Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments

interACT D.4.1. Preliminary interaction strategies for the interACT Automated Vehicles

Work package	WP 4: Suitable HMI for successful human-vehicle interaction
Task(s)	Task4.1: Development of generic human-vehicle interaction strategies
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Glossary of terms

Term	Description
Addressed messages	Messages that refer to one or more specific TPs
Automated vehicle (AV)	Vehicle that provides automation of longitudinal and lateral vehicle control and can free the driver from the driving task - at least in some driving situations
HMI	Human-Machine Interface of the AV that is meant to communicate with the user on board
eHMI/external HMI	External Human-Machine-Interface of the AV that is meant to communicate with surrounding traffic participants
Non-addressed messages	Messages for everyone in the environment
Non-motorised TP	Pedestrians or cyclists (not on the road)
On-board user	Human on-board of the AV who acts as a driver in all cases the AV cannot handle (SAE level 3) or is a passenger for all SAE 4 and 5 applications
Other road user	All possible road users from the perspective of the ego vehicle (the AV) i.e. pedestrians, bicyclists, motorcyclists, vehicles, automated vehicles
Parking Slot	Shared space environment with very low velocity
Perceivable for one or more specific TPs	Sent messages (no matter what modality) that are only perceivable for specific TPs (one or more)
Perceivable for everyone in the environment	Sent messages (no matter what modality) that are perceivable for anyone in the environment
Scenario	Description regarding the sequences of actions and events performed by different actors over a certain amount of time
Scene	Snapshot of the environment. All dynamic elements, as well as all actors and the scenery are included in this snapshot
Use Case	Functional description of the behaviour of the AV in a traffic situation
Vehicles	Passenger cars, busses, trucks, motorcycles and bicycles driving on the road

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List of abbreviations and acronyms

Abbreviation	Meaning
ADS	Automated Driving System
AV	Automated vehicle
D	Deliverable
EC	European Commission
eHMI	External Human-Machine-Interface
HMI	Human-Machine-Interface
HRU	Human road user
TP	Traffic participant
WP	Work package

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Executive Summary

As Automated Vehicles (AVs) will be deployed in mixed traffic, they need to interact safely and efficiently with other traffic participants (TPs). The interACT project is working towards this safe integration of AVs into mixed traffic environments.

In its Work Package (WP) 4, the interACT project aims to develop overall interaction strategies to govern the interaction between the AV and the on-board user, as well as between the AV and other traffic participants in the surrounding.

This document is the first deliverable of WP 4 and presents the overall objectives of the WP, the design process and the preliminary interaction strategies for the four interACT must-have use cases which have been selected in WP 1. The interaction strategies are described in detail by specifying what kind of information should be transferred by the AV to its on-board user and to other traffic participants in the surrounding. interACT partners developed three design variants of the interaction strategies in an iterative design process. These variants are the environment perception based design, the intention based design and a combination of these two.

Finally, the document describes the next steps in WP 4. These are the design of HMI and eHMI elements and the set-up of HMI and external HMI (eHMI) prototypes for the interACT project. In addition, the preliminary interaction strategies are tested in user studies, further refined and extended towards further and more complex scenarios.

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1. Introduction

1.1 Purpose and scope

With the introduction of AVs in mixed traffic environments, designers are facing the challenge to design an appropriate interaction strategy between the AV and other traffic participants and the user on board. It seems likely that central elements of the existing human-human interaction need to be replaced by technical means for the AV-traffic participant's interaction. The purpose of the deliverable is to give an overview on the achieved results of WP 4, Task 4.1. In this WP we are working on suitable HMI and external HMI (eHMI) solutions for successful human-AV interaction. The deliverable describes the objectives of the WP, followed by the design approach that we take in the different tasks of the WP. As human-human interaction is quite complex we extracted four categories of information from human-human interaction and applied these to our design work of AV-human interaction. These four categories are described in this deliverable as a basis of our design work. In the last section of the deliverable, we document the the preliminary interaction strategies, in which we define what messages should be transferred for the interACT must-have use cases (section 3.2.2). These interaction strategies set the framework for the further design work in Task 4.2 and Task 4.3. In these tasks we will work on the concrete HMI and eHMI design and prototype development.

1.2 Intended readership

This deliverable gives an insight into the design work of WP 4 and reports the results for the four must-have use-cases defined in D1.1 of WP 1. Therefore, this document serves primarily as an input for all interACT partners from WP 2, 3 and 5 presenting relevant information on the interaction strategies for the selected use cases. It also serves as a documentation of the on-going work in WP 4 for our Project officer, the reviewers and the EC.

As this deliverable is public, the document is also written for our stakeholders, for other researchers and industrial partners who are interested to know more about the project's design approach and first results of the design work.

1.3 Relationship with other interACT deliverables

As shown in Figure 1, WP 4 is closely related to the scenario definition in WP 1 *"Scenarios, Requirements and interACT System Architecture",* as the selected use cases for the first WP 4 designs, documented in this deliverable, are the must-have use cases defined in D1.1. Further, the Human Factors/HMI requirements reported in D1.2 influence the work of WP 4.

