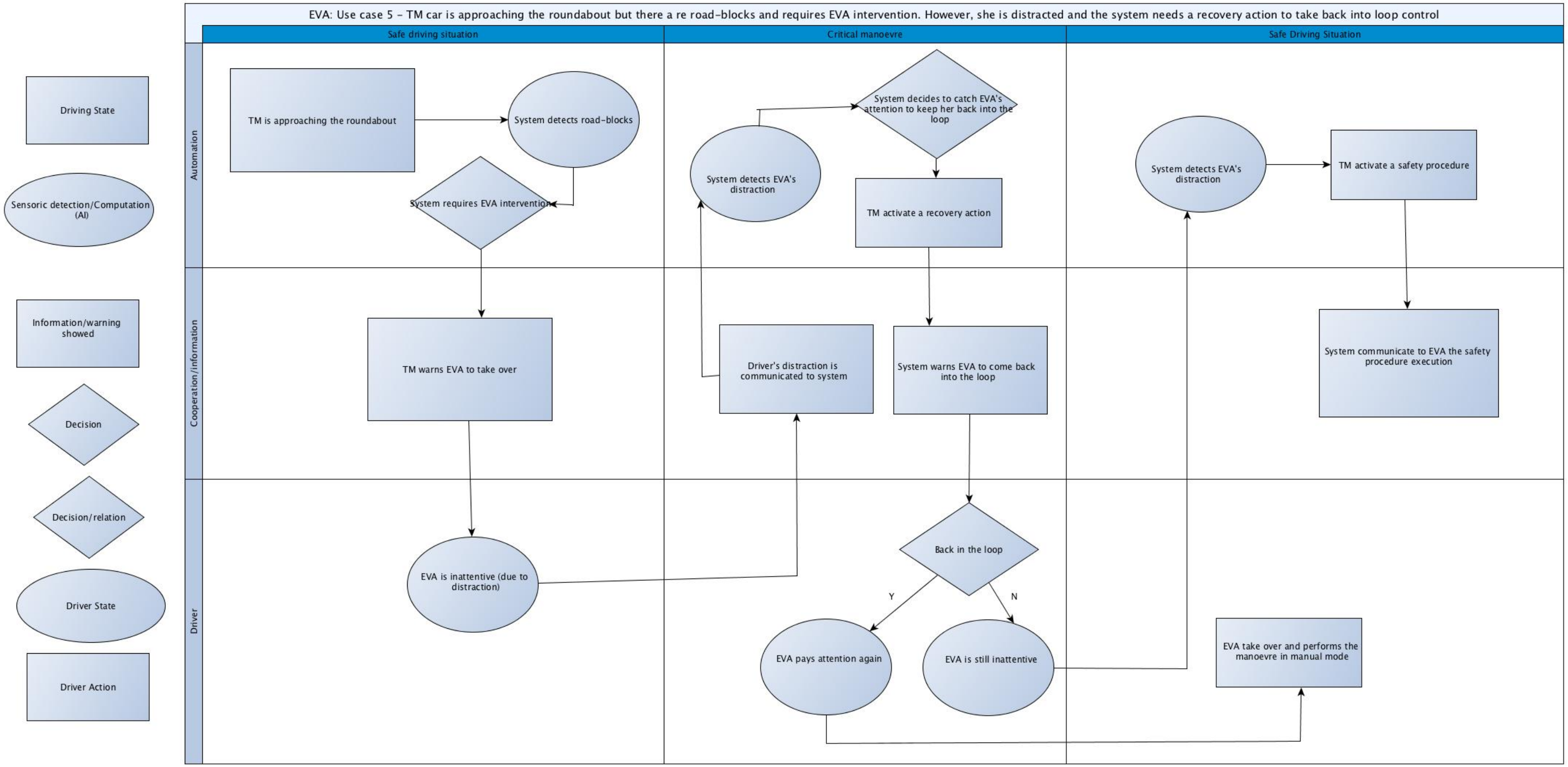


Figure 17. Eva - Use case 5

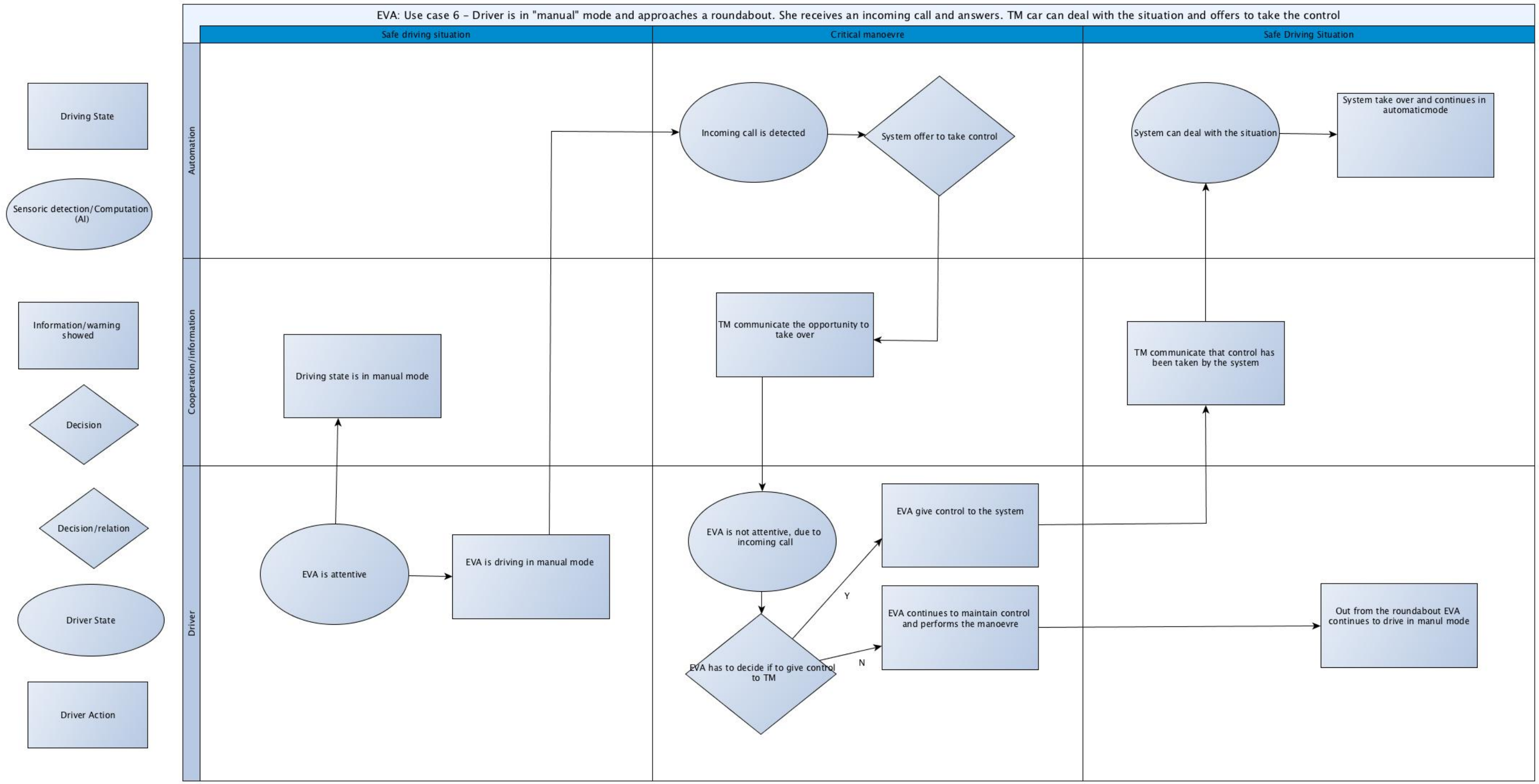


Figure 18. Eva - Use case 6

4 HMI design initial concepts

The HMI in the Automate project has been designed by involving the partners in several collaborative activities and hands-on workshops, described in details in the next sections.

4.1 Approach

The approach used for designing the HMI for the TeamMate concept, is an environment-oriented technique, Ecological Interface Design (EID). EID can be defined as "a framework for creating advanced user interfaces for complex socio-technical systems" (Upton, 2008). This approach consists of defining functional constraints of the system in a stated environment or work domain and using the consequent model as a structure for creating the visual interface. The design derived from EID "embeds the functional relationships between physical components into the display at different levels of functional abstraction" (Upton, 2008). The key concepts of EID are the Abstraction Hierarchy and the S-R-K model. The Abstraction Hierarchy is a tool to manage complexity that is used in the EID framework to determine what is the necessary information to be shown on the HMI and the how to show it. The S-R-K model is a well-known theory in human-machine interaction that suggests that cognitive control behind a user's behaviour when interacting with a system can be Skill-based, Rule-based or Knowledge-based (Rasmussen, 1983). This framework influences the interaction design, that must be adapted to the application of this model. From this second concept derive three general principles of Ecological Interface Design.

- For skill-based behaviour, which requires a minimum conscious effort, direct manipulation and isomorphic representation are required.
- For rule-based behaviour a consistent one-to-one mapping between constraints and the signs given by the HMI should be provided.

- For Knowledge based behaviour, which requires maximum conscious effort (often novel situations), "the work domain should be represented in the form of an abstraction to serve as an externalized system model".

The final goals of this approach is to avoid inducing a level of information processing higher than the task requires and to support the three levels of cognitive control (Vicente, 1992). The application of this methodology seems appropriate for TeamMate HMI concept, due to the complexity of the environmental scenarios and the multiple possibilities of on-board interaction, which make the overall interaction very articulated.

The AutoMate project is made of three cycles. In the first cycle, we will create the initial TeamMate concept. In the next two cycles, the project will validate and verify the results of the first cycle and will make the necessary modifications to achieve the expected outcome, which is described in the DOW). Uses cases are serving as an input for the creation process of HMI concept. Each scenario is broken down into smaller units (i.e. specific use cases) to model them in detail. Swim-lane diagram is used to represent every use case in a standardized way. The initial HMI concept will be created in the first project cycle for each scenario. Solid professionals, experts will participate in a design thinking session and will use the swim-lane diagrams as an input. The methodology of the Design thinking session is described in the next chapter. The expected outcome is three drafts for an HMI concept. Before the HMI concept can proceed to the implementation phase, it has to be described much more in detail. The idea is to analyse each use case step and define the HMI for them. Detailed level means that at least the following parts should be defined:

- HMI components
- Required hardware elements
- Visualization points (HUD, Central Stack, etc.)
- Communication between the Car and the Driver

The final HMI concept should contain a single design, rather than as many as the use cases, bearing in mind the ease of user's learning and car manufacturer's implementation. Therefore, the similarities between the drafted HMI blocks have to be identified and then standardized. We grouped these similarities and named them HMI modes. The chapter on General HMI modes represents the results of this design procedure. In the second project cycle, the initial HMI concept will evolve and adapt to the driver needs based on the results of testing phase in the first cycle. Regular drivers will be involved in the extension of the initial concept, their idea will be taken into consideration. The methodology of involving regular drivers will be described later on.

4.1.1 Design thinking methodology

During the AutoMate meeting in Turin, a design thinking session was planned in order to define different elements of WP4. By making use of this user-centered approach, it is possible to focalize the attention to real and effective necessities for the future AutoMate users'. The design thinking is a methodology that leverages shared design format, to develop products or services oriented toward end users, or to establish problem solving approach. It suggests the involvement of the main stakeholders (including possible target-users) in the design phase, in the form of a collaborative and structured design session (Vianna, 2011). Design thinking is nowadays a popular format in different areas of design, from IT services (Brooks, 2010) to business (Martin, 2009).

The design thinking process is typically divided into five steps:

- **Empathize:** an introductive phase used to establish an emotional contact between the designer and the final user (in this phase a common approach consists in the use of Scenarios and Personas)
- **Define the problem:** the main issues raised in the first phase are synthesized to define the problem (or the design solution) from a human-centred point of view.
- **Ideate:** e.g. in the form of brainstorming, useful to stimulate creativity and free thinking; in this phase is important to get as many ideas as possible, to then select the best one later;
- **Prototype:** with low-fidelity prototypes, wireframes or mockups, useful for further evaluations;
- **Test and validate**: in this phase, the product (or the intermediate prototypes obtained) is evaluated to identify usability and functional problems;

A further step has been added in some models, **Iterate**, a phase that suggests restarting the design from a stated point (e.g. the prototyping phase) to transform the design into a cyclical process. Design thinking, in fact, is a non-linear process: for example, results from testing phase may reveal some insights about users, which in turn may lead to another brainstorming session or the development of another prototype (www.interaction-design.org). The most important advantage of using this methodology consists in the possibility to evaluate the object in the early design stage, obtaining continuous feedback from the system.

The design thinking was divided in five sections (an introduction and five design sessions) mentioned below:

1. Intro – process and methodology;
   - Session 1 – Interviews;
   - Session 2 – Brainstorming;
   - Session 3 – Prototype;
   - Session 4 – Presentation and discussion.

The design thinking process can be easily described with the double diamond, as reported in the images above. Indeed, there are four phases (discover, define, develop and deliver), two divergent stages and two convergent stages: the divergent ones represent the moment in which the ideas are generated, and the convergent phases represent the decision stage, in which the best idea is selected. As already mentioned, the process is repeated twice, in order to firstly understand the problem and secondly to design the solution. (http://www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond).

With the aim to optimize the activity and reach the goals of each section, a timeline was defined for each phase.

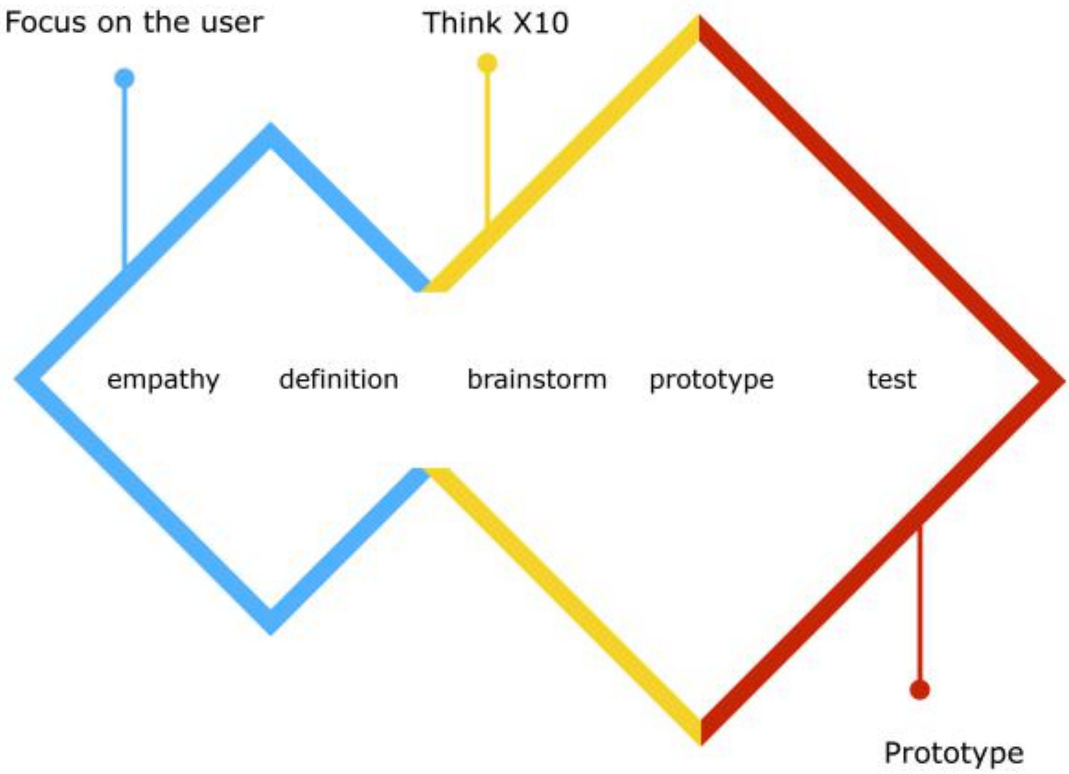


Figure 19. Design Thinking methodology

The AutoMate's consortium was divided in three groups, each one composed by five persons, in a way that every participant may express her/his ideas and opinions. The work teams were separated taking into consideration the background of each person, with the aim to realize multidisciplinary groups.

During the introduction, the moderator of the design thinking, Giulia Losi, explained the process and the methodology to the participants, explaining also the objectives and the expected results of the activity.

The first session was dedicated to the interviews; the different groups had to choose between the Eva and Peter use-case and then they investigated how the interaction and cooperation between the driver and the automation system develops in the different conditions of a selected use-case. The main objective was to discover users' needs by relying on users' stories, emotions

and insights. In this phase, each group prototyped an HMI concept, keeping in mind the AutoMate HMI objectives (research and develop a multi-modal HMI using haptic, visual, audio and speech-based communication channels).
In the second session, there were group and individual brainstorming and the principal objective was to generate ideas on human-automation interaction concepts. The groups had to draw their ideas emerged during the brainstorming. Each group had also to select the best idea arisen for the following session of prototyping.
The groups then prototype the best and successful HMI concept selected. In this phase, participants used different material for the realization of their prototype, as dashboard layout, sheets, colors and colored post-it.
Finally, each work team presented its prototype and explained their ideas to the overall consortium.

4.1.2 "HMI Kitchen": hardware elements

To create an HMI concept we have to define the elements that can be used to give or gather information to/from the human driver. In the first cycle we use existing and non-existing hardware elements to put ideas into the concept. We call these elements HMI kitchen, a place where the elements are combined to enhance the interaction.

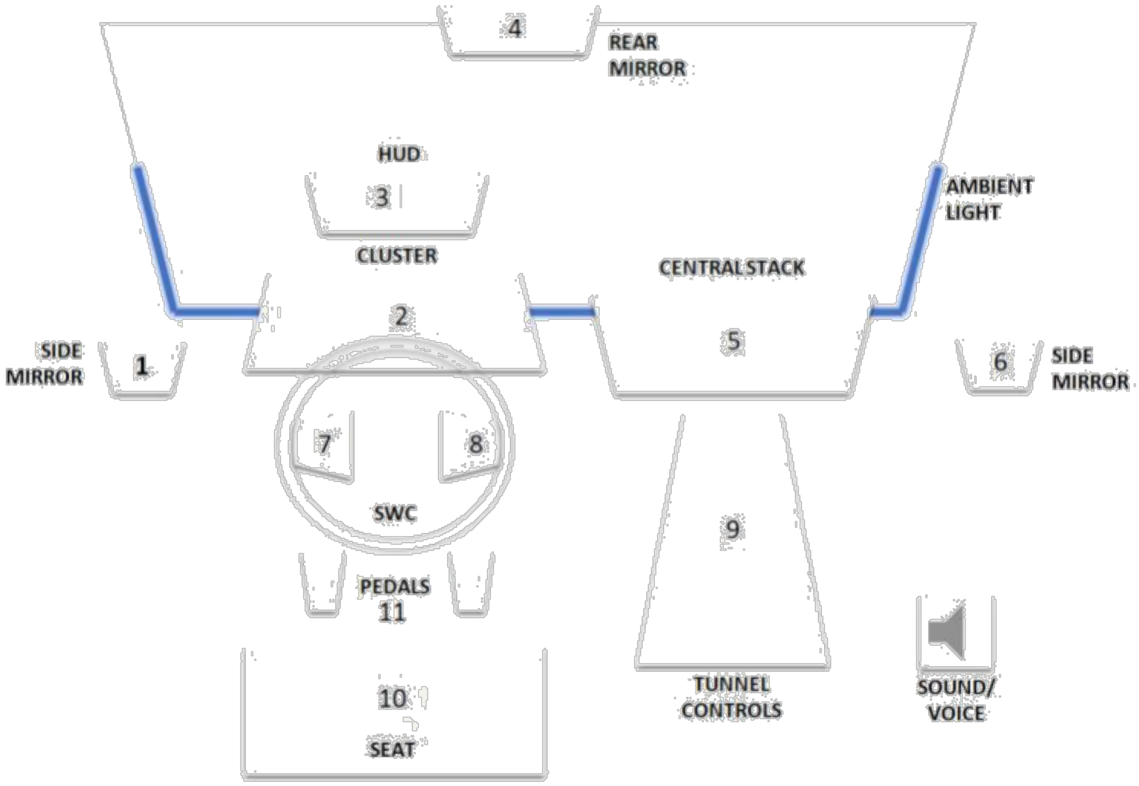


Figure 20. HMI Kitchen

As shown in Figure 20, the following elements have been considered:

1. Side mirror
2. Cluster (mainly led screen)
3. Head Up Display
4. Rear mirror
5. Central stack (mainly touch led screen)
6. Side mirror
7. Steering wheel buttons left
8. Steering wheel buttons right
9. Tunnel controls

10. Vibrating driver seat
11. Pedals with leg position sensor
12. Vibrating steering wheel
13. Sound (speaker)
14. Ambient light (it is placed around the dash)

4.2 Description of HMI workshop

On 15th of December 2016, the partners REL, OFF, HMT, CRF, CAF, ULM and BIT organized a one-day workshop on HMI of highly autonomous vehicle in the facilities of REL (in Reggio Emilia, Italy) in order to define a first set of HMI concepts that addresses the constraints and potentials of driving a partially-automated car.

Figure 21. Scene from a workshop session

The objectives of the morning session were to discuss the way the interaction between drivers and their cars has changed with the introduction of automated vehicles (i.e. State of the Art overview) and how it would change further in the near future. The objectives of the afternoon session were to define scenarios and use-cases, to identify the main touchpoints of interaction in two specific use-cases and to realize an exploration of high level HMI requirements that could be used to validate the HMI in Automate (the results of the workshop as well as high level requirements for the first cycle have been summarized in D4.1 and D1.1).

The HMI workshop was divided in three main phases.

In the first phase, AutoMate HMI framework was introduced, analysing the essential key concepts of the HMI relevant for the AutoMate project, i.e. cooperation and communication.
In the second phase, the focus switched to the overview of HMI for automated systems already on the market and at a prototype level.
In the third phase, a particular attention was given to the HMI required for the use cases to be addressed in AutoMate.

In the first phase, Martin Baumann (ULM) explained the concept of "Human-Machine cooperation", which means that "two agents are in a cooperative situation if they meet two minimal conditions:

- Each one strives towards goals and can interfere with the other on goals, resources, procedures, etc.

- Each one tries to manage the interference to facilitate the individual activities and/or the common task when it exists" (Hoc, 2001, S. 515).

With respect to the human driver, cooperation means to facilitate

1) Transparency: the understanding of what is the automated system doing
2) Comprehensibility: the understanding of why is it doing it, and
3) Predictability: the understanding of what is it doing next.