This deliverable is also very much related to D 2.1 "Preliminary description of psychological models of human-human interaction in traffic", from where the results on human-human interaction are directly taken into account for the definition of the AV-human interaction.

All results presented in this deliverable will directly influence the further work in WP 4 and the related deliverables D4.2 "Final human-vehicle interaction strategies for interACT AVs" and D 4.3 "Final

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Design and HMI solutions for user on board and other traffic participants”. The outcome of WP 4 is also closely related to all results of WP 3 “Cooperation and Communication Planning Unit” and WP 5 “Integration, Testing and Demonstration” that deals with the integration of different components including HMI for the interACT test vehicles.

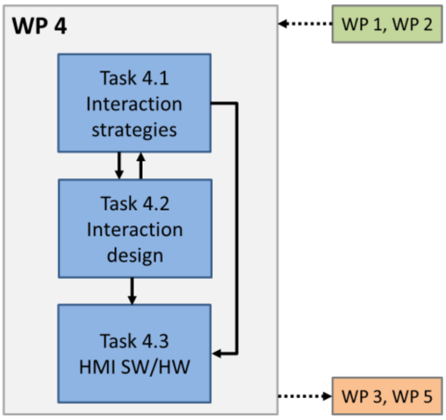

Figure 1: Connection of WP 4 to other work packages

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2. Objectives in WP 4

WP 4 “Suitable HMI for successful human-vehicle interaction” develops the overall interaction strategies and HMI solutions to govern the interaction between the AV and the on-board user, as well as that between the AV and other traffic participants, such as pedestrians and drivers of other vehicles.

In more detail, the objectives of this WP are summarized in Figure 1. These objectives are to:

- Develop generic interaction strategies and general HMI messages to enhance the cooperation and safe interaction between traffic participants, the on-board user and the AV. This work will be based on the interACT scenarios and the requirements of WP 1, as well as the findings and human-human interaction models of WP 2.
- Design the concrete HMI messages to be used by the AV. These will include explicit communication via HMI and the transfer of implicit cues, by adjusting the driving behaviour of the AV.
- Develop and adapt multimodal technical HMI hardware solutions, to be employed as explicit communication means (e.g. visual, acoustic and audio-visual messages), and provide software modules for controlling the HMI hardware elements for simulators and demonstrator vehicles via the CCP Unit of WP 3.

All this will be done in an iterative, user-centred design process to allow for improvements of the chosen design based on user feedback during the whole design process. Figure 2 shows this process followed within WP 4 of interACT.

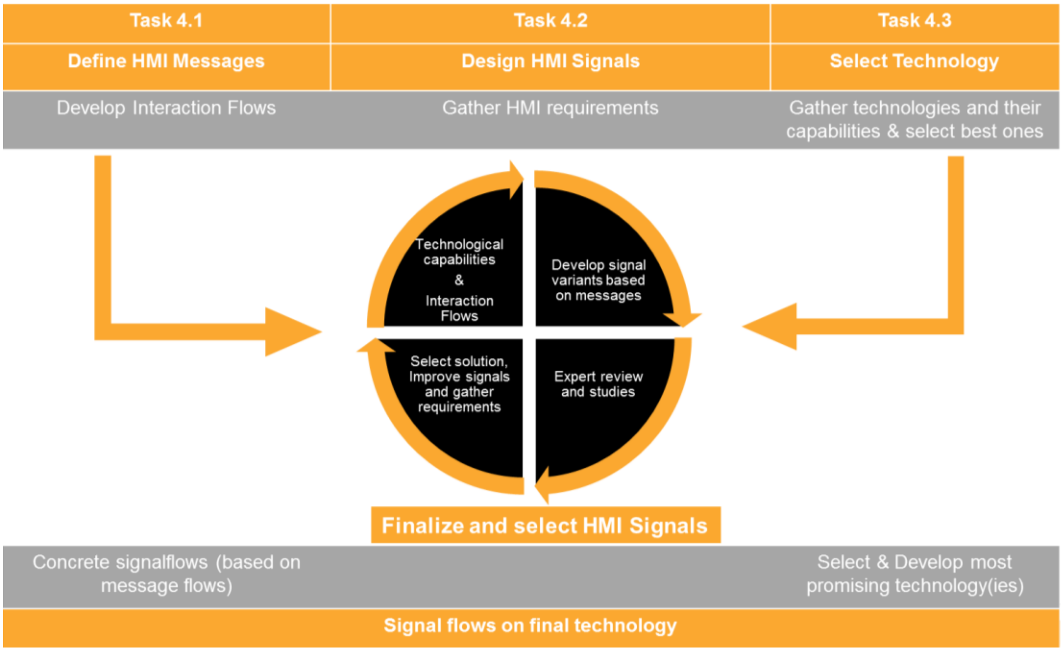

Figure 2: WP 4 working process in interACT

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In the following, the different tasks of WP 4 are described in more detail.

2.1 Task 4.1: Development of generic interaction strategies

In this task, the strategies for the interaction of the AVs with other traffic participants and the on-board user are defined for the interACT use cases selected in WP 1. The results of this task are presented in this deliverable. In this task we also work on the design principles for the interactions, and determine which kind of information needs to be communicated between different actors (AV, user on board, other TPs). These interaction strategies provide an overview of the expected implicit communication of intention by the AV, as well as the explicit communication which should be portrayed via different HMI in each scenario. The interaction strategies are based on the requirements defined in WP 1, on the findings of the observational studies and the psychological interaction models developed in WP 2. The goal is to maintain the benefits of human-human interaction but not re-implement if it is inconsistent or can lead to misunderstandings. For the second half of the project, a more abstract level of such interactions, applicable to a larger number of scenarios will also be developed. The interaction strategies of this task are the basis for the design work on the concrete HMI and eHMI (see task 4.2), as well as for the software and hardware development of the HMI elements (see task 4.3) to be controlled by the CCPUnit in WP 3.

2.2 Task 4.2: Development of specific design solutions

In this task specific solutions for the HMI of the AV are designed in an iterative manner. While task 4.1. focuses on what should be communicated, this task looks at how the information can be communicated, and also how interaction can be improved by HMI, considering different types, positions, timings and functionalities of HMI elements. Based on the interaction strategies of task 4.1, integrated multimodal and time-synchronised specifications of design solutions will be offered for the AV's interaction with the on-board user and other traffic participants. These solutions will allow smooth and safe interaction solutions with the AV, by providing information that helps other traffic participants to anticipate the driving manoeuvre of the AV and to negotiate next actions in ambiguous traffic scenarios. For the user on-board the AV, the HMI will be based on existing HMI work conducted for AVs (e.g. from the interactIVe and AdaptIVe projects), and other developing guidelines. However, in addition to current understandings, which mainly focus on the safe transition of control between the AV and the on-board user, one main focus of the HMI design in interACT, will be on providing information on the AV’s likely interactions with other traffic participants. This will go beyond obstacle localisation and avoidance, and provide information to the on-board user regarding whether they have responsibility and options for intervention in specific situations. This task will follow a user-centred, iterative design approach. Starting with mock-ups such as simple paper-pencil prototypes, studies will use simple prototypes in driving and pedestrian simulators for early user tests and conduct iterative improvements. The best solutions from this task will be selected and provided to task 4.3 and WP 3.

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2.3 Task 4.3: Technical development of HMI software and hardware components

In this task, the specific HMI solutions of task 4.2 will be technically developed. This includes technical components for visual or multimodal messages, i.e., the technical development of new light-based exterior components for the AV, and new on-board HMI interfaces. Based on the results of tasks 4.1 and 4.2, HMI and eHMI hardware solutions focussing on multi-modal communication will be developed for testing in more basic versions, in simulators. One final output of this task will be the development of a prototype, which will provide a light-based communication system around the vehicle for communication with other traffic participants. The number, size, position, angle ranges, colour(s) and luminous intensities of the eHMI have to be adapted to the targets and different environments (e.g. photometric values for day- and night-time emission). In addition to these hardware components, we develop the software modules for the control of the different HMI and eHMI elements in this task. These software components will be triggered by the CCP Unit developed in WP 3 and will be provided to WP 5 for the integration into simulators and demonstrator vehicles.

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3. Design process in WP 4

3.1 Defining the design space and terminology

When starting the design process for the interACT interaction strategies (Figure 3), we defined the design space at first and agreed on a common terminology for our work. Based on previous work of partners we agreed on four categories of information that are of relevance in the area of AV interaction design. Secondly, we worked on a common terminology for describing the interaction as well as the communication of the AVs. This was done in collaboration with partners from WP 2. The design space is further shaped and influenced by the selected scenarios for the design work, the interACT requirements as well as the requirements currently under discussion in the related ISO and SAE working groups.