Martin also explained the modes of cooperation, namely, perception mode, mutual control mode, function delegation mode and fully automatic mode, as well as the levels of cooperation. According to this categorization, the AutoMate use cases have been defined as a continuous switch between different levels of automation, from manual to full automation. Four basic requirements for the human-machine cooperation were identified:

- Mutual predictability: the capacity to foresee the plans and actions of the partner;
- Directability: the ability to assess the activities of the partner and modify them when conditions and priorities change;
- Common situation representation: it is a common representation of the current situation and the state, the plans and actions of the partner;
- Calibrated trust: the appropriate level of trust based on the current capabilities of the cooperating partner.

With respect to the communication aspects of human-machine interaction, Maria Giulia Losi (REL) gave an overview of the TeamMate system communication. Communication plays a major role in maintaining a shared situation representation by explaining the manoeuvres, situation and task distribution to the driver, by asking for information and by asking for decisions.

On the one hand, the TeamMate Car needs to communicate to the human driver its situation representation, goals and plans in a way that does not overload the driver. All communication takes driver's situation awareness into account to prevent annoying the driver. Consequently it provides only information that is not yet known. On the other hand, there has communicate goals and plans TeamMate Car to be mechanisms that allow the driver to and relevant aspects of the situation to the Consequently, HMI designers need to be prepared to learn from these transformations as they happen, meaning that designers have to recognize that the design concepts represent hypotheses or beliefs about the relationship between technology and human cognition/collaboration.

A set of initial general performance expectations from an HMI have been identified:

- Enable multimodal user inputs
- Suggest and request support or decision from the driver
- Communicate suggested behaviour (i.e. manoeuvre) in a way that is:
    - personalized
    - adaptive to the driver status
    - multimodal (visual, acoustic, haptic)
- Explain traffic status (current and foreseen)
- Explain automation status (current and foreseen)
- Explain driver status (current and foreseen)
- Enable bidirectional communication between driver and automation

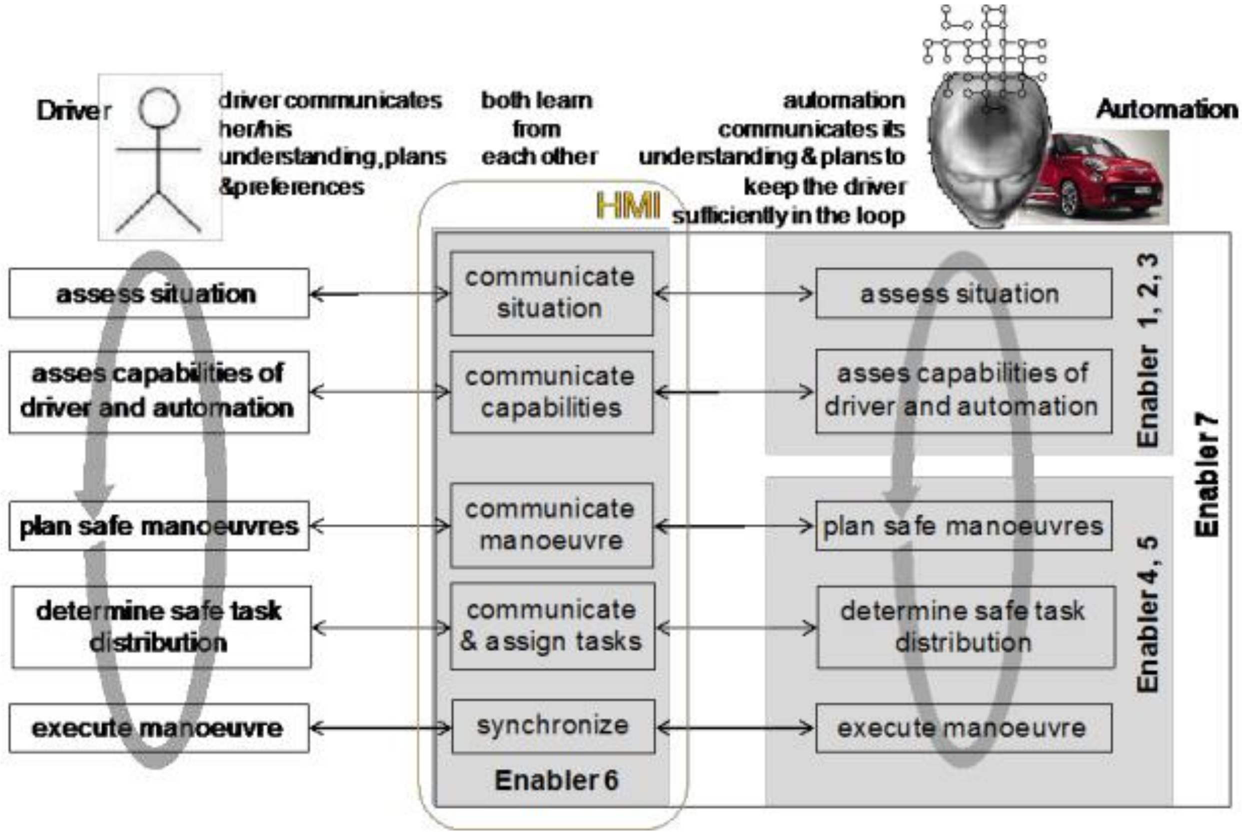


Figure 22. AutoMate HMI

The HMI, Enabler 6, (shown in) has been described as following in terms of human-machine communication:

"AutoMate will create a highly reliable automated driving system that users can understand, accept, trust and eventually will regularly use" a set of initial research questions have been identified:

- RQ1) Does HMI improve driver understanding?
  - Does HMI improve system predictability?
- RQ2) Does HMI improve calibration of driver trust in the system? (i.e. over-reliance vs. mistrust)
- RQ3) Does HMI improve driver acceptance in the system?

- RQ4) Does HMI improve performance of the whole system (driver and TeamMate)? (i.e. TeamMate can manage more situations without going back completely into manual mode)
- RQ5) Does HMI have an impact on the intention of regular usage of such systems?
- RQ6) Does HMI allow a cooperation between driver and human

In order to address RQ1 (i.e. Does the driver understand the situation?), an initial set of hypothesis have been identified concerning how to communicate the driving situation. The HMI communicates the situation means:

- HY1) The driver understands TeamMate status correctly and at the right time
- HY2) The driver understands if TeamMate is active or inactive
- HY3) The driver understands what TeamMate is doing (current behaviour)
- HY4) The driver understands why TeamMate is doing what is doing (current behaviour)
- HY5) The driver understands environment/traffic situation correctly and at the right time
- HY6) The HMI communicates to the driver mission status correctly and at the right time.

As a conclusion of the first phase, partners agreed that the research questions, hypotheses, performance indicators and metrics would be included and finalized in D4.1.

Regarding the second phase of the workshop, an overview of HMI for automated systems on the market was given by Anna Portelli (REL). The presentation reported a benchmark in the field, describing the state of the art, in particular of ACC (Adaptive Cruise Control), Steering Assistance (the system assists the driver in keeping the vehicle within the lane by steering independently) and Lane Keeping Assist (which detects lane markings on the road and can warn you before you leave your lane unintentionally).

Subsequently, the overview of HMI prototypes for automated vehicles from EU research projects has been presented by Jürgen (ULM) with reference to the results of CityMobil, AdaptIVe and Have-it projects, and stressing the attention on the relevant aspects for the AutoMate project.

The third phase of the workshop focused on the HMI of one use case and the main outcome was the agreement and understanding among the project partners on how to describe, by means of a flow diagram, the interaction between the human driver and the automated system. ULM then took the responsibility to formalize in a UML diagram a first example to be circulated.

Finally, the first HMI workshop of AutoMate produced the following outcomes:

1. Identification of main issues related to interaction with highly automated vehicles;
2. Development and definition of Scenarios, in order to realize the flow charts explained below;
3. Identification of common HMI requirements for metrics' definition

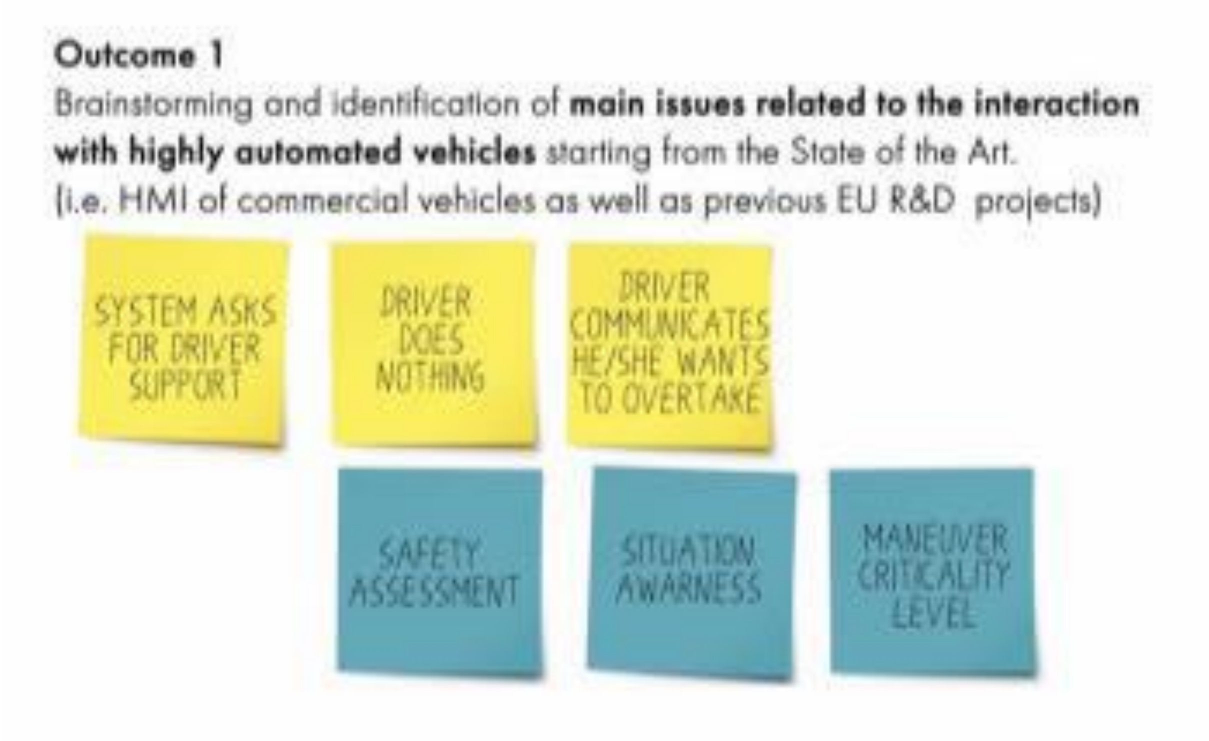


Figure 23. Main issues

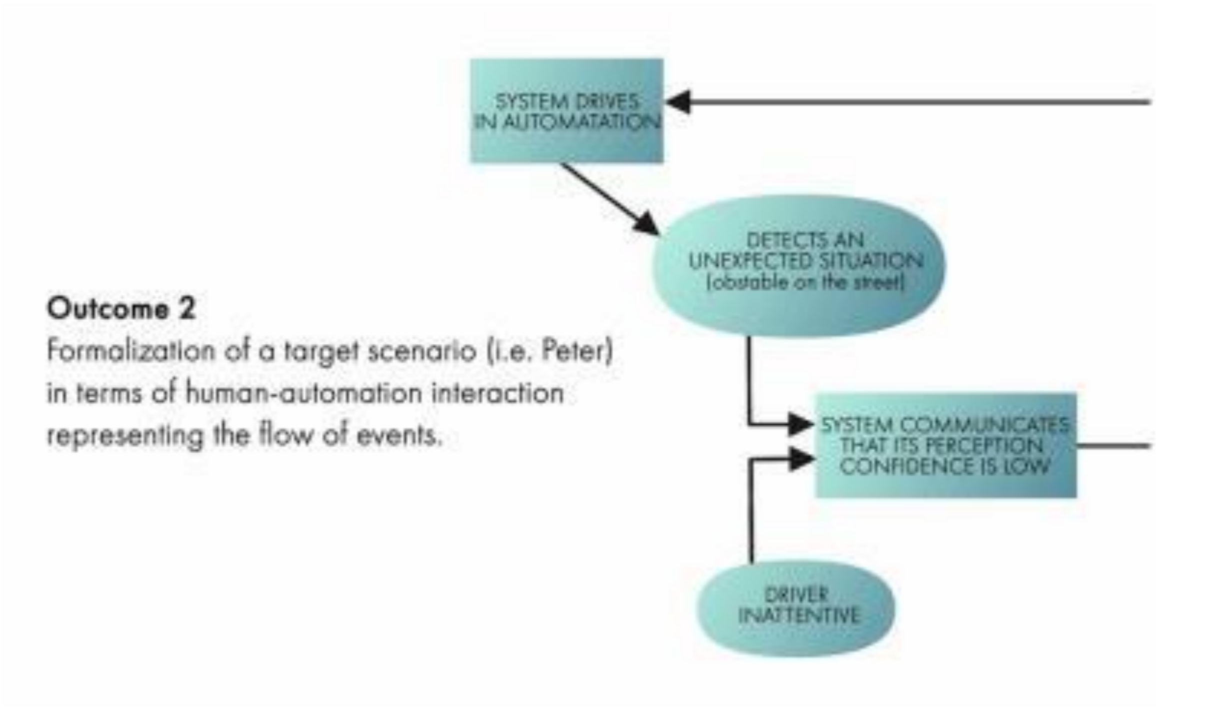


Figure 24. Example of flowchart

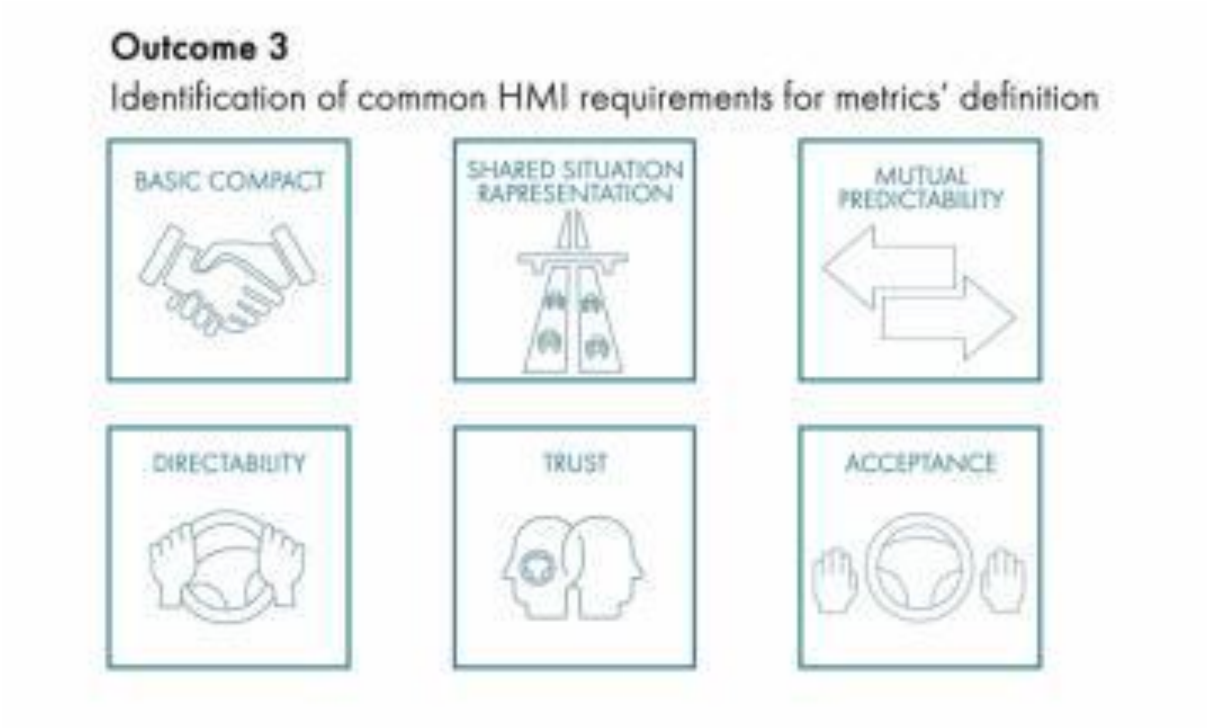


Figure 25. HMI requirements and common metrics

Another important outcome of the workshop was the definition of the initianl concept for the EVA scenario.

The scenario, concerning driver-automation interaction, was described according to the following main events:

1) Approaching the roundabout (RA)

In the approaching phase, the TM should inform the driver about the surrounding situation and upcoming manouver (e.g. visualization of the RA in the map), and the potential criticalities about it in advance.

The information provided by TM (I.e. the amount of information, the mode of communication and the timing) depends on (1) what the system understands of the criticality of the maneuver and (2) the driver detected status (I.e. either attentive or inattentive).

1. *Driver attentive + simple situation* = Visual mode - HUD information (I.e. navigation information, automation status)
2. *Driver inattentive + critical situation* = Visual and acoustic mode - (I.e. voice message, warning sound, directional lighting changing the car atmosphere in order to prepare the driver, color lighting indicating criticality of the maneuver).

The driver can also ask for more information. In this case, the information must be displayed in the line of sight of the driver, which includes the HUD and the instrument cluster.

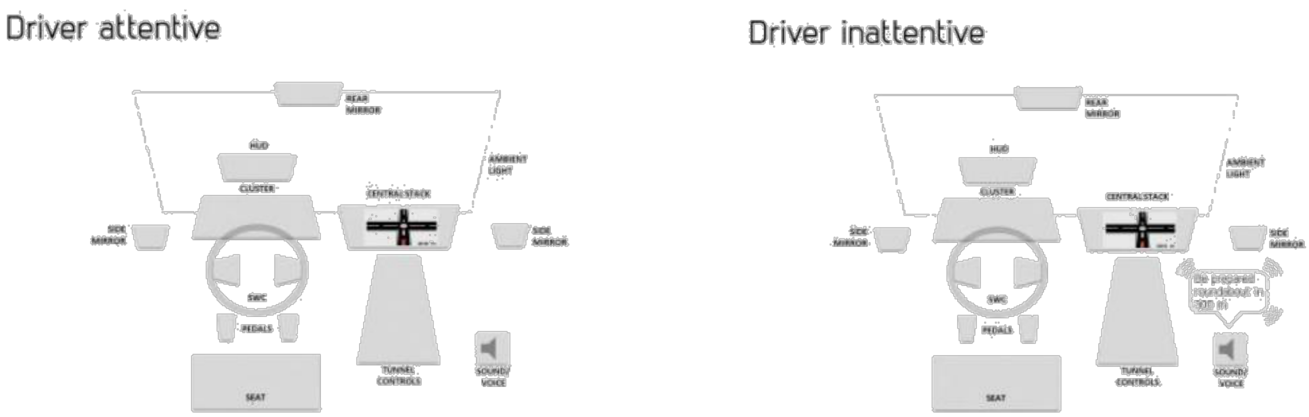


Figure 26. EVA initial HMI concept

2) Before entering into the RA

In the case in which an unexpected event is detected (I.e. UC2, UC3, UC5), the driver is asked to take back control of the vehicle (I.e. put hands back on the steering wheel).

For the communication of an unexpected event, the visual channel cannot perform the whole task, especially if the driver is inattentive, and it must be combined with acoustic information. Moreover, an escalation strategy could be applied to wake the driver up. A sensible spot for humans to be waken up, is the back of the neck, where a flow of air could be provided (I.e. shoulder tap).

The shared control of the vehicle can be applied by means of different levels of automation (e.g. either longitudinal or lateral control). In fact, the TM could:

- Ask the driver for confirmation and performs the maneuver automatically,
- Help the driver in performing a selected maneuver,
- Leave the manual control to the driver,
- Stop the vehicle, in case of emergencies.

If the driver has to take over lateral control of the vehicle, directional lighting could be provided on the steering wheel.

If the driver has to take over longitudinal control of the vehicle, a vibrating platform on the ground under the driver's feet could be provided.

The final concept of Eva scenario is depicted in Figure 27.

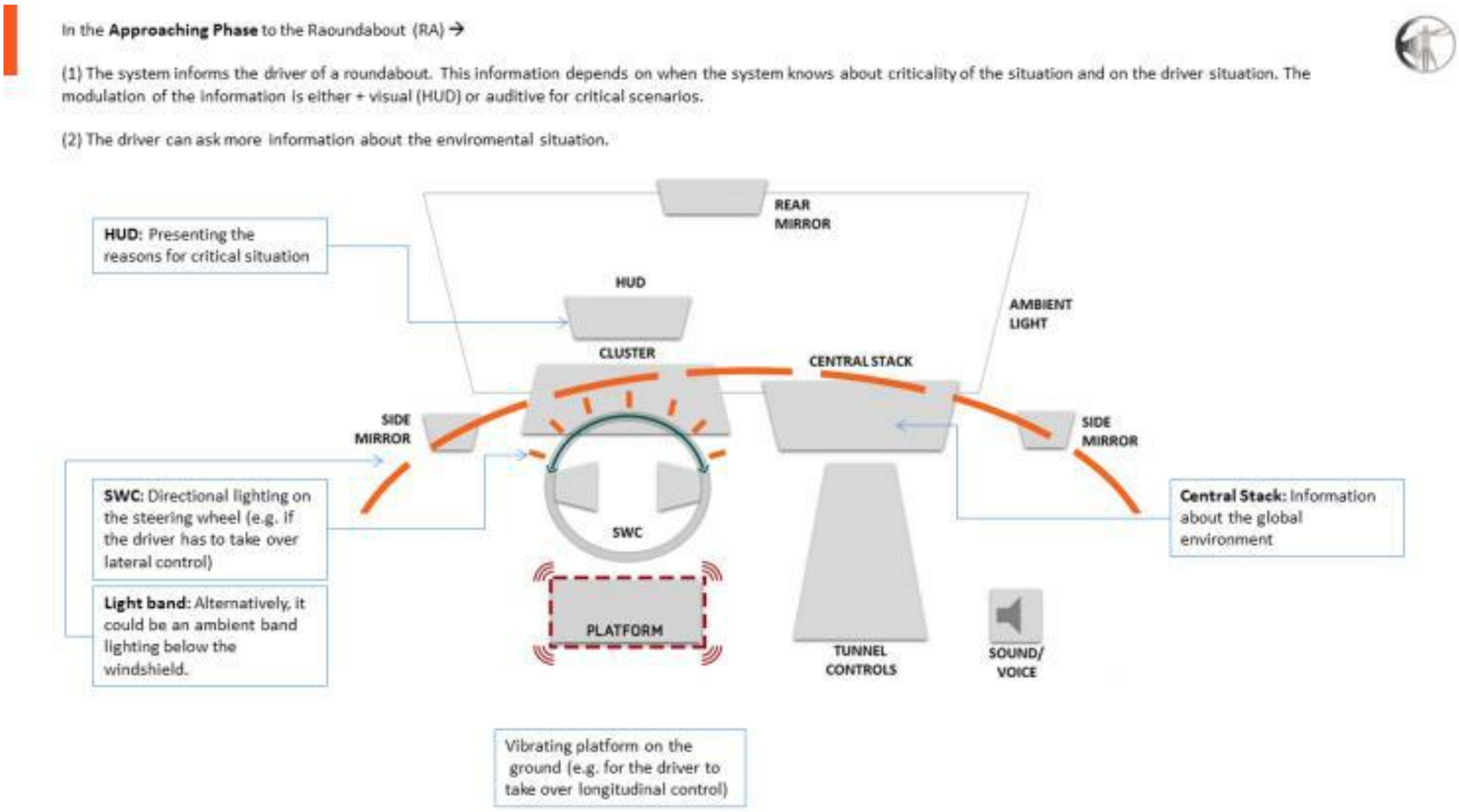


Figure 27. EVA final HMI concept

4.3 Internal workshops

Several internal workshops have been organized by each partner to design the initial HMI concept in a collaborative and iterative way.