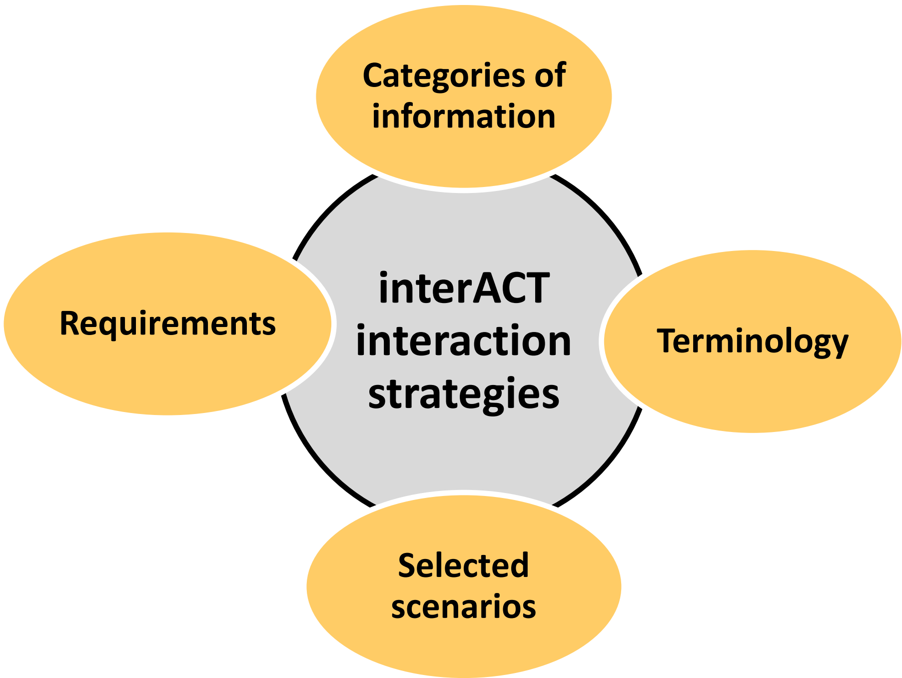

Figure 3: Design process for the interaction strategies in interACT

3.1.1 Categories of information for the interaction strategies

Based on common publications of interACT consortium partners presenting results from former projects (Schieben et al., accepted for publication; Merat et al. 2017), on the results of the observational studies and on a literature survey, we analysed which information human traffic participants use to build their expectations of future vehicle behaviour and their decisions and what kind of information they use to coordinate their actions. We decided to work with the following four

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categories of information. The categories are meant as a structuring aid for the interACT in the complex design space and are intended to help interACT partners to understand which information is needed by other traffic participants to successfully interact with an AV. It does not mean that all four categories of information should be used for all scenarios. Which information categories are chosen is a decision of the design team. The categories, as described in Schieben et al. (accepted for publication), are defined as:

Information about vehicle driving mode: This category includes all information that activates specific schemata about AV characteristics. All information that supports other traffic participants to develop the right expectations about the AV behaviour, for example by informing others about the vehicle driving mode, are summarized in this category. Examples are information if the vehicle is driverless, or driven in automated, or manual driving mode.

Information about the vehicle's next manoeuvres: A central element of conventional human-human communication is the vehicle movement, for example changes in a vehicle's trajectory, deceleration, and acceleration and resulting changes in gap size (interACT D2.1; Björklund & Aberg 2005; Demiroz et al. 2015; Kitazaki, S., & Myhre, N. J. 2015; Sucha et al. 2017; Várhelyi 1998; Zito et al. 2015). This is why we assume that the AV also might need to provide information about its next manoeuvres. This information is summarized in the category *vehicle's next manoeuvres*.

Information about perception of environment: In several situations vehicle movements (such as vehicle deceleration) are interpreted as an indication that a driver has detected surrounding road users and is willing to react to those. This expectation is becoming even stronger when more explicit signals such as eye contact between traffic participants and/or head orientation of the driver are taken into account in low speed environments as indication that the driver has detected the traffic participant (interACT D2.1; Guéguen et al. 2015; Kitazaki, S., & Myhre, N. J. 2015; Schneemann & Gohl 2016; Sucha et al. 2017; Ren et al. 2016). Therefore, we define the category *perception of environment* for the AV design that covers all information that helps others to understand that they were detected by the AV. As common human-human communication is no longer available for AVs, this interaction might need to be replaced by technical means.

Information about cooperation capabilities: In common human-human interactions in mixed traffic, establishing explicit cooperation is often indicated by gestures, eye contact, or the use of headlight flashes in addition to the adaptation of vehicle movements. This is often done in situations where a potential conflict could occur (interACT D2.1; Sucha et al. 2017, Imbsweiler et al. 2017 a, b). Therefore, we conclude that there is a need for AVs to inform other traffic participants about their capability to start direct bilateral coordination of actions and to give information about their planned cooperation to others. This could be information of different kind e.g. give right-of-way to other traffic participants; or explicit advice such as ask them to stop; advice pedestrians to cross, etc.

3.1.2 Definition of terminology for the interaction design

To support the analysis of the observational data in WP 2 and the design process in WP 4 we agreed on the following terminology for the interACT project (Markkula, G et al., manuscript in preparation).

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Movement-achieving (MA) behaviour: Behaviour that moves a road user in the world. This definition applies to any human body or vehicle movement that has an effect of how the region of space occupied by a road user changes, or does not change, over time. This behaviour can typically be succinctly described in terms of positions, speeds, accelerations, etc.

Movement-signalling (MS) behaviour: Behaviour that can be interpreted as giving information on how a road user intends to move in the future. An alternative term could be "intention-signalling behaviour". Examples include (1) a pedestrian walking in a way that can be taken to suggest that their current path is unlikely to change, or (2) a human-driven car or AV decelerating to yield to another road user, or (3) the same vehicle also showing an external sign indicating the intention to yield (e.g. headlights or some AV eHMI).

Perception-achieving (PA) behaviour: Behaviour that determines what a road user perceives. This definition applies to any human body or vehicle movement that has an effect on what the road user perceives. Examples include head/eye movements, or a vehicle advancing in an intersection to get a better view of surrounding traffic.

Perception-signalling (PS) behaviour: Behaviour that can be interpreted as giving information on what a road user is perceiving. Examples include (1) driver eye or head orientation/movement indicating that the driver is looking at a pedestrian while approaching a crossing, (2) a pedestrian head/arm posture indicating that the pedestrian is busy interacting with a mobile phone, (3) an AV shining a directed light at a certain human road user (in an attempt) to indicate that the AV has detected the human road user.

As should be clear from the above, these four types of behaviours are not mutually exclusive, rather the opposite; the figure below provides some examples of possible ways they may overlap.

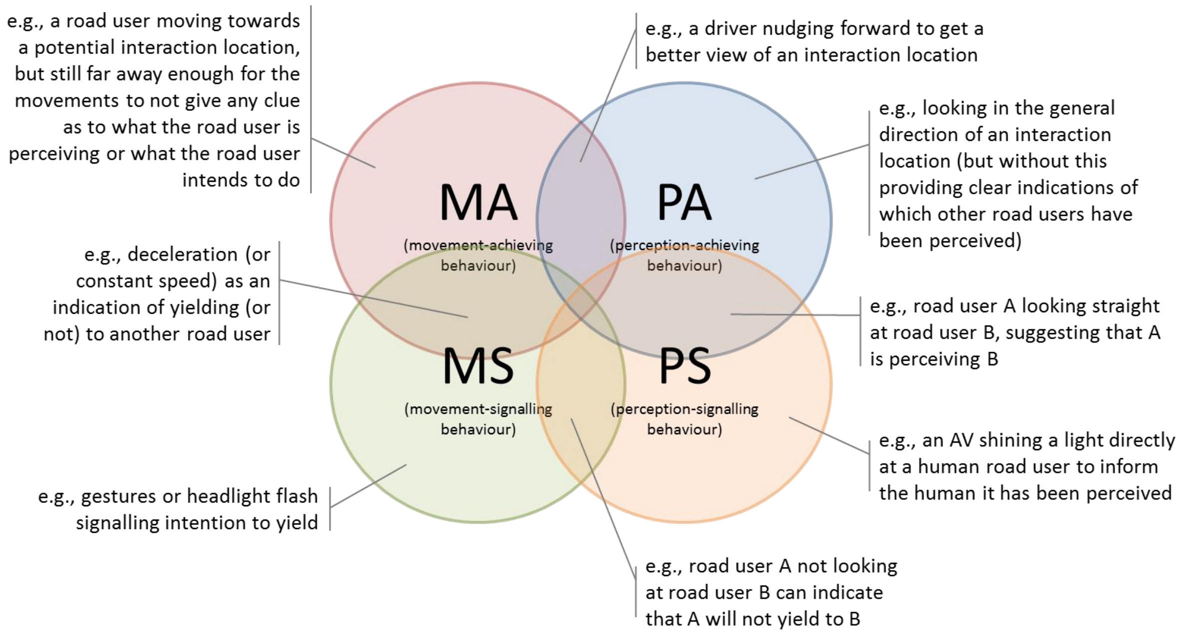

Figure 4: Interaction terminology in interACT

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Implicit communication: A behaviour which is at the same time **both achieving and signalling** movement and/or perception.

Explicit communication: A behaviour signalling perception and/or movement without at the same time achieving either of these.

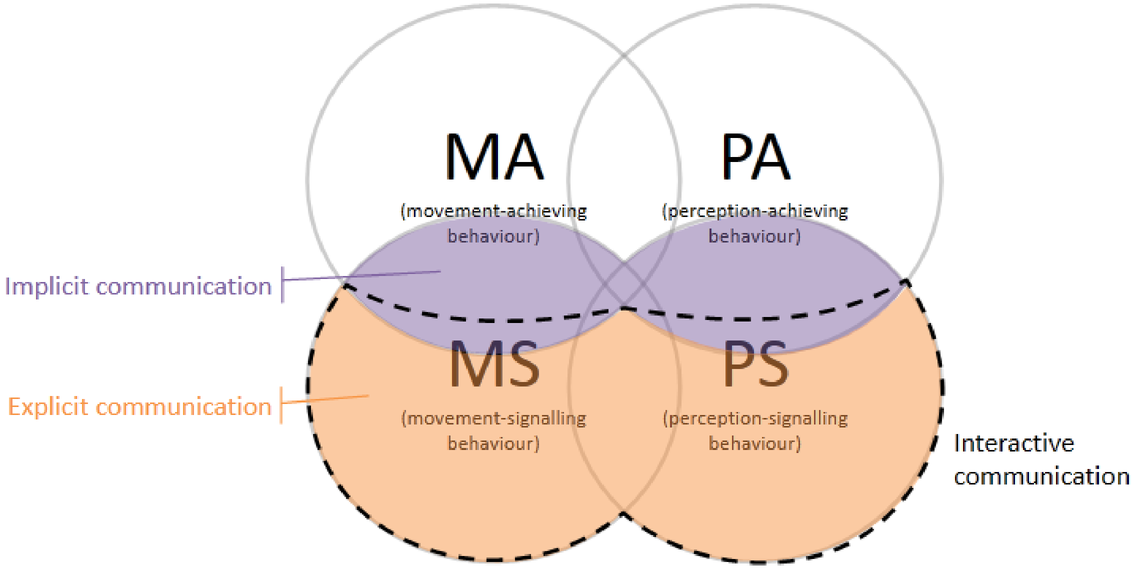

Figure 5: Implicit and explicit communication

Interactive communication: A sequence of movement-signalling and/or perception-signalling behaviour that can be interpreted as being carried out with the specific goal of resolving an interaction-demanding situation.

Addressed communication: Addressed communication uses messages that have a certain number of recipients. This means that an addressed message has a pre-defined number of recipients to whom the message is for. The message is not intended for everyone in a scenario.