4.3.1 Workshop in BIT

BIT did the first empirical interface approach in two session with the methodology described above (3.2 Design thinking methodology). During the workshop, we discussed "Peter" and "Eva"-Scenario as well. Each use-cases were discussed in detail.

Participants

There were six participants in one group. The participants were all employees of BroadBit. Four of the participants were it technical engineers and one of them was a project manager and the last person was a business analyst.

Procedure

The use cases were projected on a wall next to a table each after each in two cycles. In the first cycle the team members were thinking together about the information should be visible by the system to solve every step within a use case. At the second cycle the team were focused on the HMI "Kitchen" and tried define the place for the information which should be visible at a certain use case step.

Results and discussion

After the two cycles the team created so called HMI modes that have been reported to the other partners and that have been used to define the final modes described in chapter 6.

4.3.2 Workshop in ULM

In Ulm we did the first empirical interface approach in one session with the methodology described above (3.2 Design thinking methodology). In this workshop, the use-cases of the AutoMate "Peter"-Scenario were discussed. Two of the six use-cases were discussed in detail, whereas the other four were compared to the results from the first ones.

Participants

There were eight participants divided into two groups. The participants were all employees of the Ulm University. Seven of the participants were research associates and one of them was a professor.

Procedure

After dividing the participants in two groups by four people, the six use-cases were introduced. Each group chose one of the use-cases and started to interview one person of the group, how he or she would handle the given situation. These thoughts were written down on sticky notes and placed on a wall. Afterwards each group divided into two separate teams both of which had to rearrange the sticky notes and find a fitting title for groups of thoughts that could be realized by a similar HMI idea. Then finally the group of four people discussed about the titles and the design ideas for an HMI. The result was an HMI that could realize the "Peter" use-case in the best possible way. After finishing all of the activities, all participants discussed about the two HMIs that resulted from both use-cases. Finally, the remaining four use-cases were audited to the HMIs and it was found, that the two HMIs could realize all of the use-cases of the "Peter"-scenario . The whole workshop lasted about four hours.

Results and discussion for Peter scenario

During the design workshop conducted with the employees of the human factors department from Ulm University, several elements were pointed out to be useful during the Peter scenario. These elements and their functions are described below.

Ambient light. An ambient light should capture the attention of the driver while the car is driving in full automation. This ambient light could bring the driver slowly back in the loop of the driving task and could direct the gaze of the driver to a certain position. This position could possibly be the place where additional information are shown. The ambient light could be implemented with light strips which can be built in all around the driver. The different colors of the ambient light should display the different system states. A red color for example could mean that the system needs fast assistance of the driver.

Steering wheel interface. The steering wheel should be extended by an adaptive interface. This interface can suggest maneuvers and actions that can be taken in the current situation. The driver could communicate with the car by touching different parts of this adaptive display. It fits the user need of the simplest interaction.

Driver attention. The attention of the driver is assured by two instances. First there is an eye-tracking system. The driver must focus on the central part of the windshield. If the gaze of the driver is somewhere else, the system will assume that the driver is not attentive. The second instance is the touch sensitive steering wheel. If the driver has to be attentive, the hands should be on the steering wheel. This is needed because then the system could safely hand over the control to the driver.

Head up display. In order to show the driver important information about the system state and possible trajectories or actions, an head up display (HUD) will be used. This HUD should be able to show information across the whole windshield. Dangerous objects, like the big vehicle in the Peter scenario, can be highlighted and therefore be made more visible for the driver. This can increase the safety and helps to combine the situation representation of the driver and the system.

Center console display. An additional display in the center console will provide additional information to the driver. In several use-cases of the Peter scenario a "2d bird view" can be useful to help the driver understanding the current situation. These information are optional and can be switched off by the driver at any time.

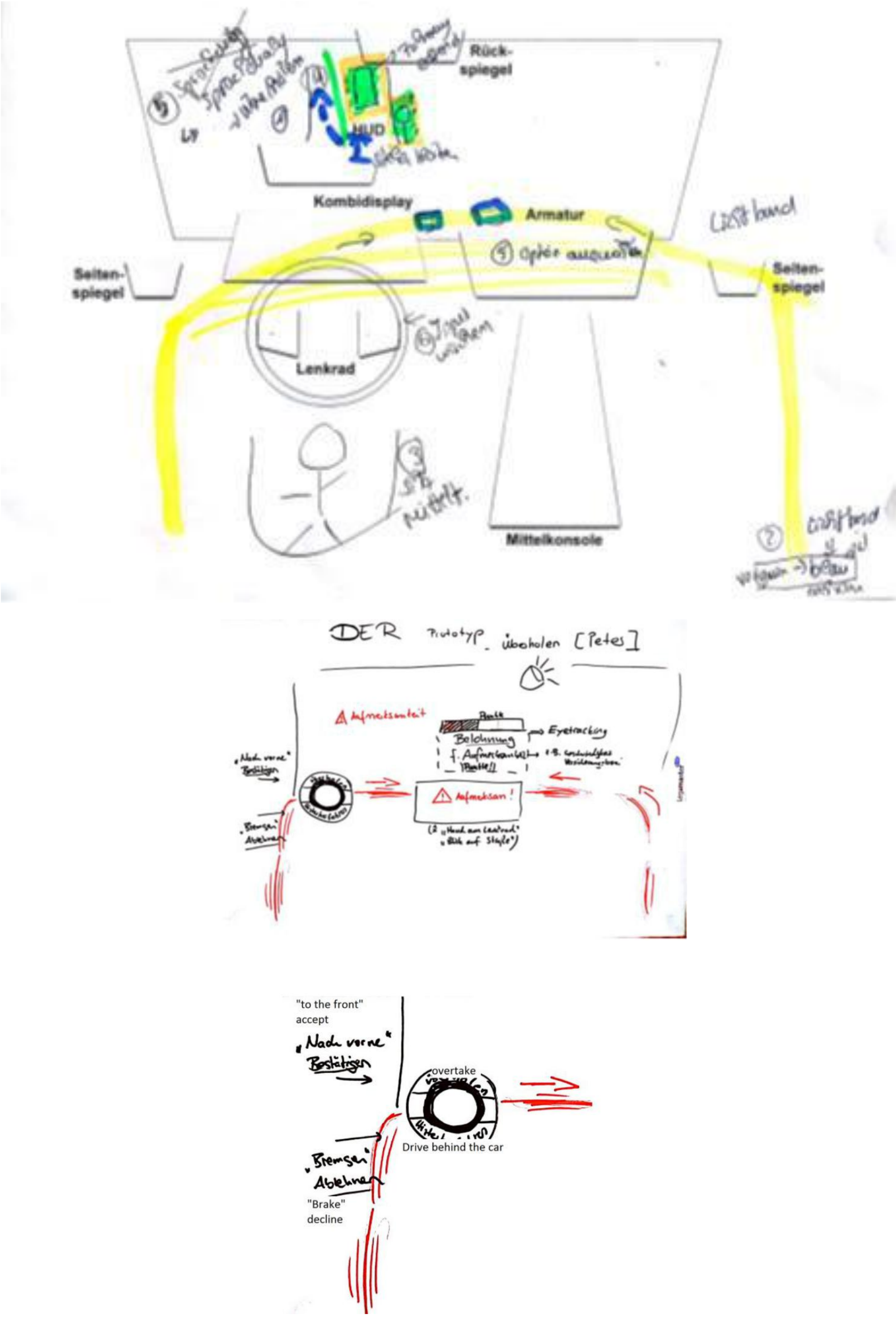


Figure 28. Peter initial HMI concept 1

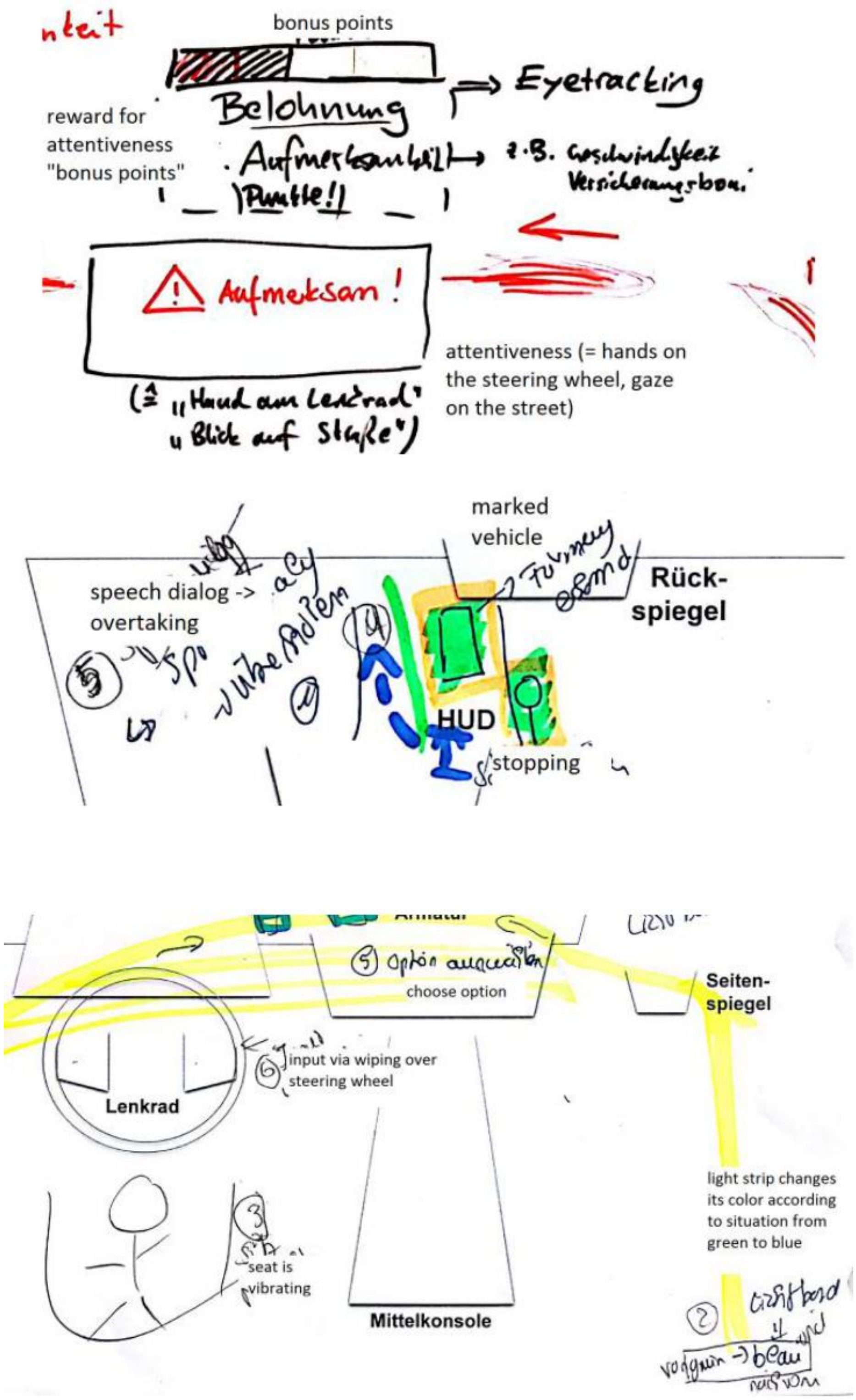


Figure 29. Peter initial HMI concept 2

During the design workshop conducted with the employees of HMT a first concept was developed. For the Peter scenario, the communication between the driver and the automation were analysed. The communication necessary for all use-cases including the information and input interaction which needs to be visualized are shown in Table 2.

Direction	Description	Type
Driver to Automation	Intention to overtake.	Input
	Don't use overtaking possibility.	Input
	Confirm attentiveness.	Input
	Select option for manoeuvre.	Input
Automation to Driver	Provide manoeuvre options.	Information, Input Request
	Switch to automation/manual mode.	Information
	Show progress on automated manoeuvre.	Information
	Detect overtaking possibility and ask the driver to confirm.	Information, Input Request
	Intended manoeuvre not possible (due to traffic rules | uncertain situation | risky).	Information
	Manoeuvre abort | fail.	Information
	Ask for attention or help for a manoeuvre.	Action Request

Table 2. Interaction needs

To indicate that the TeamMate car needs an input to deal with a certain situation or needs the drivers attention, there are several options like using light, acoustics and other modalities (e.g. vibrations). One goal should be to draw the attention of the driver to a certain screen or to draw attention in general if the driver is inattentive. The auditory feedback and his function is described below.

Auditory Feedback. Auditory feedback is divided in two instances. First the system can use acoustic signals to draw attention or to give feedback on changing his state. The level should depend on the priority of the task /

information. The second instance are gently voice messages about what happens. Voice messages may be used for a multi-modal interaction as well. Audio messages shouldn't be overused, because of distracting the driver, and should be seen as an optional modality.

In the Peter scenario the HMI has to ask for an input whether an overtaking manoeuvre shall be started. For the same task, this can look different (see figures below). In below figures this is displayed in the HUD with a textual and a visual representation. The green AutoMate icon indicates that the automation is running. The driver can choose between three options: (A) Drive behind, (B) Initiate overtaking, (C) Handover control to driver. The options in figure 1 are represented by simple icons to support learning. An option can be selected using the steering wheel controls (SWC) on the right hand side, easily reachable with the right thumb.

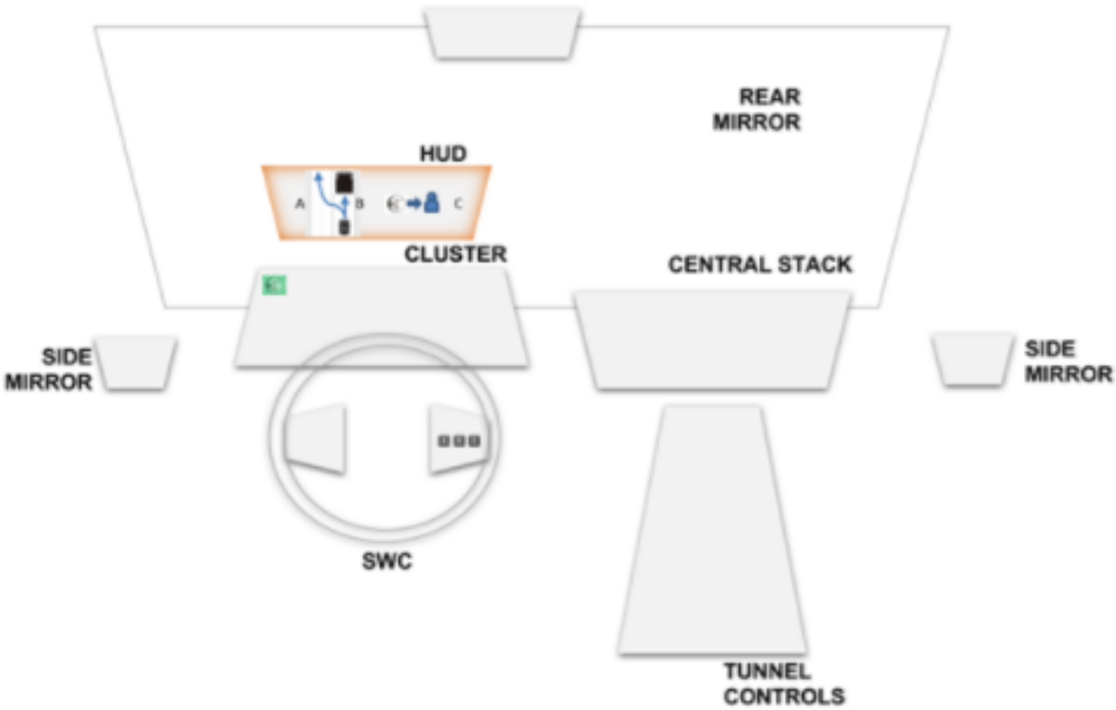


Figure 30. Peter initial HMI concept 3

Instead of simply displaying information on a HUD the next generation of HUD uses augmented reality to „paint" information on the road. Augmented reality is a technology term that implies merging computer-generated content with a real world view. For the car, that means projecting information on the windshield in such a way that it looks like it is part of the real environment. Another way could be to directly project something on the road using a laser projection. As this would be visible to all participating in the road traffic it would produce legal issues. Below, in Figure 31, there is an example for using augmented reality.

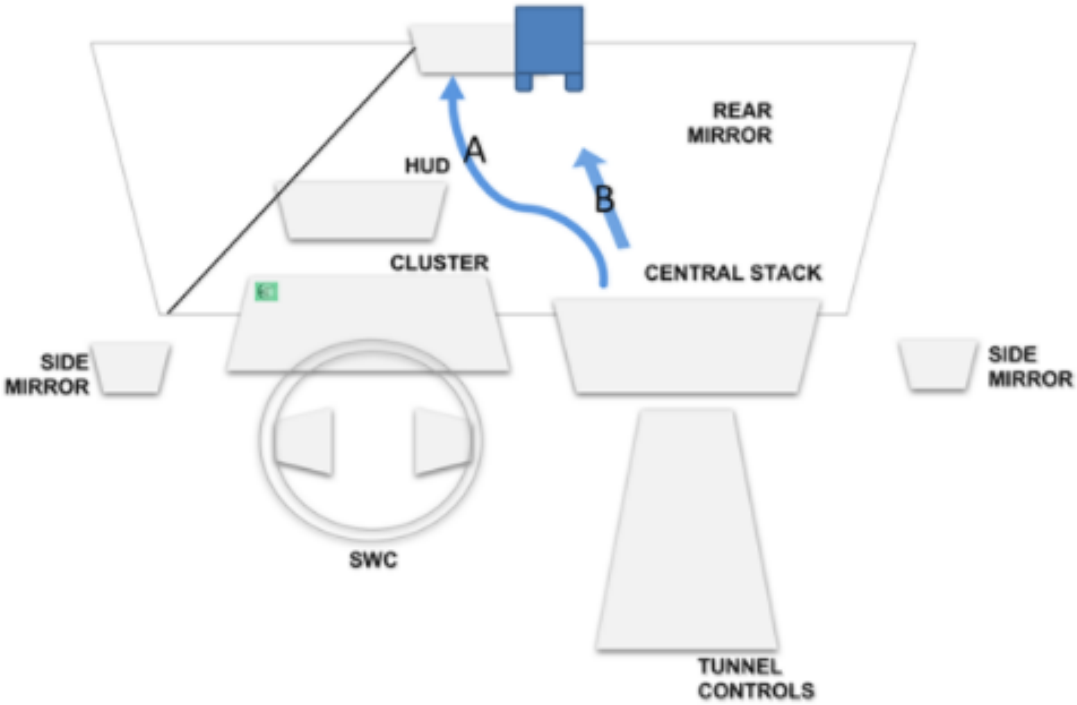


Figure 31. Peter initial HMI concept 4

4.3.3 Workshop in VED

In VED, we organized one session in order to realize conception of an HMI, following the Design thinking methodology (Section 3.2). First, all the use cases of the Martha scenario were presented. Then, the use cases covering different modes and modules of the TeamMate system were selected for further detailed work in order to make sure that the final design would respond to all situations.

Participants

Fours researchers at VED participated in the in-home workshop on the HMI design. The group consisted of two PhD students working on cognitive psychological and ergonomics issues related to automated vehicle, one researcher working on driver state, and a principal investigator.

Procedure

Ebru Dogan, who has attended the face-to-face meeting in Turin, explained the HMI design process and the method, detailing the objective, each step to be followed, and the expected outcome.

The first step was to have an interview with a randomly chosen potential user in the group. The aim of the interview was to understand the way a potential user imagines to interact with the AutoMate car and her expectations during manual and automated driving periods. In the meantime, the rest of the group tried to prototype how they would respond to the needs expressed by the potential user, that what kind of information to provide on the TeamMate HMI, its modality, and timing.

In the second step, a group discussion enabled participants to brainstorm on the ideas they generated on human-machine interaction corresponding to user's needs. They used the layout of HMI kitchen to apply their ideas. Then, they evaluated different proposals in order to select the most pertinent one.

In the prototyping step, participants of the group used some material (e.g. post-its, colored pens, HMI layout) in order to realize the HMI that they have selected in the previous step.

In the final step, the outcome was presented by one group member and discussed among the participants of the group.

Results and Discussion for Martha scenario

During the in-home HMI workshop, we identified two key phases for the HMI, namely, transition of control from driver to vehicle and transition of control from vehicle to driver, including a minimum risk maneuver (Figure 32).

Transition of control from driver to vehicle

Before the transition of control, the TeamMate would verify the conditions to propose automated driving system, such as operational design domain (e.g. GPS coordinates, vehicle speed) and driver state via driver monitoring system. Vehicle status is displayed on the dashboard at all times in order to avoid mode error.

If the driver is distracted, which is the case for Martha while she is using her mobile phone, TeamMate HMI warns the driver via a visual alert (e.g. "**!**") and colored LEDs around the windscreen turns to yellow or orange. TeamMate also displays a visual icon and auditory signal to propose automated driving to the driver.

If the driver does not respond and is still distracted after X seconds (to be defined during the pre-tests) of the initial warning, the HMI would gradually intensify the strength of the stimuli by turning the colored LEDs around the windscreen to red until the driver accepts or refuses via a button or a voice command.

Transition of control from vehicle to driver and Minimum risk manoeuvre

If the vehicle perceived end of automated driving due to reaching system boundary (e.g. end of automation zone is informed via GPS, roadwork zone is informed via V2I/ V2V), TeamMate verifies the driver state via driver monitoring system.

The timing of different HMI modalities are adjusted to the time-to-collision (TTC) before impact. As a basic principal, TeamMate HMI informs the driver about the reason underlying the takeover request with a visual illustration and a short text (e.g. "Roadwork ahead"). As the (TTC) is reduced, the visual icon is accompanied by auditory signal. Colored LED lights around the windscreen changes color as the TTC is reduced.

If the driver does not respond during X seconds after the TOR (to be defined depending on the on-board technology), the vehicle initiates a Minimum risk maneuver, informing the driver about this decision via the TeamMate HMI.