Non-addressed communication: Non-addressed communication uses messages that are shared with the environment and not explicitly addressed to specific recipients in the surrounding of the AV. Non-addressed messages could be used to interact with all TPs in the surrounding at the same time.

Message perceivable for one specific TP: A message that is sent by the AV is transferred in a way that it is only perceivable by one specific TP. This can be done by the specific selection and technical design of the used eHMI hardware devices.

Message perceivable for more than one TP: A message that is sent by the AV is transferred in a way that it is perceivable for more than one TP. This can be achieved by a specific selection and technical design of the used eHMI hardware device.

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3.1.3 Selected scenarios

There are various traffic situations that show a need for interaction between traffic participants. To limit those to an amount that could be handled in the design process we decided to take the must-have use cases of the interACT project as starting point. They will be extended over the project duration to more other use cases. The must-have use cases were defined in WP 1 and described in D 1.1. The must-have use cases were also taken into account for the observational studies in WP 2. Thus, this allows us to transfer results from the human-human observations in WP 2 to our design work in WP 4 (see section 3.2.1).

The must-have use cases for task 4.1 are:

- React to crossing non-motorised TP at crossings without traffic lights;
- React to an ambiguous situation at an unsignalised intersection;
- React to non-motorised TP at a parking space;
- React to vehicles at a parking space.

For each of these use cases we worked on a specific scenario with reduced complexity to define the preliminary interaction strategies. These interaction strategies will be extended to more complex, multi-agent scenarios during the course of the project and documented in D4.2. In Table 1 we describe which scenario we selected for each of four the must-have use cases.

Table 1: Selected use cases and scenarios in WP 4

No.	Use Case	Selected scenario	Scenario Description
1	React to crossing non-motorised TP at crossings without traffic lights	React to a single pedestrian, crossing at a distance from 3m-10m from right to left at a crossing without traffic lights	Pedestrian intends to cross the street. AV intending to turn right. The pedestrian crosses in front of the AV.
2	React to an ambiguous situation at an unsignalised intersection	Open a gap for a motorized vehicle at a T-intersection	The AV approaches a non-signalized intersection. Behind the intersection the way of the AV is blocked by dense traffic. AV intends to open a gap for another vehicle to merge into the lane. The other vehicle merges into the lane.
3	React to non-motorised TP at a parking space	React to multiple non-motorised TP (two from left one from right) at a parking space	AV is searching for a free parking slot on a parking space. The AV finds a parking slot but its way is blocked by multiple pedestrians. AV yields for the pedestrians and parks in after the pedestrians have passed.
4	React to vehicles at a parking space	React to a vehicle while reverse parking in a parallel parking slot	The AV is searching for a free parking slot. The AV reacts to another vehicle that leafs a parking slot and wait till this vehicle parks out. The AV then takes the free parking slot. The AV communicates to the other vehicles that it will wait and take the parking slot.

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3.1.4 interACT Requirements

In the interACT project we started with the collection of requirements for all components of the interACT system in WP 1. These are documented in D1.2 “Requirements, system architecture and interfaces for software modules”. In D1.2 several requirements that affect the HMI design and Human Factors issues were collected (category “HF”). For the work described in this deliverable the following requirements are of importance for the definition of “what” should be communicated (see Table 2). The list of requirements is continuously updated based on new insights and results of the different WPs.

Table 2: Requirements for eHMI and HMI design

ID	Name	Description	Rationale
WP3_OPE_REQ_v31	CCPU 5	The system shall provide consistent information provided by the HMI and by the vehicle manoeuvres	Vehicle behaviour and HMI should not contradict each other
WP5_HF_REQ_v03	Interfaces to the driver	The system shall be able to communicate with the driver	The driver has to be always aware of what happening
WP3_HF_REQ_v13	Intention communication	The system shall be able to communicate its intention to the other traffic participants	Other traffic participants have to be aware of the AV's intention
WP3_HF_REQ_v15	HMI internal 1	The AV shall be able to communicate its next planned driving manoeuvres to its driver	The driver needs to know what is happening
WP3_HF_REQ_v16	HMI external 1	The system shall be able to communicate its next planned driving manoeuvres to other TPs	Other TPs need to know about the intentions of the AV
WP3_HF_REQ_v18	HMI external 3	The system shall be able to indicate its vehicle automation status to other TP	e.g. let other TPs know how to interact and with whom
WP3_HF_REQ_v19	HMI external 4	The system shall be able to present information about its perceived environment to other TP	e.g. other TPs can check whether they were detected
WP3_HF_REQ_v20	HMI external 5	The system shall be able to present information about its cooperation capabilities to other TP	e.g. show whether a hand wave signal was understood or not
WP3_HF_REQ_v21	HMI internal 2	The system shall be able to indicate its vehicle automation status for the on-board user	e.g. on-board user can check the automation status, take control
WP3_HF_REQ_v22	HMI internal 3	The system shall be able to present information about its perceived environment for the on-board user	On-board user can check if perceived environment is 'complete'
WP3_HF_REQ_v23	HMI internal 4	The system shall be able to present information about its cooperation capabilities for the on-board user	On-board user can check planned cooperation of the AV

The requirements listed above are defined on a general level. They were taken into account for the design work of task 4.1.