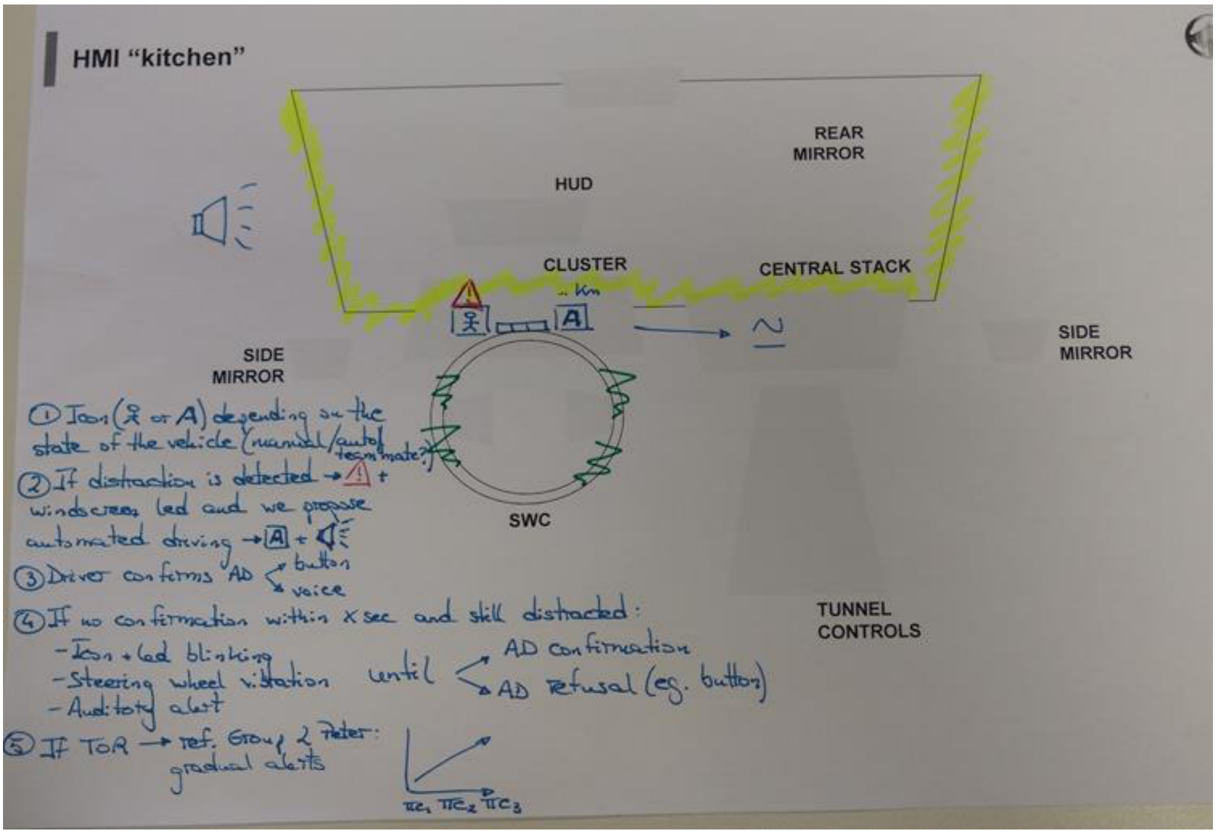


Figure 32. Martha initial HMI concept

The group discussion was centered on the current HMI that we have in the demonstrator vehicle and driving simulator. Additionally, we tried to benefit from our previous experiments to enrich the interface. A recurring idea was the use of LED light strip and the HMI transparency in order to reassure driver during the automated driving and transition of control. Another strong need expressed by the participants in our previous studies was desire to be informed about the reasons underlying the vehicle's decisions. Thus, we believe that such explanatory properties should as well be considered in the design of the TeamMate HMI.

5 General HMI features

The HMI concept is made up from multiple parts. Hardware elements are used to transmit the information which is coming from the features. HMI features help the user and the system to solve traffic situations. In the first cycle we identified the following items:

- General Instruments
  - o Speed o meter
  - o Revolutions per minute (RPM)
  - o Fuel
- Navigation info:
  - o Remaining time and distance from destination (ETA)
  - o Speed limit
  - o Lane and/or routing information
- Surrounding:
  - o Bird's-eye view (BEW)
  - o Blind spot detection
  - o Distance/time of reaching/reacting of other vehicles in front of the driver
- Suggestion from vehicle:
  - o Ghost View: animated action plan, e.g. slow down, take over, change lane, take other route etc.
  - o Remaining time to complete the maneuver
  - o Visual tracking/assistance of maneuver execution

- Safety mode:
  - o Remaining time before safety mode (sliding window)
  - o Changing to safety mode
  - o Intervention type: slowing down, changing lane, other steering maneuver performed etc.
  - o How to leave safety mode
- Warning:
  - o Pictogram
  - o Image
  - o Steering wheel vibration
  - o Seat vibration
  - o Sound

5.1 General instruments

The TeamMate car still can be used in manual driving mode where the human driver controls the car. General Instruments such as Speed, RPM, are implemented in the HMI concept. These standards instruments will be shown on LCD cluster as the other components.

Figure 33. Speedometer, RPM, fuel level

5.2 Navigation information

TeamMate car has several core systems. One of them is the navigation system where the human driver can specify the desired destination. Based on the current position of the car the navigation system can give useful information to the driver and to the vehicle also.

Remaining time and distance (ETA):

The system can show the remaining time to reach the destination and the current distance. It is possible to show the Estimated Time of Arrival.

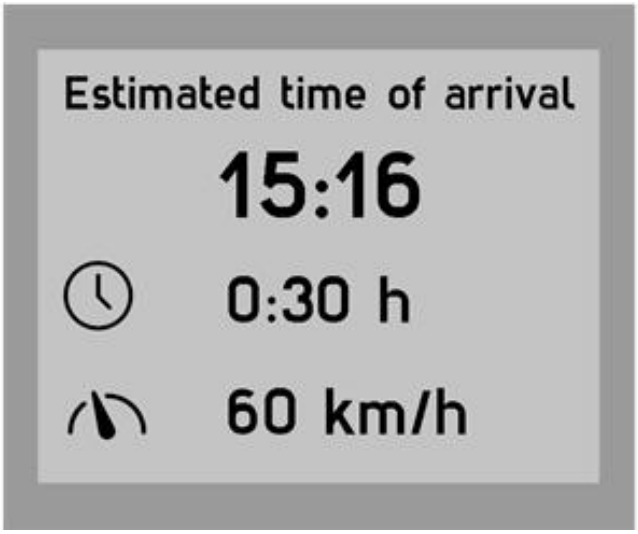


Figure 34. ETA

Speed limit:

The system is using map information and external sensors such as cameras to detect the specified speed limit on the current road section. The limit can be shown on the preferred HMI device to help the driver.

Figure 35. Speed limit

Lane and/or routing information:

When the driver is using the car in manual mode the navigation system helps to select the correct lane or route in the specific traffic situation.

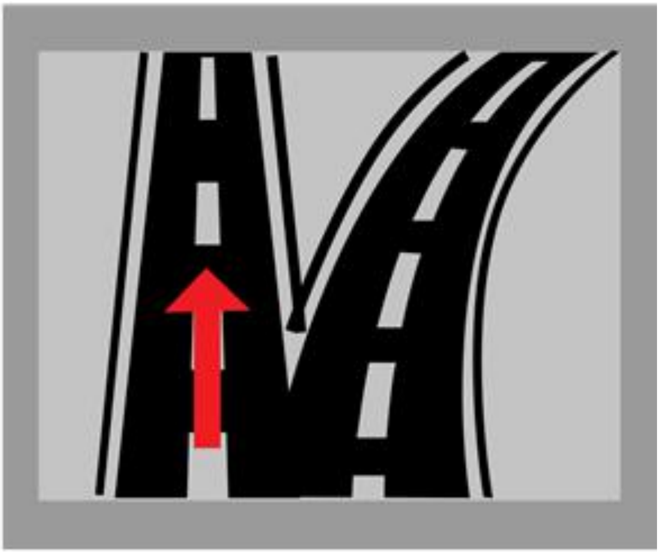


Figure 36. Route information

5.3 Surrounding information

The purpose of the AutoMate project is to develop a concept where the car and the human driver controls the can in a team. This is called TeamMate mode. In certain traffic situations the automated car requires the driver to provide input or to take over the control. For safety reasons when the system requires intervention from the driver then the system has to get the driver back in the loop first. Surrounding information helps the driver to get back into the loop quickly. By looking over the surrounding information provider instruments it is possible for the driver to see through the current traffic situation.

Bird's-eye view:

In this view the surrounding traffic is displayed from above based on GPS, V2V and V2x data. The display also shows the planned movement of the vehicles and the driver's own car with a highlighted pictogram.

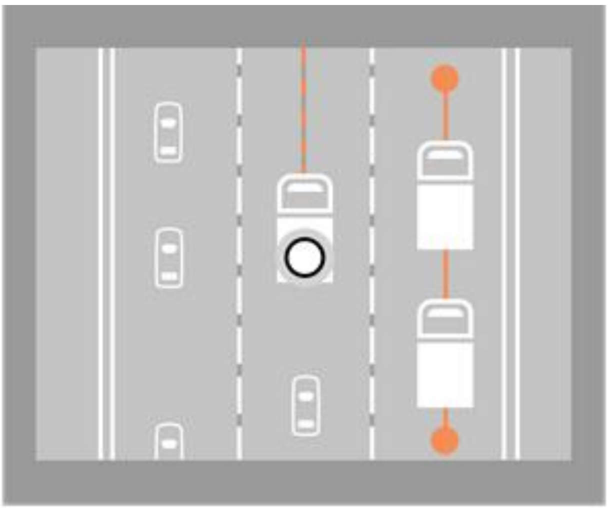


Figure 37. Bird's eye view

Blind spot detection:

Blind spots are areas outside of a vehicle that the driver is unable to see. Blind spot detection systems use sensors and cameras to detect the presence of objects like cars and people that are outside his range of vision.

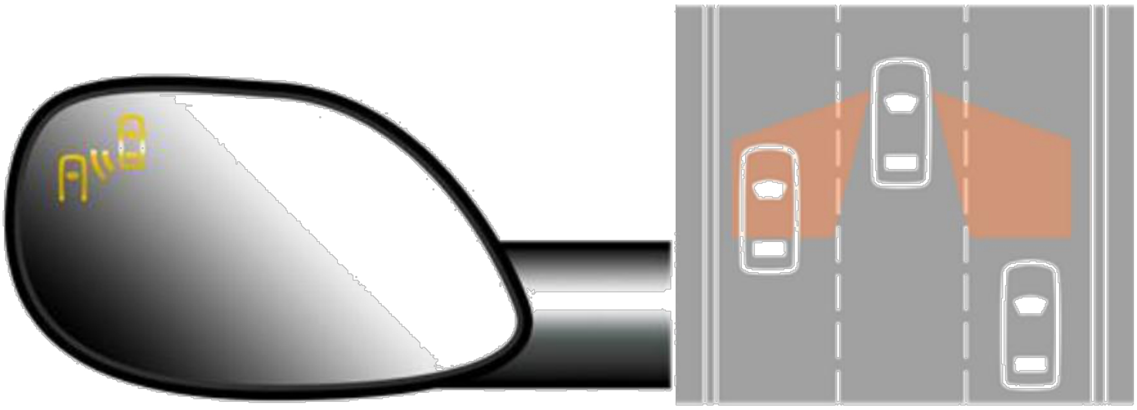


Figure 38. Blind spot detection

Distance/time of reaching/reacting of other vehicles in front of the driver:

While the system tries to cooperate with the drive to solve the upcoming traffic situation there is always a time frame (window) within which the driver has to make a selection before the safety procedure takes place. For better understanding multiple information is displayed.

A progress bar which indicates the remaining time (from full to empty direction) to react.

A counter which indicates the remaining time to react.

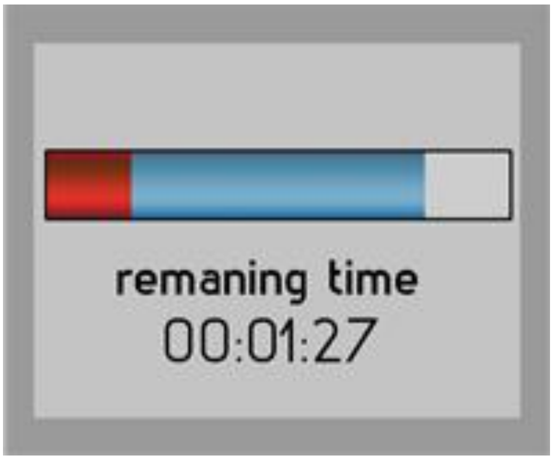


Figure 39. Remaining time to react

5.4 Suggestion from the vehicle

In TeamMate mode the human driver and the car are solving traffic situations together. This chapter describes how the car tells the driver about the upcoming steps or actions needs to be done by himself.

Ghost view:

This view is similar to the bird eye view but it is more interactive. It also illustrates the drivers car and other cars (the number is depending on how many cars involved in the current situation) The main purpose of this view is to show the next action to the driver. The system will inform the driver if a lane change, a take over, a slow down and so on, is required.

The driver's car will be in the center of the view and the necessary manoeuvre will be shown animated. The animation will show the driver simply and transparently the expected manouver.

Time left to complete manouver:

This indicator will be visible when the driver or the system begins the expected manoeuvre. The indicator will be separated into two parts.
A progress bar which indicates the remaining time (from full to empty direction) to react. A counter which indicates the remaining time to finish.

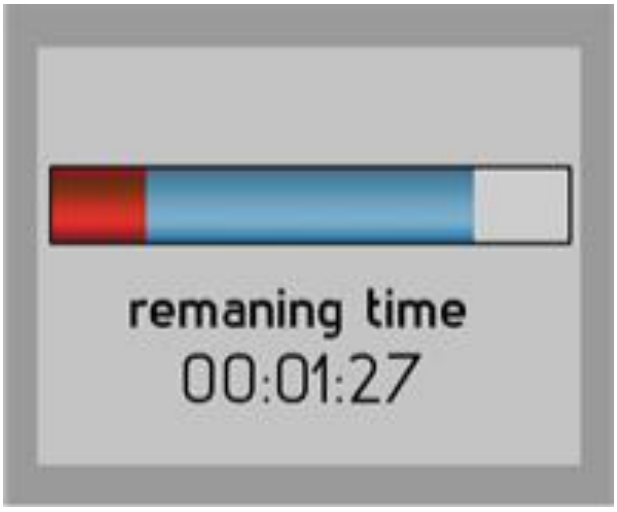


Figure 40. Remaining time to complete the manoeuvre

5.5 Safety

As mentioned in the Surrounding information chapter the purpose of the Automate project is that the driver and the car solves traffic situations together. In certain case the car is requiring information from the driver. If the driver did not responds in the given time frame and the system detects some hazard then it will turn into safety mode. The driver is informed before the mode change.

Time left before safety mode:

This indicator will be visible when the system locates hazard in the surrounding area and the driver stays inattentive. The indicator will be separated into two parts.

A progress bar which indicates the remaining time (from full to empty direction) to react. A counter which indicates the remaining time to finish.

6 Strategy for safe and robust transition for hand-over of vehicle control

6.1 Takeover strategy

In AutoMate we follow two strategies, namely, the TeamMate paradigm and bimodal automated mode. The TeamMate paradigm is a cooperative mode where the driver and the vehicle collaborate in certain situations, especially when the vehicle automation needs help to perform complex manoeuvres or handle a complex traffic situation. The driving task is split into individual tasks that can be performed either by the automation (e.g. adaptive cruise control –ACC-, lane keeping system –LKS- etc.) or the driver. The interaction to deactivate partial features of the automation could be designed inspired by the systems available in the market. In the case of the longitudinal control, the driver could take over control by pressing the brake pedal shortly, as in the state of the art ACC system. The lateral control could be deactivated by oversteering the automation with the steering wheel, as in the case of LKS.

Bimodal automated mode implies that either the automated system or the driver has the control at a given time. In this respect, the vehicle asks the driver to take over the entire driving task in a takeover situation. To deactivate the automation completely, the driver has to press an "automation button" on the steering wheel or react on the vehicle control command while being attentive to the forward roadway, which will be verified by the driver monitoring system.

In principle, driver should be able to take over control manually in any situation due to legal reasons. Moreover, Volvo (2016) conducted a survey about the possibility of taking control back while driving in automated mode. In this survey, 92 percent of the respondents stated that they "should be able to take control of autonomous cars at any moment". Hence, this issue seems to be important for the acceptability of automated vehicle as well.

It is crucial to make sure that the driver really wants to take over control and that the action is not accidental, for instance, by an unintended contact with vehicle control command. One way to tackle this problem is that the vehicle asks the driver if he/she really wants to take over control, partially or completely via HUD. HUD is chosen for two main reasons. First, to confirm that the driver is attentive to the forward roadway via the driver monitoring system. Second, to make sure that the driver has a back in the driving scene and has a certain level of situation awareness before takeover (Endsley, 1999). An intentional takeover could be confirmed by requiring the driver to press the automation button on the steering wheel or by means of simultaneous actions.

The vehicle should issue a takeover request to the driver as soon as it recognizes limited sensor capabilities or detects a situation where it does not know what to do next. However, in highly automated vehicles, a certain time budget should be envisioned in order to allow the driver to get back into the control loop and be aware of all information that are needed to perform the task safely. For instance, taken the lateral control as an example, the driver must be aware of the position on the road, the road markings and the street course that he has to drive. Studies suggest different periods of time to announce the handover (e.g. Gold et al., 2013). These studies conducted on the time to warn the driver before the actual takeover show, that the reaction time is faster if the time budget is shorter.

We base the design of the time budget in TeamMate paradigm and bimodal automation on the results of previous research. Tests in Cycle 2 should allow us to fine tune the duration of the time budget and to determine whether different time budgets could be considered for the two types of takeover situations.

In the first cycle of WP4, a general HMI concept was defined by all partners (see "5.General HMI features"). This HMI concept comprises the base to design the takeover and every interaction between the driver and the vehicle, as well as all the inputs and outputs that are planned to be used in the TeamMate car. Each scenario, then, adapts this general frame according to the specificities of the use cases and the technology of the demonstrator vehicle.

6.1.1 Peter Scenario

In one use-case of the PETER scenario the driver needs to take over control partially. In the use-case the sensors of the system are not confident enough to overtake a big vehicle. Therefore, when the driver wants to overtake he possibly has to take over the lateral control of the vehicle. The driver should be warned via the central stack of the car and has to confirm that he will stay attentive. An optical system should assure that the driver is attentive and the confidence of the sensory data should be displayed in the HUD. If the sensor confidence drops beyond a predefined threshold, the lateral control should be given to the driver after a short warning after a time budget, which will be defined during the Cycle 2 tests of WP4.

In another use-case the automation does not allow the driver to overtake because the road is not safe enough. This is a special case because there is no real takeover request as defined before. The car is driving in automated mode behind a car until the driver decides to overtake manually. Different than the first one, this is a complete takeover. In other words, driver will be responsible for all driving tasks. To take over manual control, the driver has to turn off the automation. This will be realized by multimodal TeamMate HMI.

6.1.2 Martha Scenario

The use cases of Martha scenario require transition of control in foreseeable situations, such as roadwork zone and end of automated driving zone. The vehicle can have an accurate estimation of the takeover moment in advance by means of GPS and connectivity information. Once driver's level of attention and environmental state is verified, vehicle can communicate TOR to the driver in a timing that will be defined in Cycle 2. The multimodal TeamMate HMI can transmit TOR via visual and auditory channels.

6.1.3 Eva Scenario

In one use case of the EVA scenario, the system is not able to deal with a complex roundabout in automated mode. Before ceding control, the system has to detect the driver's level of attention. In this use case, the driver is in the loop and can decide to take over. The transition of control between the system and the driver is completed and the new "automation level" is shown to the driver. The system must give an appropriate amount of time to the driver to resume control despite the complexity of the dynamic situation. As in the Peter scenario, budget time will be defined during the experiments in Cycle 2. The takeover request, which is the core of the transition of control and a crucial information for highly automated vehicles, will be graphically displayed in all the three visual support on-board the vehicle. A written take over request will be also displayed. Other modalities to reinforce the quality of information will be considered in the Cycle 2.

In the use case 6 of EVA scenario, the takeover is performed in the opposite direction. The driver is driving in manual mode and receives a phone call, thereby, decides to give control to the system. In this use case the detection of the call and the handover request from the driver to the system lead to a biunivocal flow of information between the driver and the system. In particular, the message from the system to the driver should be displayed in an effective way to make the driver aware that the situation is safe for a transition. At the same time, the detection of the driver and of the environment state are essential in order to establish the right moment to present the information. Moreover, the transition from manual to automated mode needs the creation of a protocol (e.g. the combined activation of more than one button) to avoid unattended activation. The precise definition of the protocol will be discussed in the next cycle.

6.2 Fallback strategy

Fallback strategies are fail safe backup plans for critical situations. These are necessary for the situation, in which a possible (partial) system failure cannot be compensated by the driver actions. In these situations a driver has to find a way to clear the situation or make it the least harmful, whether it is because of the driver's inattention or an incapability of handling the situation. If the automated system is not capable of performing a safe fallback strategy at any time, the control of the failing part of the system has to be handed over to the human driver, even if the system would be able to drive in the current state autonomously. It will be crucial for car manufacturers to think about the fallback strategies in the future, because an accident could be fatal for an inattentive driver.

6.2.1 Application of the strategy in the scenarios

The scenario owners reviewed their scenario for a possible critical situation. A critical situation was defined as a situation, where the handover from the autonomous system to the human driver could possibly fail. The figures below show the flow-diagrams of the fallback strategies for each scenario. The fallback design process is described in a table, only for the first use case of the first scenario.