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3.1.5 Assumptions based on ISO and SAE discussion for eHMI design

Many vehicle manufacturers, suppliers and research organizations are currently working in the field of eHMI design for automated vehicles. Thus, there are first attempts to agree on a common terminology and a common definition of the design space. E.g. the technical committee ISO/ ISO/TC 22/SC 39 is working on ISO/PRF TR 23049. In parallel, the SAE J3134 is working on a recommended practice J3134 that summarizes existing concepts and defines some relevant input for the design of eHMI devices. Some recommendations are of relevance for task 4.1 on interaction strategies. E.g. the recommendations propose three different messages of the AV. These are:

- Vehicle's Automated Driving System (ADS) is engaged;
- Vehicle's ADS is yielding;
- Vehicle's ADS transition from 'yielding' to 'not yielding'.

Secondly, there are SAE recommendations that are of relevance for task 4.2 and task 4.3: These are recommendations for the colour used for visual signals (currently: colours blue-green/cyan and white), the installation position (currently defined in a wide range as 38 cm to 211 cm) and luminous intensities (orientated on existing exterior signal and marker lamps).

With the date of this deliverable, no official publications of the committees are available. However, we follow these discussions intensively by participation in the specific committees of our partners TUM, Hella and BMW as they have important influence on the project decisions and actively participate in the discussion to provide input and research results from interACT to other committee members.

3.2 Designing preliminary interaction strategies

In the following the process of designing the preliminary interaction strategies (task 4.1) is described. First of all, we discussed the outcomes of the observational studies in WP 2 to fully understand human-human interaction in the above mentioned interACT use cases. From the results of the WP 2 studies we derived some basic considerations for our design of the interaction strategies. In parallel, we worked on the collection of potential messages for the AV. These were documented, rated and finally selected in several iteration for the above mentioned scenarios. The finally selected messages were then used for the design of the interaction strategies. These interaction strategies are preliminary in a way that the will be review and improved over the WP 4 duration. The final interaction strategies will be documented in D 4.3 of the interACT project.

3.2.1 Results from the observational studies in WP 2

The design work in this WP is significantly linked to the outcome of the observational studies in WP 2. The main idea of the interACT design process is to take insights on human-human interaction in mixed traffic into account to design the appropriate interaction strategy for the automated vehicle with other traffic participants. Because of this, the results of WP 2 were carefully discussed in WP 4. As the goal of the design work in WP 4 is to maintain the benefits of human-human interaction but not to just replicate it, an appropriate understanding of the observed human-human interaction and its

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advantages and disadvantages is essential. The detailed results of the observational studies are reported in D2.1. Here, we sum up the most important results of WP 2 that influenced our design work.

Results on pedestrian-vehicle interaction

For interaction of pedestrian and vehicles the following outcomes (see interACT D 2.1, page 79) are of importance for our design work:

- "Interactions where explicit communication is utilized occur rarely in pedestrian-vehicle encounters.
- By behavioural adaptation of either involved road user, most potential interaction-demanding situations are resolved before they actually form. This means that the CCPU has to identify potential encounters early and try to resolve them by adapting the driving behaviour in a way that the other road user understands the intention of the vehicle without utilizing any explicit communication.
- Within the observations, explicit communication from drivers towards pedestrians was used, when the kinematic adaptation did not result in the expected behaviour and the relative velocity and distance was very low."

In D2.1 we also report a typical example for pedestrian-vehicle interaction that is cited here (interACT D 2.1, page 80):

"A pedestrian approaches a road which he intends to cross and looks towards an approaching vehicle, which has the right of way.

This could end up in the following scenarios which are resolved before any conflict occurs:

- The vehicle keeps its speed (or accelerates), the pedestrian slows down. Both driver and pedestrian non-verbally and mutually agreed that the vehicle passes first.
- The vehicle decelerates with the intention to stop before the pedestrian. This is perceived by the pedestrian, who keeps his pace (or accelerates) and crosses the road (sometimes thanking the driver and turning his head away from the vehicle).

Scenarios which typically lead to readjustments and – in some cases – explicit communication:

- The vehicle keeps its speed but the pedestrian does not slow down still looking at the vehicle. As this situation develops more critical the more time passes, at least one of the road users usually yields, letting the other one pass (resulting in the examples above).
- The vehicle decelerates, but so does the pedestrian. This potential "deadlock" situation usually results in the examples above (i.e. one of the TPs decelerating), with some sort of explicit communication by either road user. As the driver has the right of way but already decelerated, he usually will wave the pedestrian through if the velocity is low enough.

Figure 6 documents the percentages of how often a specific action occurred in the different observational site for the chosen scenario of WP 4, task 4.1. The figure shows a sequence diagram of observed pedestrian-vehicle encounters at intersections, where the pedestrian crossed in front of the vehicle. The figures give the percentage of occurrence in the different observational sites.