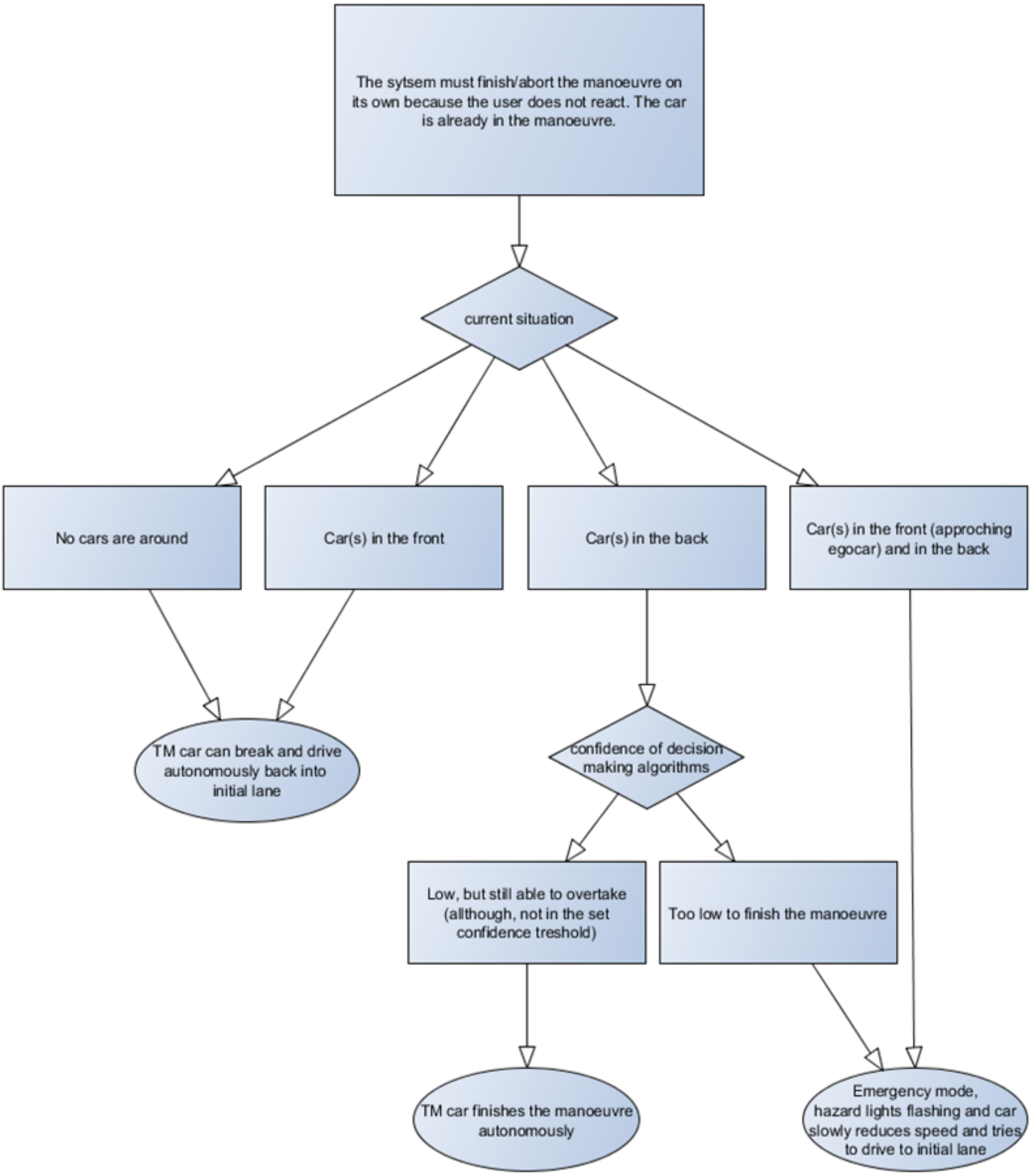


Figure 41. Fallback strategy – Peter use case 1

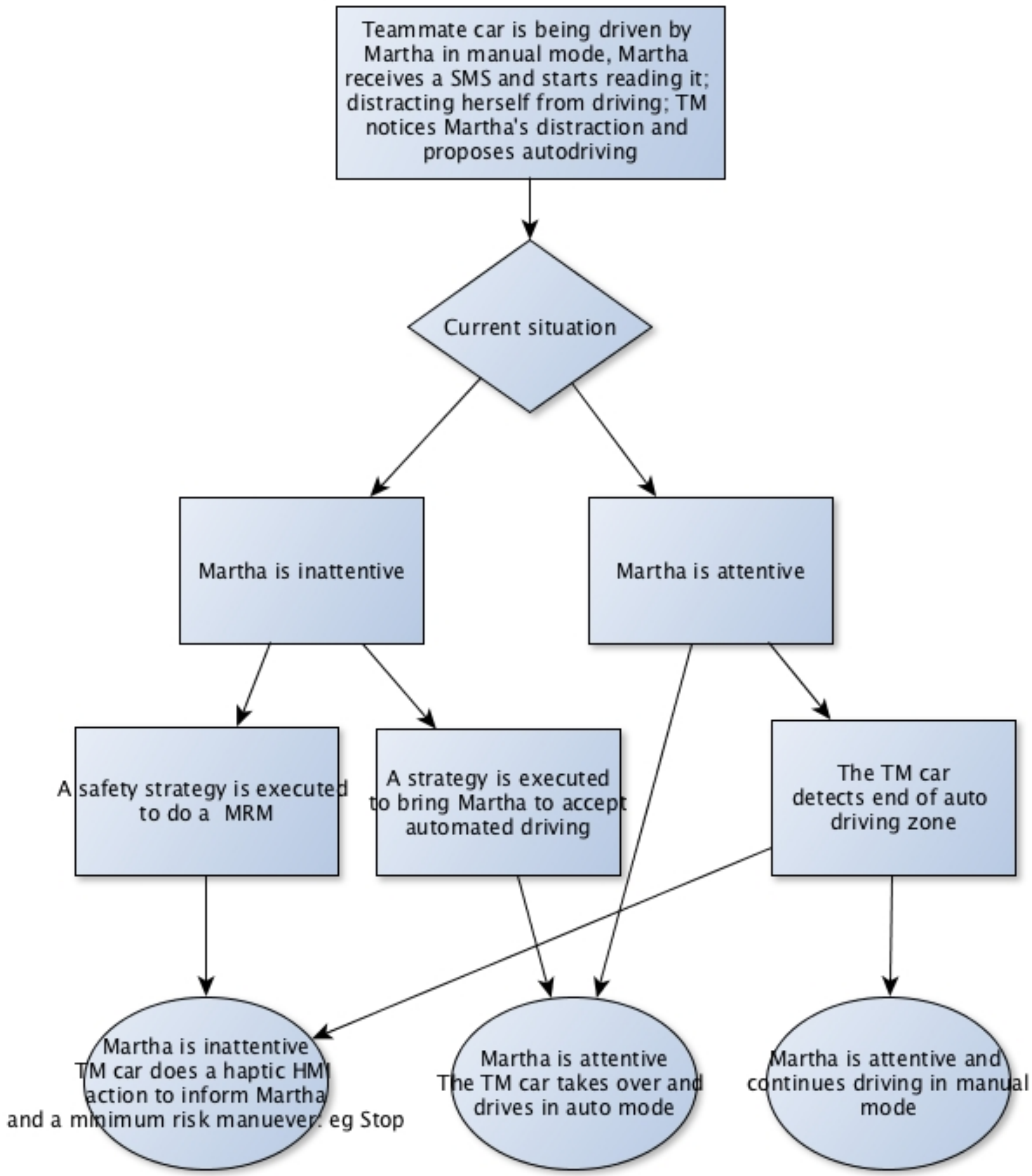


Figure 42. Fallback strategy - Martha use case 2

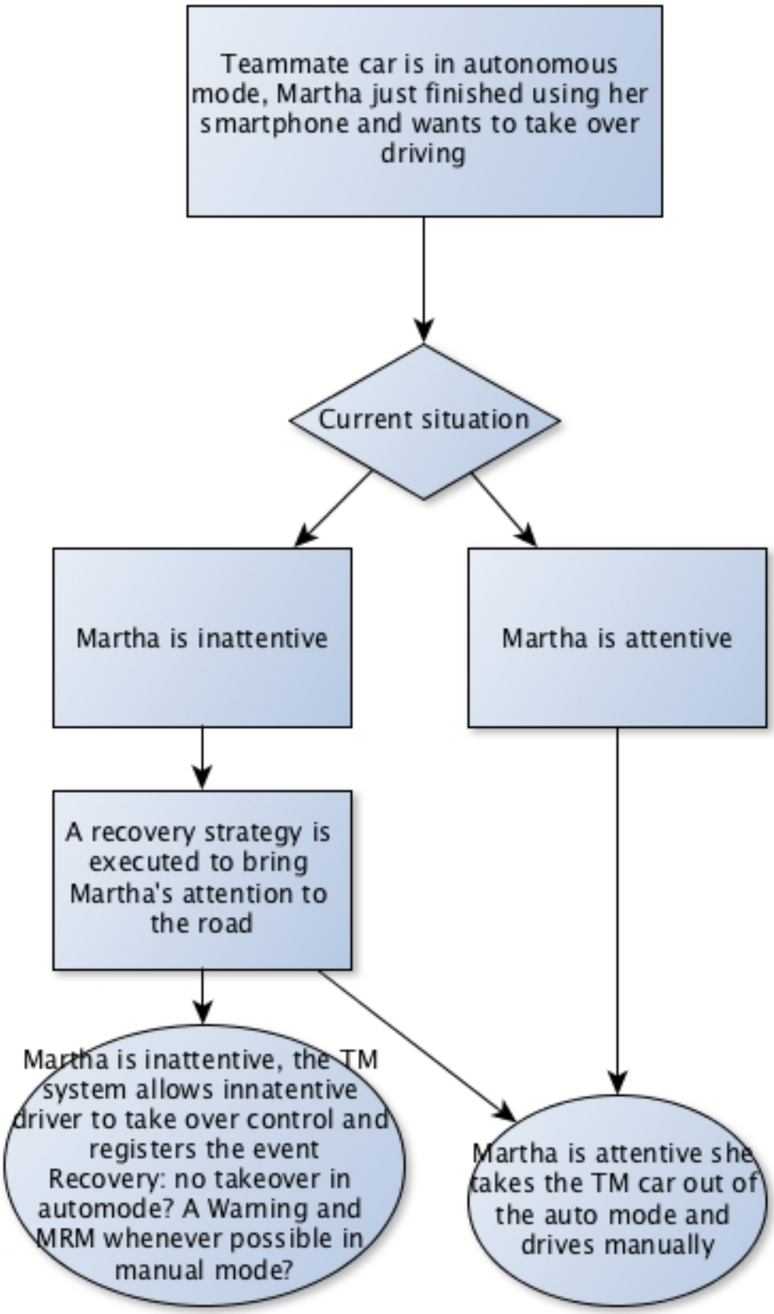


Figure 43. Fallback strategy - Martha use case 5

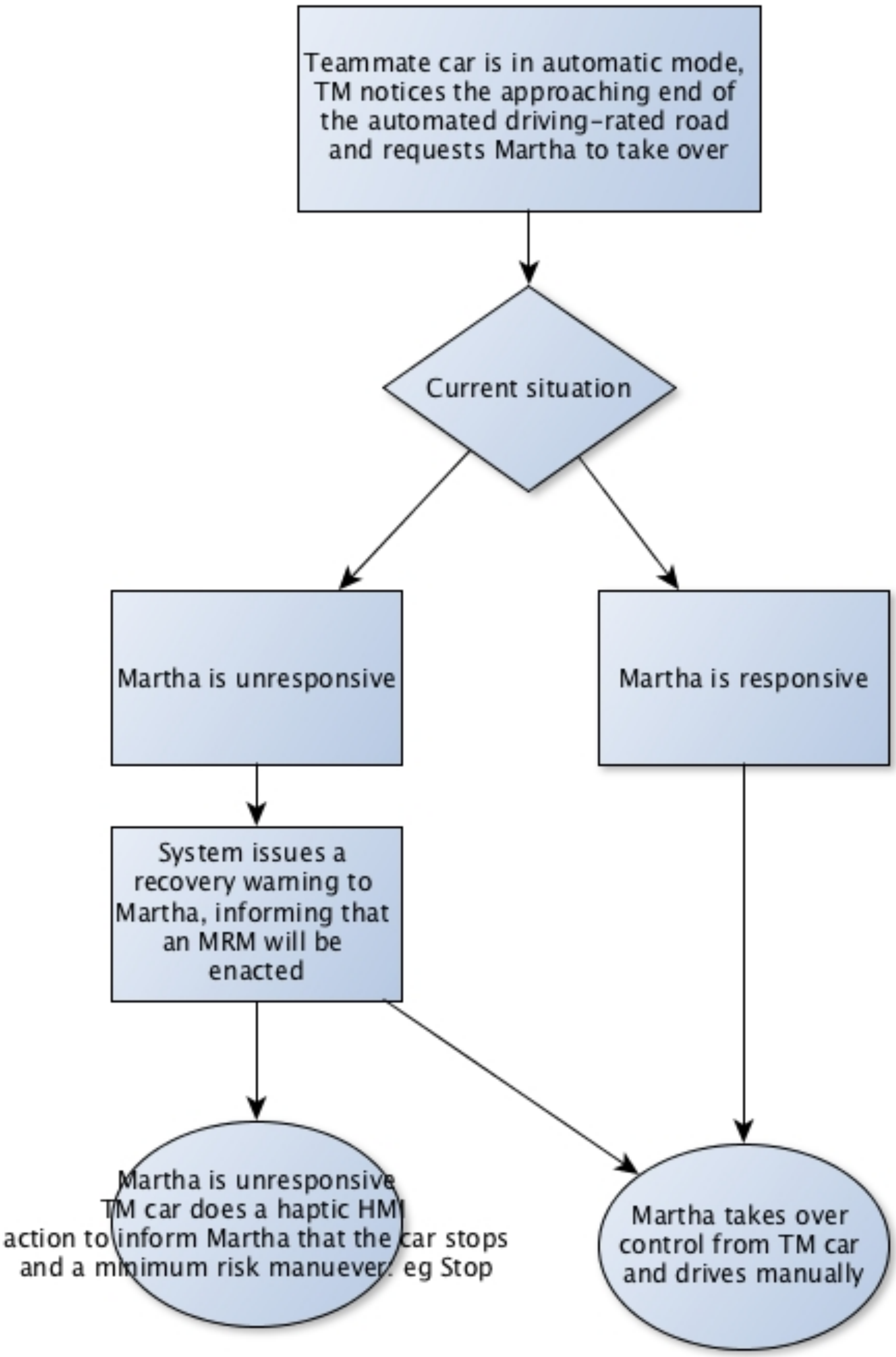


Figure 44. Fallback strategy - Martha use case 6

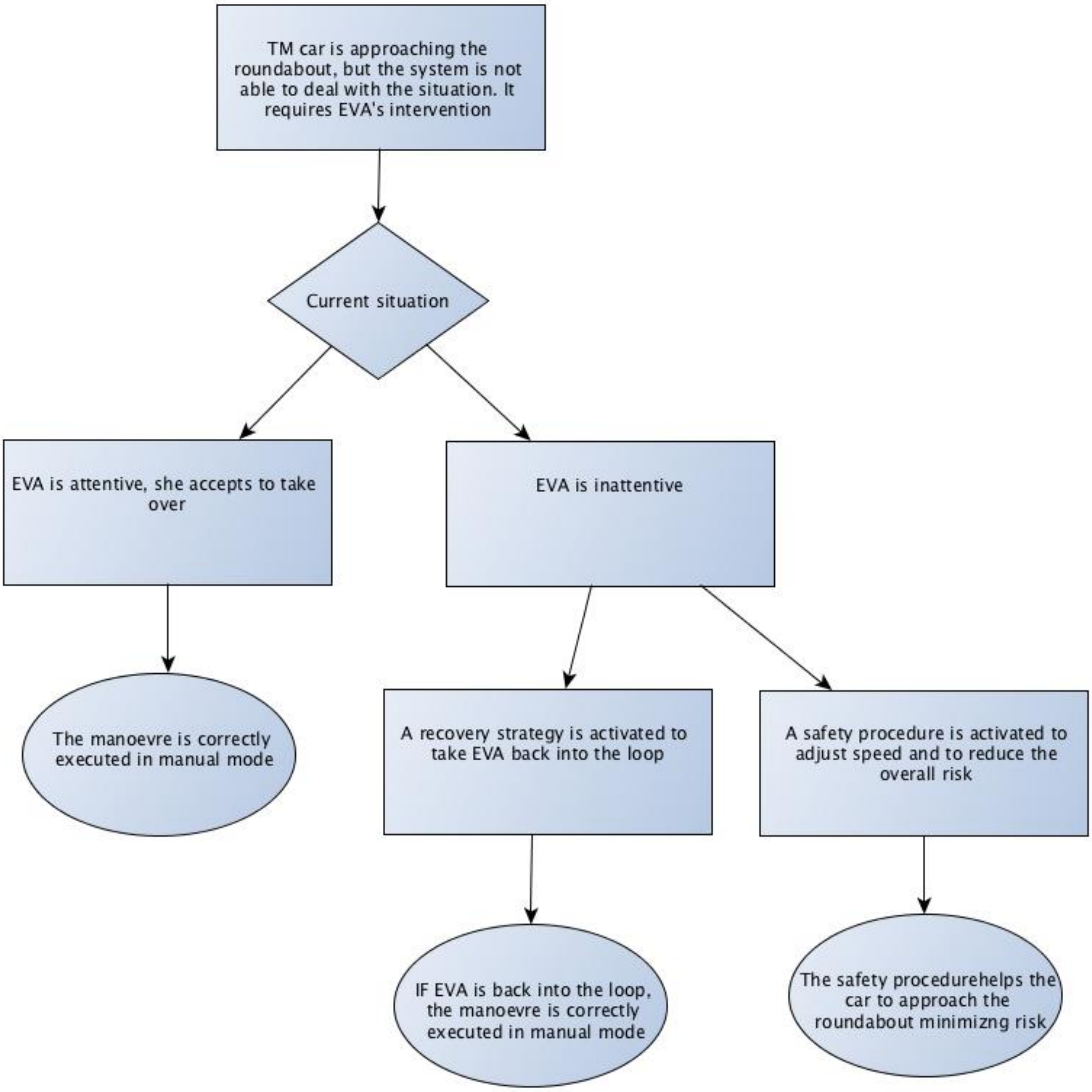


Figure 45. Fallback strategy - Eva use case 2

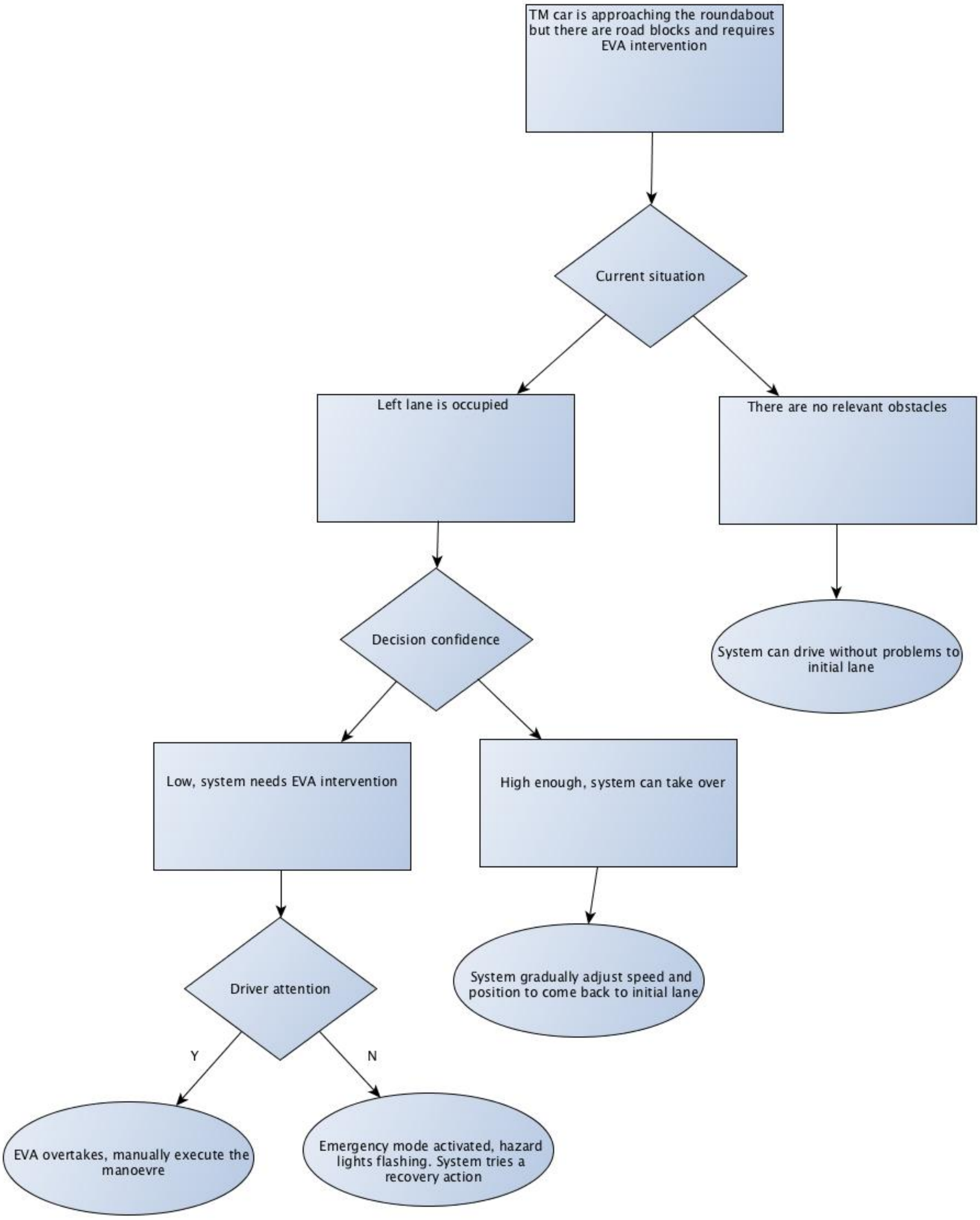


Figure 46. Fallback strategy - Eva use case 4

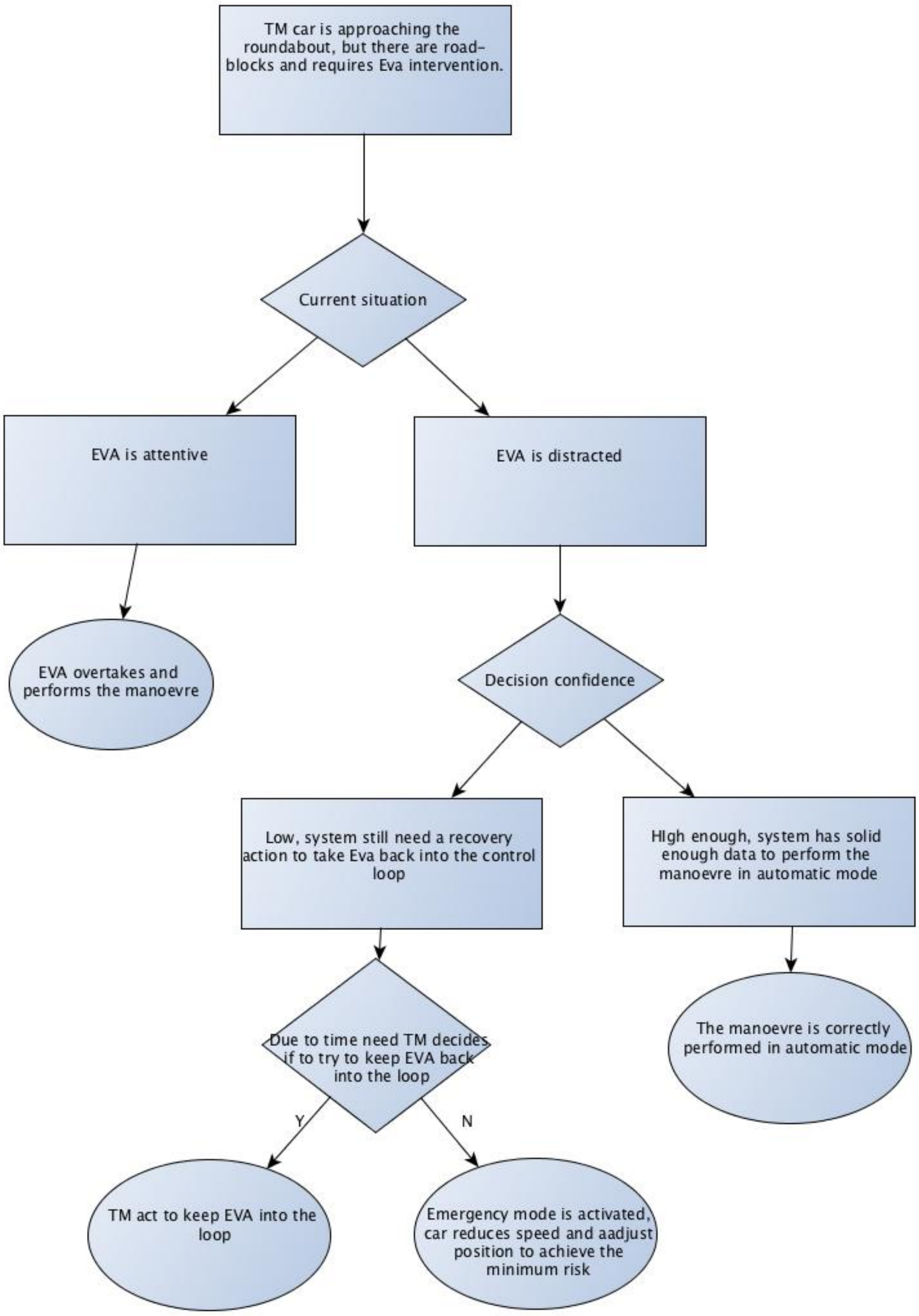


Figure 47. Fallback strategy - Eva use case 5

7 HMI modes

The TeamMate concept is based on the cooperative behaviour of the driver and the automated system. The cooperation is the consequence of the mutual support between the vehicle and the driver. The aim of this paragraph is to establish a solid interaction strategy between the human and the technical part of the system. The scenarios and the use cases, established in the early design stage, served as inputs to define the interaction modes. In the TeamMate system, the aim is to build a cooperation able to adapt the interaction modalities, through the detection of vehicle, the environment and the driver state. In particular for the vehicle state, it is important to define that the TeamMate concept, based on the flexibility of the automation levels, presents a set of different states. For each state, we defined an adaptable HMI solution: the HMI presents some common elements in the structure and in the information visualization style, to ensure a sort of *continuum* among the different states. However, some elements are capable to adapt their configuration in relation with the automation state. From these evidences, the TM system can be described as a solution with four stable automation modalities:

- **Manual mode** (a level 0 SAE vehicle without any support from the car);
- **Automatic mode** (a full autonomous vehicle that can still require driver's intervention);
- **TeamMate mode** (the cooperative format of driving);
- **Emergency mode** (in which the system is not able to detect the driver's state and informs him/her that no support is available).

The first three conditions are to be considered as "normal driving conditions" and the emergency mode as a provisional "emergency condition", as shown in the Figure 48.

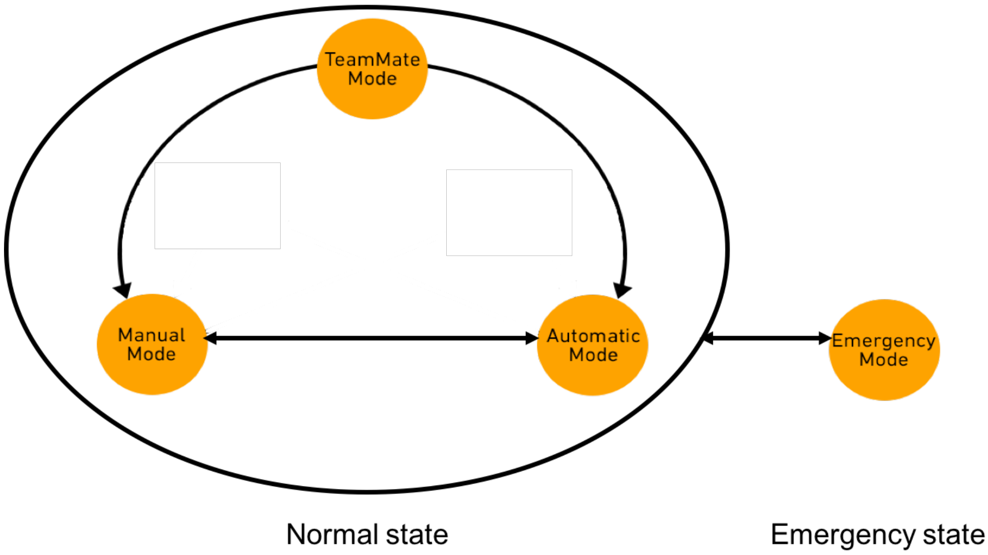


Figure 48. State machine (stable modes)

As stated in the previous paragraphs, a critical element for an effective interaction between the driver and a highly-automated vehicle is the transition between the different states. The stable modes are linked by two transition modes, able to provide a smooth transition of administration on the driving tasks among the system and the driver. That way, the TeamMate system has two transition modes, to ensure, respectively, a correct window of time for the handover and the take-over. These states are not to be considered stables, because they are limited in time and only related to a single action (i.e. the resumption of control).

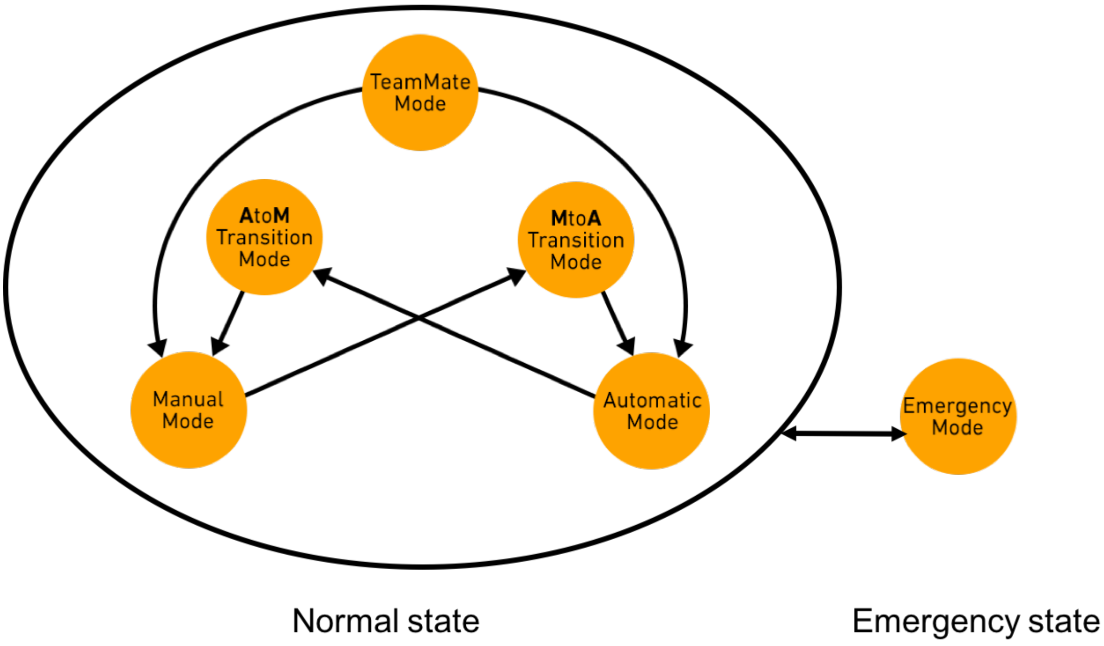


Figure 49. State machine (all modes)

7.1 Information structure and multimodal interaction concept

Among the main pillars, partially described in this document, the "concurred abbreviations" (i.e. a set of adaptable messages and interactive set of messages between the vehicle and the driver) (Koo et al., 2014) and the "multimodal HMI" are crucial to select and implement an efficient and failsafe interaction strategy. The multimodality seems to be an effective strategy to help the driver in staying (or coming back) in the loop: the attempt to build an effective multimodal strategy is based on the selection of the driver state regarding the attention. From this point of view, the selected channel used to improve the communication between the vehicle and the driver, strictly depends from the grade of the driver's attention detected by the system (e.g. eye-gaze, hands-on detection etc.). For example, if the driver is involved in a critical task (such as a Take Over Request), a simple visual message could possibly not be detectable or comprehensible enough. For each automation state, the main driver's tasks have been identified and then split into subtasks. For the subtasks, we used the detection of the grade of attention to select an efficient multimodal strategy. Moreover, the informative elements (in this cycle mostly graphical features) have been selected to be implemented on the different HMI states. The Main Driver Tasks along their subtasks for each mode are listed in the Table 3.

	Main Driver Task	Subtask
Manual Mode	Driving	Check the current speed
		Check the RPM
		Check the map
		Check the surrounding environment
		Check the vehicle state
		Be aware of the estimated time to arrival
		Be aware on Automation State
	Entertainment	Manage multimedia entertainment
		Manage phone call
TeamMate	Supervision or driving (based on previous automation level)	Check the current speed
		Check the vehicle state
		Check the Automation State
		Check the map
		Check the surrounding environment
	Communication with the vehicle	See a representation of the suggested manoeuvre
		Read the question suggested by TM system
		Choose the selected decision
	Entertainment (based on previous automation	Manage phone call
		Manage multimedia entertainment

	level)	Select menu settings
		Write a message
		Browse the internet
AtoM Transition Mode	Transition (supervision to driving task)	Check the current speed
		Check the map
		Check the surrounding environment
		Check the vehicle state
		Be aware of the estimated time to arrival
		Be aware on Automation State
		Be aware of the Take Over Request
		Check the map
		Check the surrounding environment
MtoA Transition mode	Transition (supervision to driving task)	Check the current speed
		Check the RPM
		Check the vehicle state
		Be aware on Automation State
	Entertainment	Manage multimedia entertainment
		Manage phone call
Automatic Mode	Supervision	Check the current speed
		Check the map
		Check the surrounding environment
		Check the vehicle state
		Be aware on Automation State
	Entertainment	Manage phone call
		Write a message
		Select menu settings
		Browse the internet

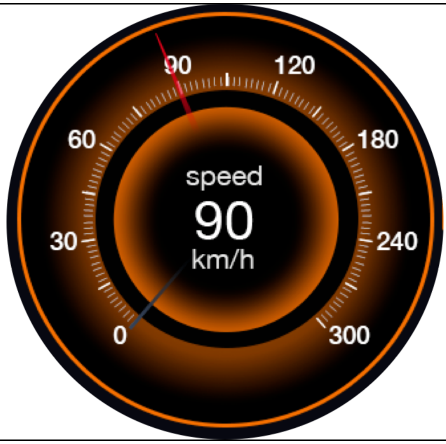
		Manage multimedia entertainment
Emergency mode	Driving	Check the current speed
		Check the RPM
		Check the vehicle state
		Be aware on Emergency State
		Check the map
		Check the surrounding environment
	Entertainment	Manage multimedia entertainment
		Manage phone call

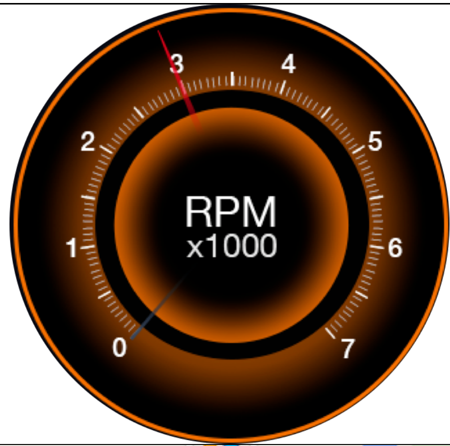
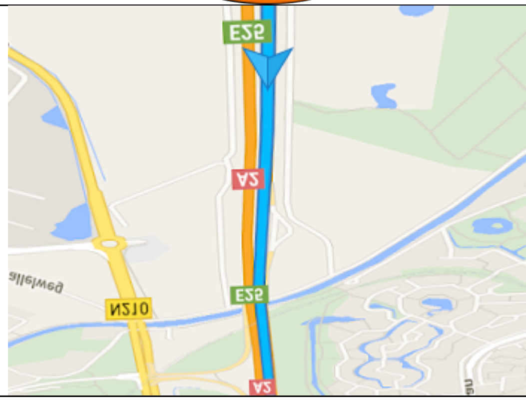
Table 3. Information structure

In the following paragraphs all different automation modes are described in detail, including the graphical features, the position of the elements on the HMI and multimodal interaction concept (i.e. sensorial channels selected to enhance the interaction between the driver and the TM system).

Moreover, the wireframes used to assess the right position of each element are also shown for each mode.

Manual mode

Task		Channel				
Main Driver Task	**Subtask**	**Driver distracted**	**Driver attentive**	**ID**	**Object**	**Position**
Driving	Check the current speed	Visual	Visual	1.1		Instrument cluster HUD (only umeric speed)

	Check the RPM	Visual	Visual	1.2		Instrument cluster
	Check the map	Visual Audio	Visual Audio	1.3		Instrument cluster Central stack display HUD

	Check the surrounding environment	Visual	Visual	1.4		Instrument cluster Central stack display
	Check the vehicle state	Visual	Visual	1.5		Instrument cluster
	Be aware of the estimated time to arrival	Visual	Visual	1.6		Instrument cluster Central stack display
	Be aware on Automation State	Visual	Visual	1.7.1		Instrument cluster Central stack display

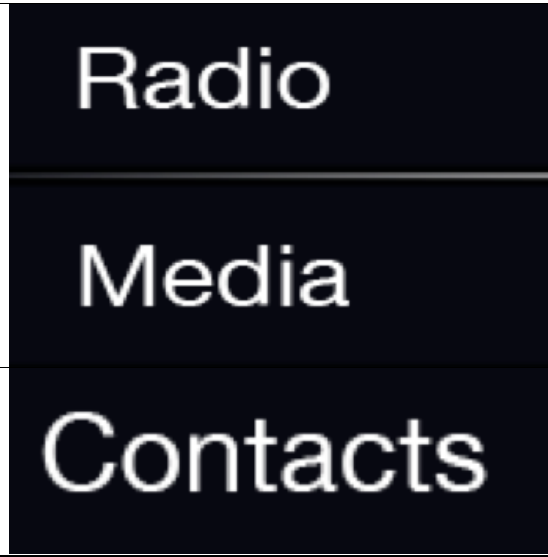
Entertainment	Manage multimedia entertainment	Visual	Visual	2.1		Central stack display
	Manage phone call	Visual Audio	Visual Audio	2.2		Central stack display

Table 4. Multimodal interaction concept - Manual mode

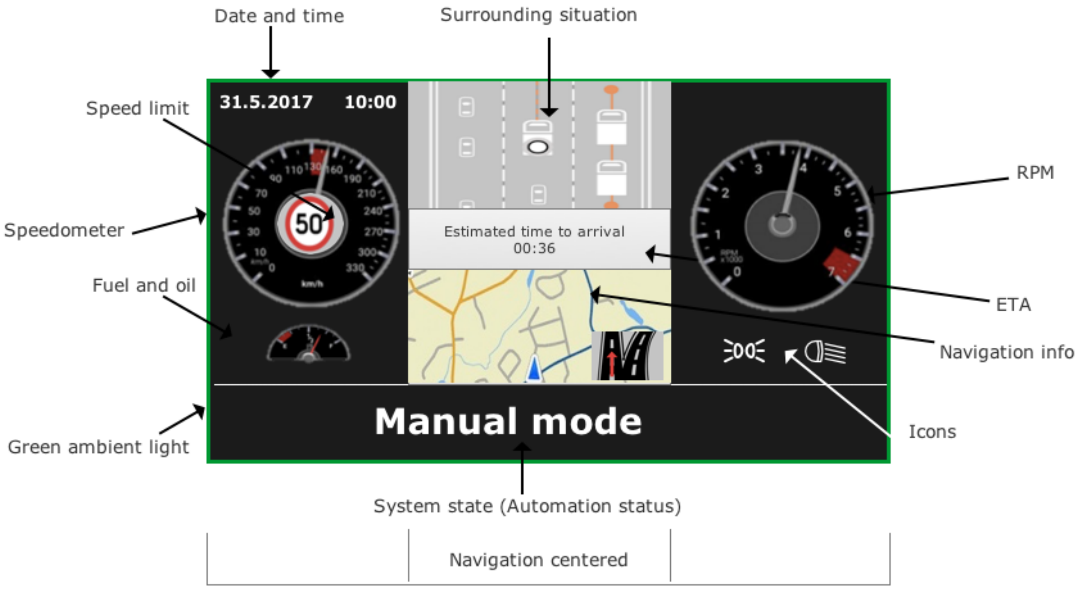
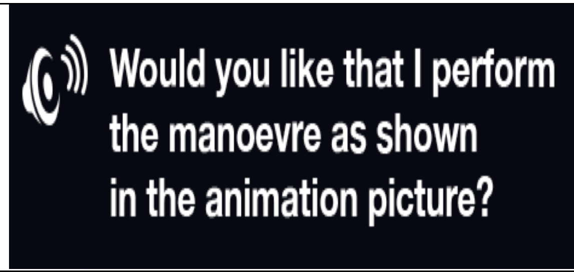
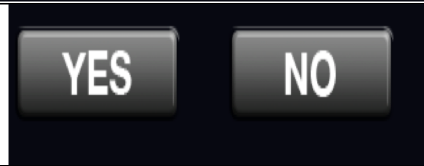
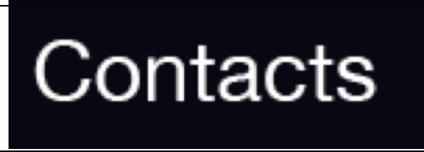


Figure 50. Wireframe - Manual Mode Instrument cluster

In Manual Mode, the primary task is the driving tasks; the HMI must show relevant data on surrounding situation, both long term information (i.e. maps) and short term information (i.e. a Bird's eye view-like element). Vehicle-related information are crucial to effectively perform the driving task: the driver must be aware on ego-vehicle current speed and the general status of the vehicle (e.g. icons). Another important element (in all the possible modes) is the information on the automation state, shown on the instrument cluster and mirrored on the central stack display. In this second display are presented information on infotainment features. The interaction with this element is partially limited, due to the complexity and the relevance of the primary task. For example, in manual mode the driver is not allowed to change the "menu settings" (i.e. date and time), or to manage the phone text messages. For other entertainment features, the choice of design is to reduce as reasonably possible the effort on visual channel, in order to avoid visual distraction shifting the information on other channels, such as visual and haptic.

TeamMate mode

Task		Channel				
Main Driver Task	**Subtask**	**Driver distracted**	**Driver attentive**	**ID**	**Object**	**Position**
Driving/supervision	Check the current speed	Visual	Visual	1.9		Instrument cluster
	Check the vehicle state	Visual	Visual	1.5		Instrument cluster
	Check the Automation State	Visual	Visual	1.7.2		Instrument cluster
Communication with the vehicle	See a representation of the suggested manoeuvre	Visual	Visual	3.1		Instrument cluster

	Read the question suggested by TM system	Visual	Visual	3.2		Instrument cluster
	Choose the selected decision	Visual Audio	Visual Audio	3.3		Instrument cluster
Entertainment	Manage phone call	Visual Audio	Visual Audio	2.2		Central stack display
	Manage multimedia entertainment	Visual	Visual	2.1		Central stack display
	Select menu settings	Visual	Visual	2.3		Central stack display

	Write a message	Visual Audio	Visual Audio	2.4	Messages	Central stack display
	Browse the internet	Visual	Visual	2.5	Web	Central stack display

Table 5. Multimodal interaction concept- TeamMate mode

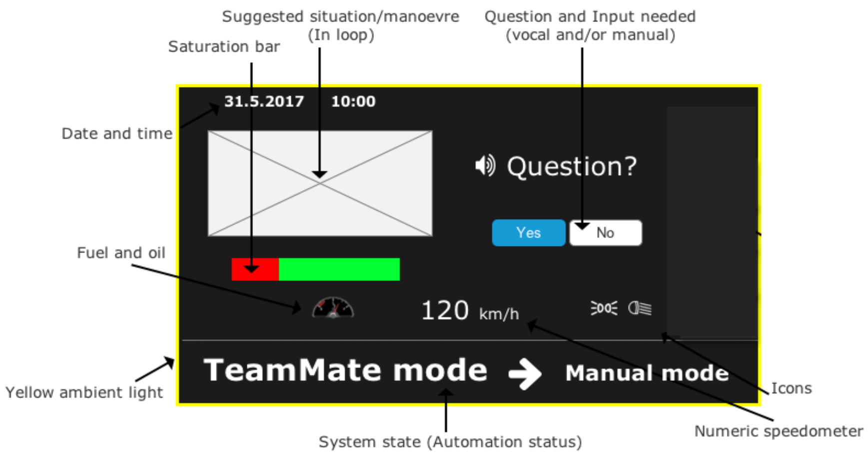


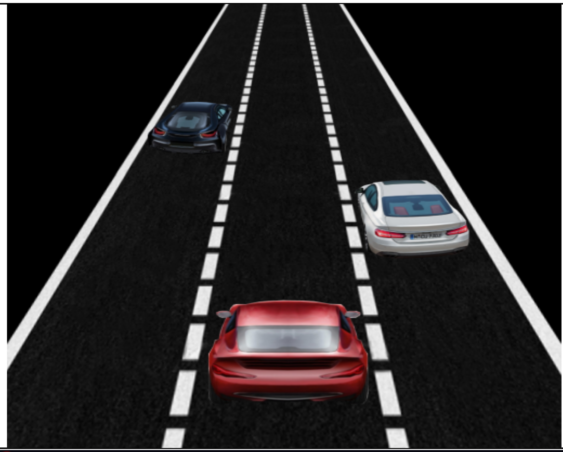
Figure 51. Wireframe – TeamMate Mode instrument cluster

The TeamMate Mode HMI, being the primary core of the TeamMate concept, has different elements and some modifications in the element's visualization. An important element in this mode, is the possibility to reach it both from Manual and Automatic Mode. This means that the driver's main task can be the driving behavior or a supervision behavior, respectively if coming from Manual or from Automatic Mode. This alternative implies different considerations on the driver status: if the driver is manually driving the vehicle, this is the primary task; the supervision task can be considered as a secondary one, and the driver can pay a major amount of attention to no-driving related tasks, such as have a phone call and so on. The core of the TM mode HMI is the representation of the suggested manoeuvre: the system, detecting and classifying the combination of the driver, vehicle and environment state, informs the driver on how to perform a task. The representation is graphically expressed and textually descripted: the driver can interact with the vehicle (to accept or refuse a suggestion) through steering wheel commands or vocal interaction. The TeamMate condition, is an intermediate state between stables and transition modes: from this condition, the driver can switch between the different states (e.g. a question, in Automatic mode, could be: "Would you like that I overtake, or do you prefer to perform the manoeuvre in Manual Mode?").

Also the secondary tasks, such as infotainment actions, depend from the previous automation state: if the state is in autonomous driving, the driver can achieve all the items in the navigation menu, including the web navigation, a complete multimedia fulfillment and the vehicle settings. Otherwise, coming from Manual Mode, only a few interactions are possible on the Central stack display.

Automatic to Manual transition mode

Task		Channel				
Main Driver task	**Subtask**	**Driver distracted**	**Driver attentive**	**ID**	**Object**	**Position**
Transition (supervision to driving task)	Check the current speed	Visual	Visual	1.9		Instrument cluster HUD
	Check the map	Visual Audio	Visual Audio	1.3		Instrument cluster Central stack display HUD

	Check the surrounding environment	Visual	Visual	1.4		Instrument cluster Central stack display
	Check the vehicle state	Visual	Visual	1.5		Instrument cluster
	Be aware of the estimated time to arrival	Visual	Visual	1.6		Instrument cluster
	Be aware on Automation State	Visual	Visual	1.7.3		Instrument cluster Central stack display

	Be aware of the Take Over Request	Visual Audio Haptic	Visual	1.8		Instrument cluster Central stack display HUD

Table 6. Multimodal interaction concept (Automatic to manual transition mode)

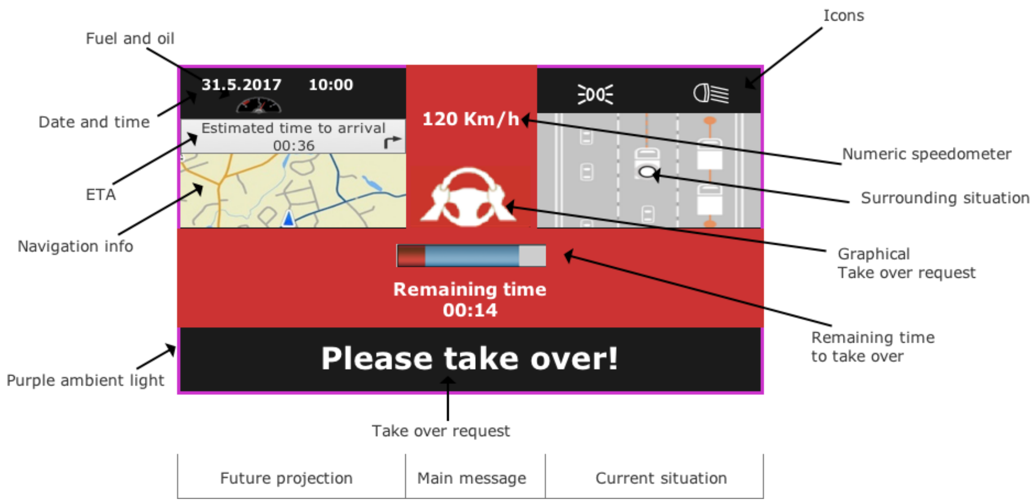


Figure 52. Wireframe - Automatic to Manual Transition Mode instrument cluster

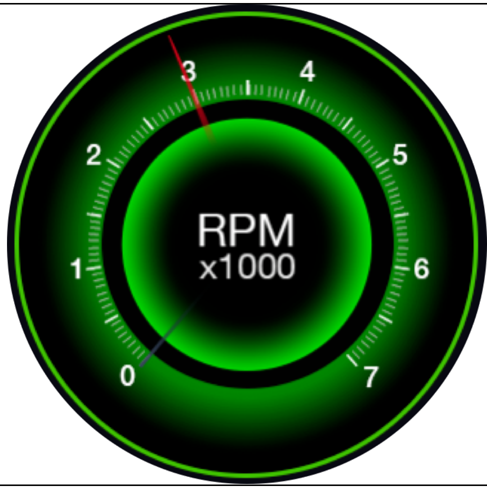
In the Automatic to Manual transition mode, a Take Over request is shown to the driver. As stated before, this is a critical task and it strictly depends on the driver's grade of attention. If the driver is out of the loop, the system should define an adaptive strategy to optimize the take over request. This implies:

- A clear and unambiguous visual strategy to inform the driver of the need to resume control;
- An adequate and clearly expressed time to complete the Take Over manoeuvre;
- The reduction of other types of information to minimize diver distraction.

On the instrument cluster, the information on current speed and navigation-oriented data are offered to ensure a gradual transition and avoid destabilizing behavior. In this mode, a part of the other elements on the HMI are turned off; for example, all the elements in the central stack display are not navigable, so that the driver's attention can be focused on the critical task. The Take Over request is shown on the instrument cluster and mirrored on the other visual displays, including the Head-Up Display. The attention recognition is performed through the eyes-on and hands-on detection. If the driver is distracted, the information is reinforced through other sensorial channels, e.g. haptic and audio, to warn the driver on the critical task.

Manual to Automatic Transition Mode

<table>
<tr><th colspan="2">Task</th><th colspan="2">Channel</th><th></th><th></th><th></th></tr>
<tr><th>Main Driver task</th><th>Subtask</th><th>Driver distracted</th><th>Driver attentive</th><th>ID</th><th>Object</th><th>Location</th></tr>
<tr><td>Transition (supervision to driving task)</td><td>Check the current speed</td><td>Visual</td><td>Visual</td><td>1.9</td><td>
</td><td>Instrument cluster</td></tr>
</table>

	Check the RPM	Visual	Visual	1.10		Instrument cluster
	Check the vehicle state	Visual	Visual	1.5		Instrument cluster
	Be aware on Automation State	Visual Audio Haptic	Visual	1.7.4		Instrument cluster

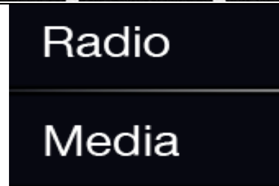
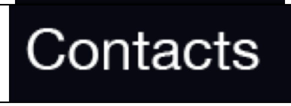
	Check the map	Visual	Visual	1.3		Central stack display
	Check the surrounding environment	Visual	Visual	1.4		Central stack display
Entertainment	Manage multimedia entertainment	Visual	Visual	2.1		Central stack display
	Manage phone call	Visual Audio	Visual Audio	2.2		Central stack display

Table 7. Multimodal interaction concept - Manual to automatic transition mode

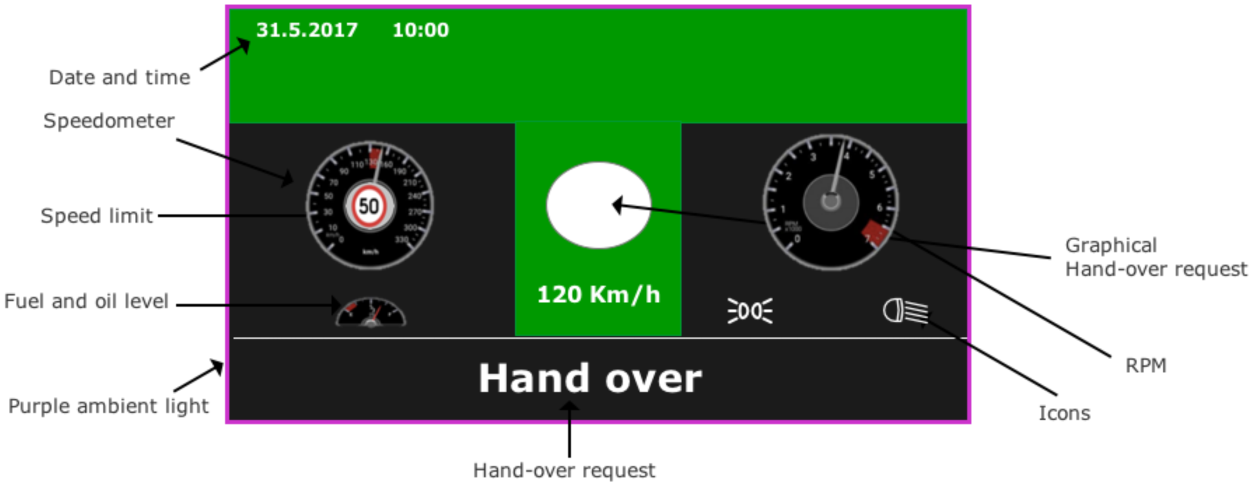
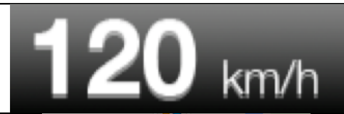
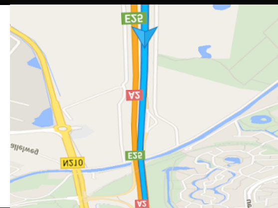


Figure 53. Wireframe - Manual to Automatic Transition Mode instrument cluster

In order to avoid a sudden transition between manual and automatic mode, the different states are connected by a transition mode, that enhance the handover performance. In this mode, the system is taking over control from the human driver. The handover can be done in two different ways: (i) from human input, when the driver instructs the system to take over, (ii) automatically, when the system detect a safe set of time to take the control of the vehicle. In this state, the smooth transition is achieved through an adaptable configuration of the HMI, where the elements are designed to avoid the possible confusion deriving from an excessive variation in the interface's layout. For this reason, the structure of the HMI is similar to the manual mode (the previous mode before the transition), but the colors inform the driver of the upcoming transition of state. In this case, the green color of the gauges, indicate a safe period to complete the handover manoeuvre. When the handover is completed a popup message informs the driver of the correct transition of control. Being a "link-state" this mode conducts to automatic mode, activating all the functions (such as the complete infotainment navigation menu) related to this state.

Automatic mode

Task		Channel				
Main Driver task	**Subtask**	**Driver distracted**	**Driver attentive**	**ID**	**Object**	**Location**
Supervision	Check the current speed	Visual	Visual	1.9		Instrument cluster
	Check the map	Visual Audio	Visual Audio	1.3		Instrument cluster
	Check the surrounding environment	Visual	Visual	1.4		Instrument cluster Central stack display
	Check the vehicle state	Visual	Visual	1.5		Instrument cluster

	Be aware on Automation State	Visual	Visual	1.7.5	Automatic Mode	Instrument cluster
Entertainment	Manage phone call	Visual Audio	Visual Audio	2.2	Contacts	Central stack display
	Write a message	Visual Audio	Visual Audio	2.4	Messages	Central stack display
	Select menu settings	Visual	Visual	2.3	Settings	Central stack display
	Browse the internet	Visual	Visual	2.5	Web	Central stack display
	Manage multimedia entertainment	Visual	Visual	2.1	Radio Media	Central stack display Instrument cluster

Table 8. Multimodal interaction concept - Automatic mode

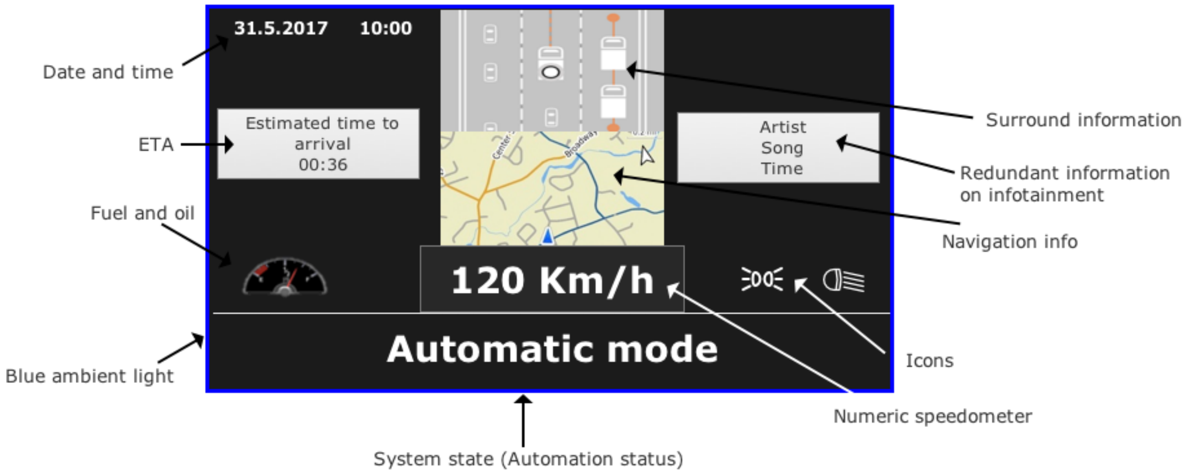
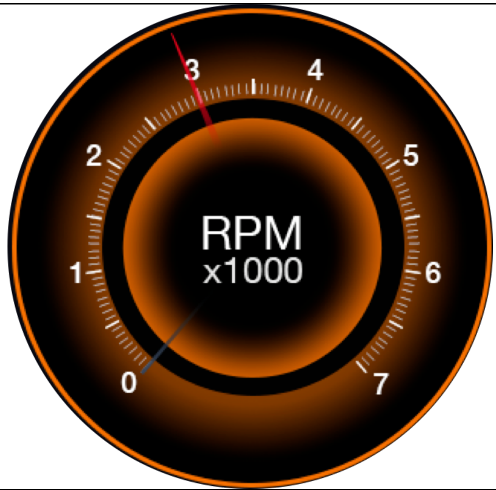


Figure 54. Wireframe - Automatic mode instrument cluster

In this mode, the system is automatically driving using the longitudinal and lateral controls. The driver is continuously monitored to maintain a minimum level of attention: if the system is not able to deal with a situation, it could require the driver's intervention. In Automatic Mode the driver's primary task is not the driving: he/she should be able to manage all the items in central stack navigation menu, including messages and complex multimedia contents (e.g. short video clips). In the instrument cluster the information on these contents are mirrored. In order to avoid a sharp transition to manual mode, the driver should be aware of the vehicle state (e.g. speed and icons) and the surrounding situation (both short and long term, i.e. maps and bird's eye view). Not being a primary information, in this mode the speed is shown with a numeric indicator and not with a gauge; RPM has not been considered a relevant information.

Emergency mode

Task		Channel				
Main Driver Task	**Subtask**	**Driver distracted**	**Driver attentive**	**ID**	**Object**	**Location**
Driving	Check the current speed	Visual	Visual	1.1		Instrument cluster

	Check the RPM	Visual	Visual	1.2		Instr clu
	Check the vehicle state	Visual	Visual	1.5		Instr clu
	Be aware on Emergency State	Visual Audio	Visual	1.11		Instr clu

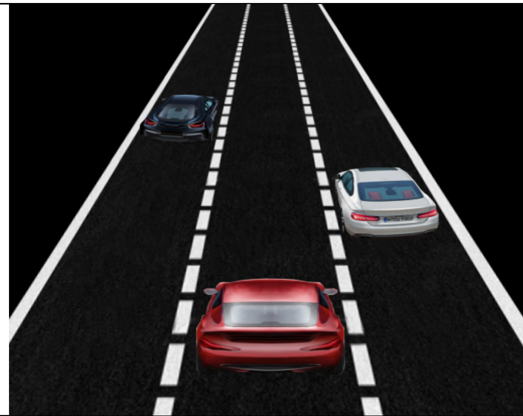
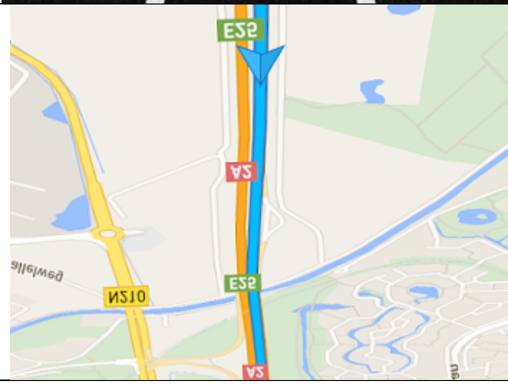
	Check the surrounding situation	Visual	Visual	1.4		Centr dis
	Check the map	Visual	Visual	1.3		Centr dis

Table 9. Multimodal interaction concept - Emergency mode

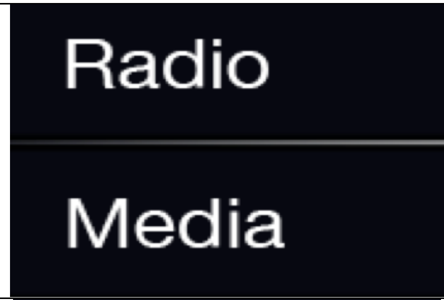
Entertainment	Manage multimedia entertainment	Visual	Visual	2.1		Centr dis
	Manage phone call	Visual Audio	Visual Audio	2.2		Centr dis

Figure 55. Wireframe - Emergency Mode instrument cluster

In this mode the system is not able to work: the driver has to drive the vehicle in manual mode. The sensors are not operating or cannot provide reliable data and the driver's state cannot be monitored. The HMI must signal to the driver the emergency state in a clear way, explaining, if possible, causes and potential consequences deriving from this state. For this reason, an emergency message is shown in the center of the instrument cluster. Navigation info are shown only in the central stack display, to make the driver aware of the primary task, that is manual driving without system support. The central stack display, in this mode, is like manual mode HMI, being similar the driver's expected behavior.

7.2 Ambient lights

Another concept emerged in the design phase is represented by the presence of ambient lights to enhance the understandability and the recognition of the automation state. For each mode, an ambient light color has been selected to make the driver aware, also without reading it on the dashboard. The proposed concept can be considered an example of "concurred abbreviation":

the driver and the system, acting as teammates, create a code to improve the effectiveness of the communication. The color selection, for each state, is described in the following table:

Automation mode	Ambient Lights color
Manual mode	Green
TeamMate mode	Yellow
Automatic to manual transition mode	Purple
Manual to automatic transition mode	Purple
Automatic mode	Blue
Emergency mode	Red

Table 10. Ambient lights

The effectiveness of the ambient lights as concurred abbreviation, and the color selection will be evaluated in the second cycle.

8 HMI design and implementation

Once defined the elements of the HMI architecture (shown in **Errore. L'origine riferimento non è stata trovata.**) as well as the features and the visual cues for each mode, the graphical layout has been realized. The HMIs have been developed in QT, ready to be mounted on the demonstrators for the evaluation phase.

In the next pages, the final version of the graphical interfaces is shown.

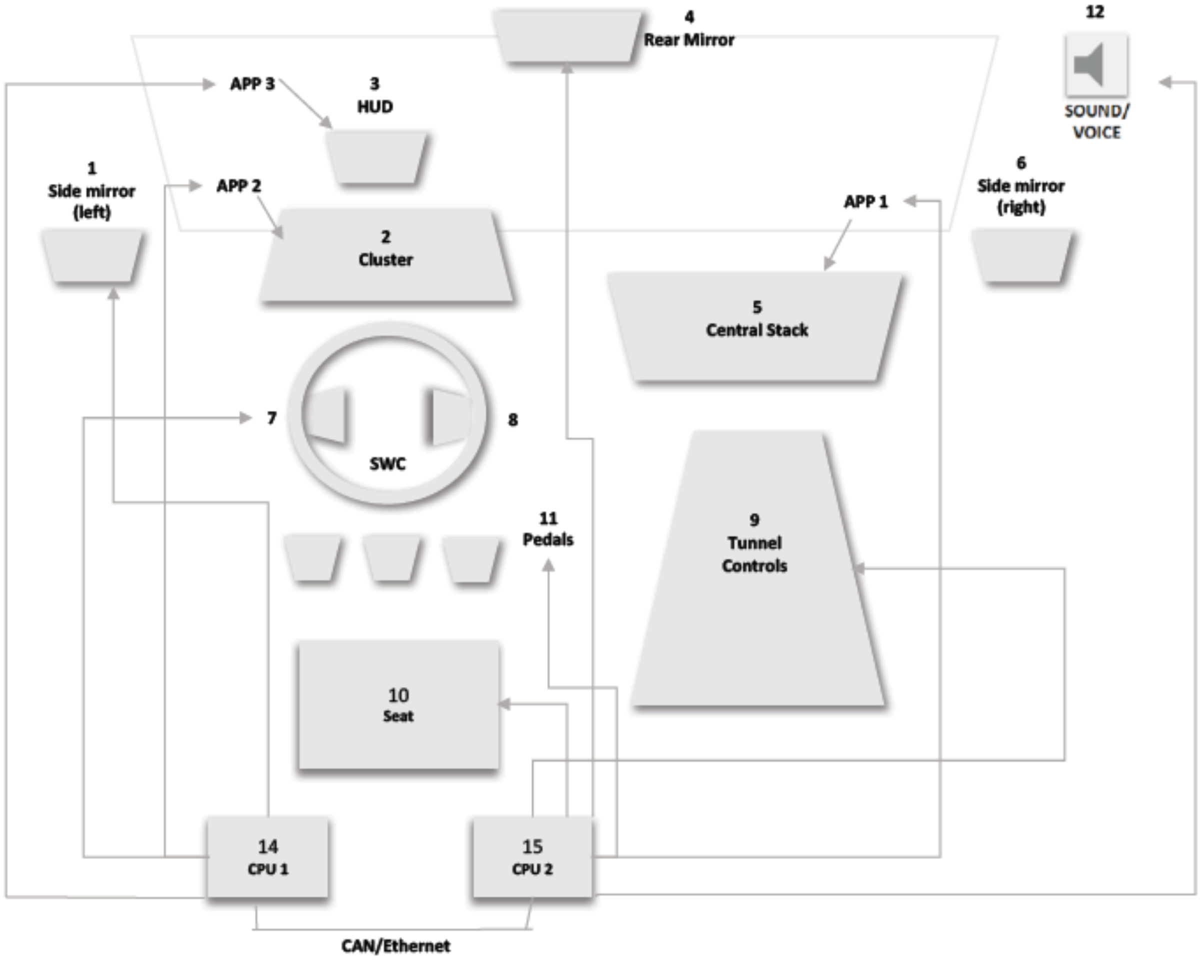


Figure 56. HMI architecture

8.1 Instrument clusters

Figure 57. Manual Mode instrument cluster

Figure 58. Manual to Automatic Transition Mode instrument cluster

Figure 59. Manual to Automatic Transition Mode instrument cluster (handover accepted)

Figure 60. Automatic Mode instrument cluster

Figure 61. Automatic to Manual Transition Mode instrument cluster

Figure 62. TeamMate Mode instrument cluster

Figure 63. Emergency Mode instrument cluster

8.2 Central stack displays

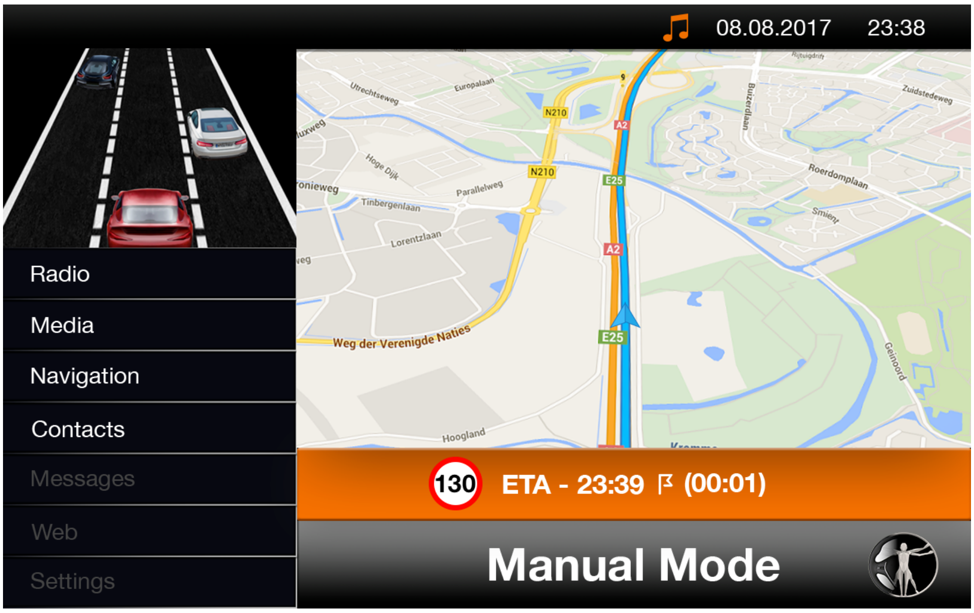


Figure 64. Manual Mode Centrasl stack Display

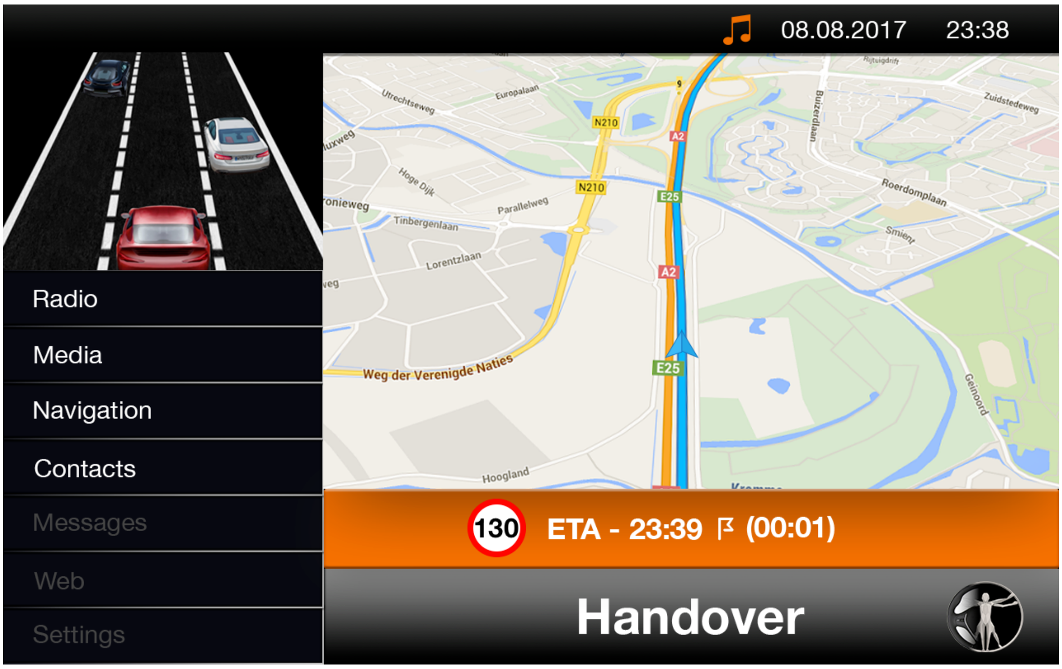


Figure 65. Manual to Automatic Transition Mode Central stack Display

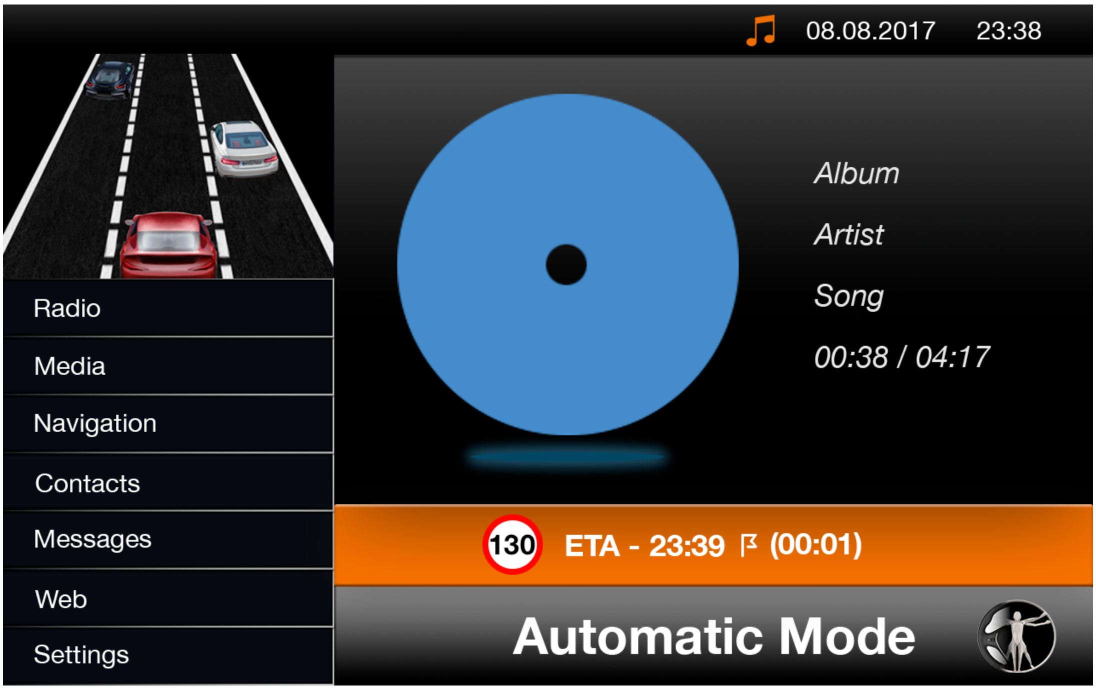


Figure 66. Automatic Mode Central Stack Display

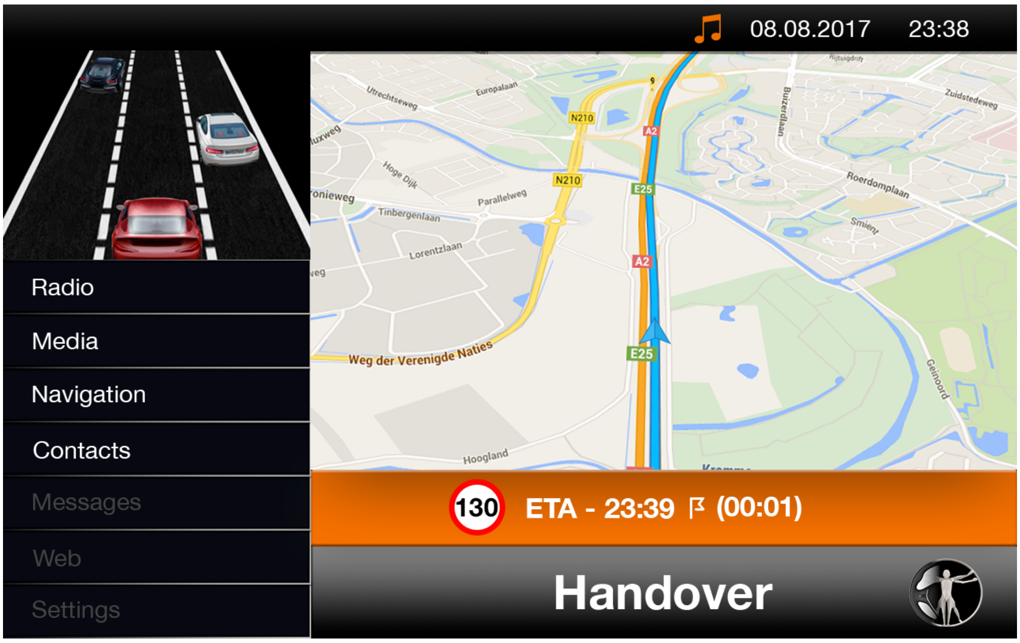


Figure 67. Manual to Automatic Transition Mode Central Stack Display

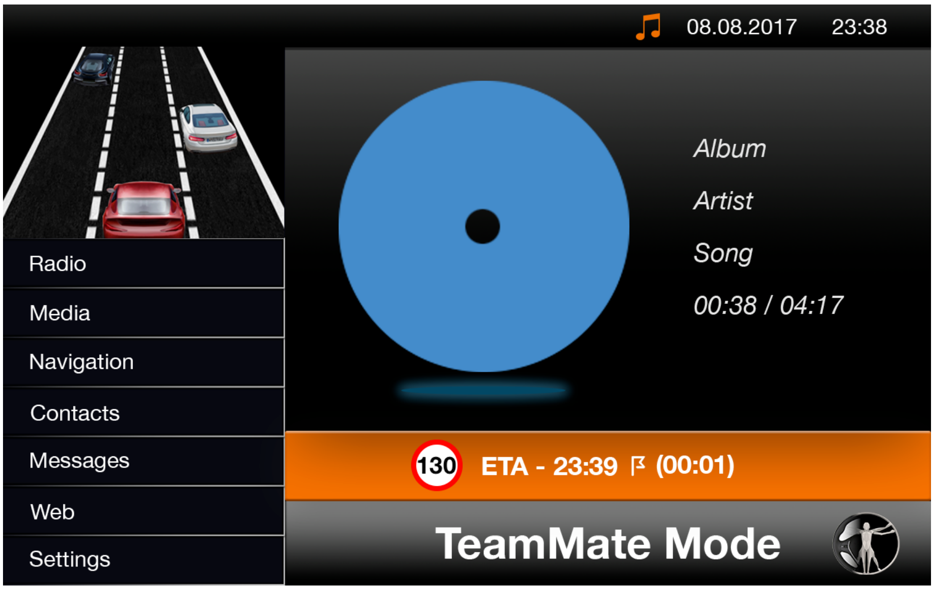


Figure 68. TeamMate Mode Central stack Display

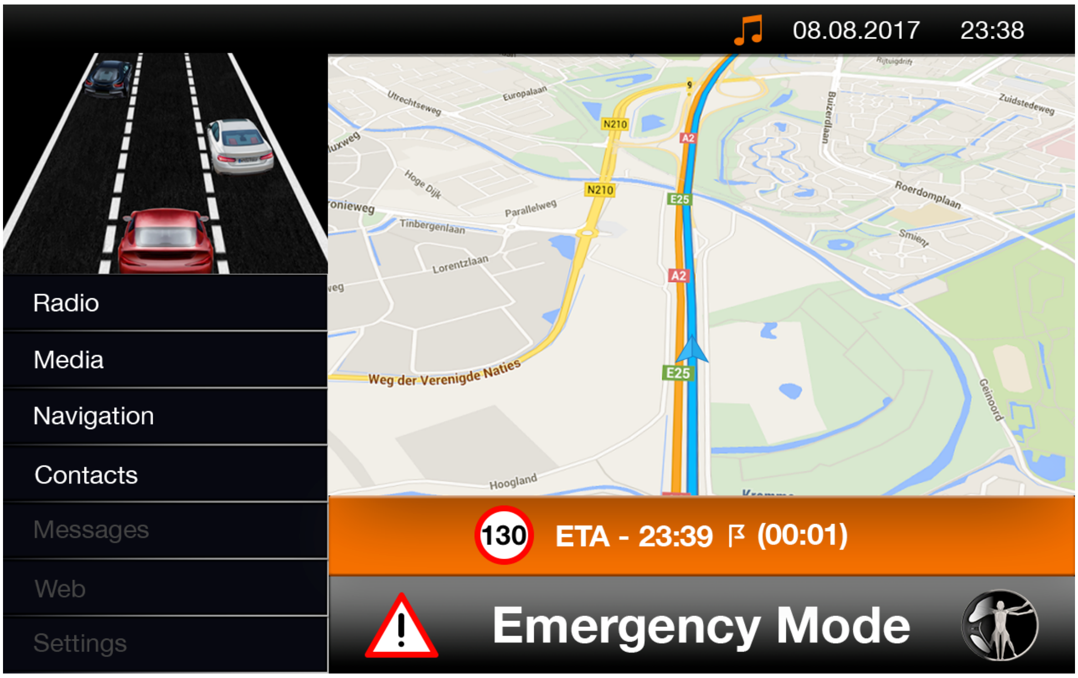


Figure 69. Emergency Mode Central Stack Display

8.3 Head-Up Displays

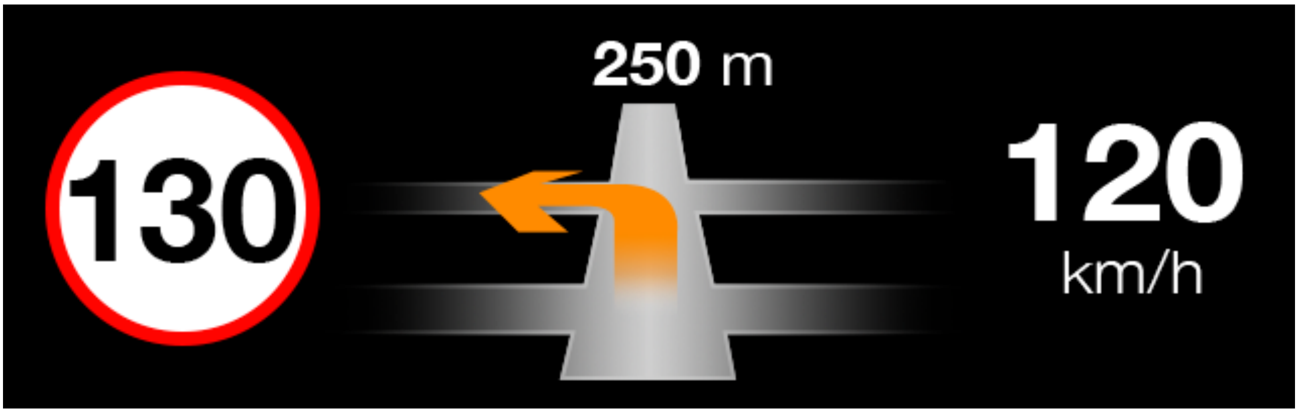


Figure 70. Manual Mode HUD

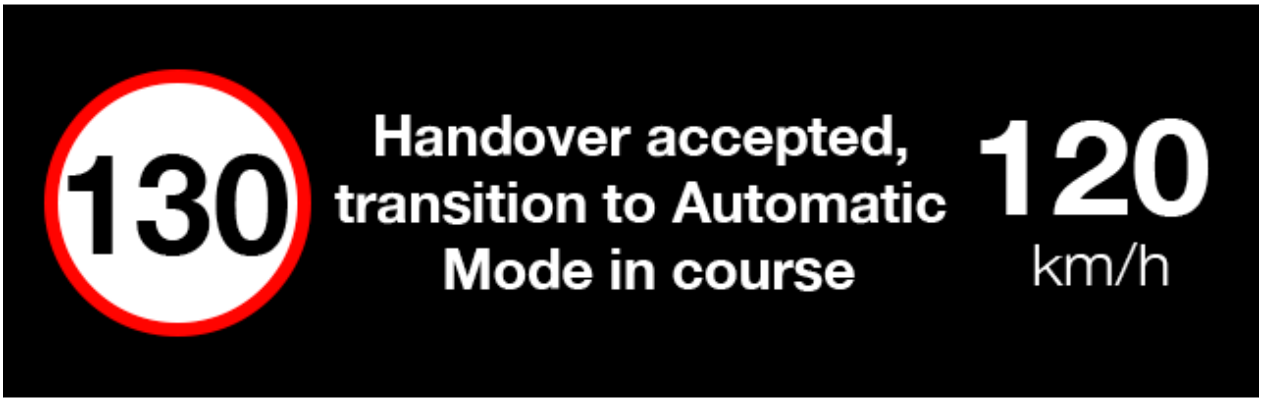


Figure 71. Manual to Automatic Transition Mode HUD

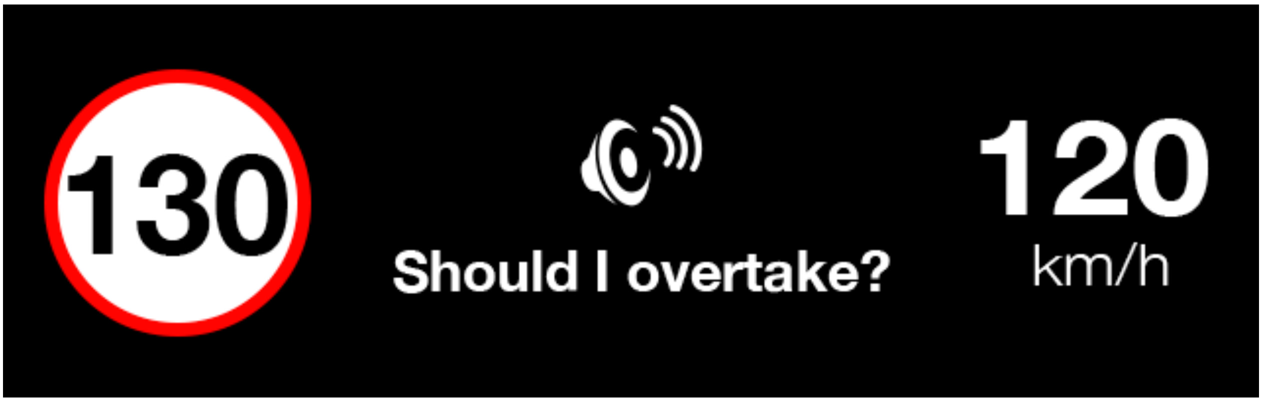


Figure 72. TeamMate Mode HUD

Figure 73. Automatic to Manual Transition Mode HUD

9 Verification and Validation activities

At the end of the first cycle, Verification and Validation (V&V) activities have been performed.

The first cycle has been mostly focus on the design of the HMI concept and the strategy for a safe and smooth transition of control. It has also included the development of the first version of the HMI (in QT), that has not been embedded in the real hardware. Therefore, in this first cycle, all V&V activities were actually Verification activities, to check that the requirements (i.e. constraints) defined by all partners in WP4 have been met. The second cycle will mainly focus on the validation of the requirements, while the third cycle will perform the evaluation of the TeamMate car (included the HMI) against the baseline (for each demonstrator).

Type of requirement	Req ID	Req description	Enabler owner
Verification	R_EN6_HMI1.1	The ambient light must clarify the driving mode (e.g. the takeover requests)	ULM
Verification	R_EN6_HMI1.2	The interaction strategy should be usable according to ISO 9241-11	ULM
Verification	R_EN6_HMI1.3	The most efficient channels of communications should be included according to the mode	ULM
Verification	R_EN6_HMI1.4	The HMI must have different states for each automation	REL

		mode	
Verification	R_EN6_HMI1.5	The HMI must show the Take Over Request on the cluster and mirror it on the Central Stack Display and the HUD	REL
Verification	R_EN6_HMI1.6	The overall HMI concept must include a strategy to modify the ambient lights to improve the driver awareness on the automation state	ULM
Verification	R_EN6_HMI1.7	The HMI must have 3 visual displays: - an instrument cluster - a Central Stack Display - a Head Up Display	REL
Verification	R_EN6_HMI1.8	In TeamMate mode the HMI must show the possibility to interact with it through vocal interaction	REL
Verification	R_EN6_HMI1.9	Navigation info and surrounding view must be visible on the instrument cluster both in automatic and manual mode	REL

Verification	R_EN6_HMI1.10	In MtoA transition mode, the Instrument cluster must show the correct handover through a popup that informs the driver of the current transition	REL
Verification	R_EN6_HMI1.11	Infotainment features must be mirrored on the instrument cluster only in Automatic Mode	REL
Verification	R_EN6_HMI1.12	In TeamMate mode, the HMI must show the suggested maneuver through animated features	REL
Verification	R_EN6_HMI1.13	In Manual mode, the Central Stack Display must redund information on navigation and surrounding situation	REL
Verification	R_EN6_HMI1.14	In Automatic mode, the Central Stack Display must allow to reach all the features of the NIT navigation menu	REL
Verification	R_EN6_HMI1.15	In Manual mode, in manual to automatic transition mode	REL

		and in emergency mode the Central Stack Display must allow to reach only some features of the navigation menu (e.g. it should not be possible to reach the "Messages", "Web" and "Settings" items)	
Verification	R_EN6_HMI1.16	In Automatic to Manual transition mode (TOR activated) the Central Stack Display shouldn't allow to navigate the menu	REL
Verification	R_EN6_HMI1.17	A HUD must be provided for Manual mode and for Automatic to Manual transition mode	REL
Verification	R_EN6_HMI1.18	In manual mode, the HUD must provide crucial information on navigation (e.g. current speed, navigation info, speed limit)	REL

Table 11. Requirements met during the V&V activity in WP4

10 Conclusions and next steps

The first design cycle of the TeamMate HMI concept has been described in this document.

In details, the main topic covered in this document is the quality of the transition between manual and automatic state. One of the AutoMate project's purpose is to create HMI solutions that can provide an effective and safe interaction. Therefore, we focused on the states of automation and on the modes in which they are displayed to the driver.

During the first cycle, the overall multimodal HMI concept has been defined as well as the strategy for the smooth and safe transition of control.

Four stable automation modes have been identified: a full Automatic mode, a full Manual mode, the TeamMate mode (the cooperative driving solution) and an Emergency mode. Two more states, defined as Transition modes (Manual to Automatic and Automatic to Manual, respectively for the Handover and the Take Over) have been designed to ensure a smooth transition between the different modes. These elements were used to define the HMI information structure, adaptable to the different configurations, but able to ensure continuity between them.

A wireframe for each mode has been developed and the graphical layout has then been implemented for the cluster, the Central Stack Display and the Head-Up display.

Finally, a V&V process was carried out to verify the adherence of the HMI implemented to the requirements defined in task 1.3 during the first cycle.

In the next project cycles, the integration of the results of WP2 and WP3 will be conducted and the overall HMI will be further verified and validated, according to the metrics defined at the beginning of the second cycle.

The aim of the next steps is to assess the quality of the interaction between real users (i.e. drivers) and the interface. Especially the strategy will be assessed for the most critical situation (e.g. the handover).

Other elements, such as haptic feedback strategy and the driver-to vehicle communication protocol to achieve the resumption of control will be further investigated and implemented.

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