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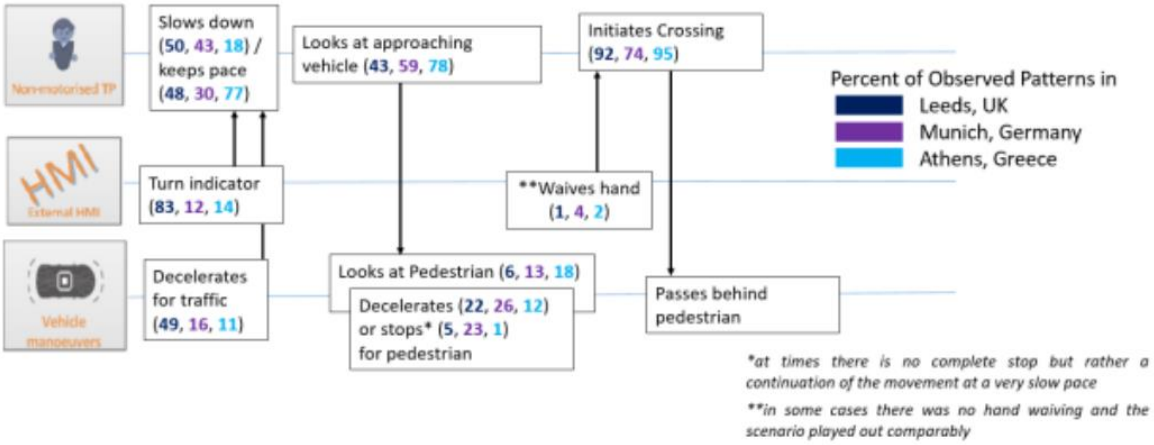

Figure 6: Sequence diagram of observed pedestrian-vehicle encounters (percentages) at intersections

Within the parking space use case for pedestrian-vehicle interaction, all traffic participants theoretically had the same priority. While this use case seems to encourage explicit communication, generally the situations played out comparably to the intersection: road users avoid communicating explicitly by adjusting their movements to resolve possible interaction-demanding situations early. E.g. if drivers see pedestrians walking on the right hand side they will adjust their lateral position towards the left and manoeuvre their vehicle around. Pedestrians usually indicate their intention to cross by turning and looking at an approaching vehicle – if the vehicle is close and keeps a lateral distance, pedestrians will cross after the vehicle. If the vehicle is further away, pedestrians will cross the road while drivers slow down or adjust their lateral position to the right.

Results on vehicle-vehicle interaction

For vehicle-vehicle encounters, the following was observed in WP 2 (see interACT D 2.1, page 82):

- "Observers perceived explicit communication more often.
- In situations with high traffic density and reduced driven velocity on the priority lane, it was observed that some drivers on a congested priority lane yield their right of way for turning vehicles.
- There are different strategies, which drivers use to communicate their yielding behaviour – the reduction of the vehicle's velocity to create a gap was in some cases accompanied with either flashing the headlights, a waving hand gesture or nodding.
- Furthermore, edging into an intersection is an effective way to make the driver on the priority lane yield. This behaviour was observed in congested traffic situations, mostly in Greece, where turning drivers were waiting for gaps or yielding drivers, but to no avail. Edging was also observed in shared spaces, when drivers tried to pull out of parking spaces.
- On a parking space normally, other drivers would continue their movement and increasing the lateral distance to the vehicle pulling out. Once the parking vehicle has backed out far enough

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(depending on the lane width), following drivers will yield and wait until the vehicle has left the parking space."

Form the results described above we revealed the the following design for the interACT WP 4 interaction strategies:

- Implicit communication is the most often used as essential form of communication;
- Explicit communication takes place in scenarios with low velocities of the traffic participants;
- Explicit communication can support the cooperation among traffic participants, especially in cases when a potential conflict exists or might occur.

That is why we decided to use explicit communication signals in interACT not continuously but mainly in scenarios where the AV has one or more interaction partner and where the information sent to other TPs might support the avoidance of potential conflict situations.

3.2.2 Collection and selection of relevant messages

In the following, the process of collecting and selecting relevant messages for the interaction with other TPs is described in detail. These messages could be perception-signalling as well as intention-signalling messages. These messages are then used for designing the interaction strategies of the AV for the selected scenarios. First of all, all involved WP partners collected a list of potential "what" messages that an AV can send on eHMI devices and categorized them into the four different categories of information mentioned above (section 3.1.1). In this first stage, we came up with 35 potential messages. Secondly, all four partners of WP 4 did a first expert rating of the messages independently and rated if each message is important with regards to the "Increase of trust in AV", the "Increase of acceptance in AV", the "Optimisation of traffic flow", the "Increase for Safety", and, if the message is required by law. The rating was done on a 10-point scale (0-10). The rating should be seen as a first aid for selecting relevant messages; it did not follow a strict standardized, scientific process. The initial list of messages and the ratings are documented in Table 3.

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Table 3: List of potential messages for interaction with other TPs on eHMI devices and rating of relevance by four WP 4 partners (Mean value, SD)

Identifier	Category of information	Increase of trust	Increase of acceptance	Optimisation of traffic flow	Increase of safety	Required by law	Comments
Vehicle Driving Mode							
VDM_1	AV drives in automated mode	3,75 (4,35)	5,00 (3,56)	2,75 (2,99)	3,75 (4,35)	Not yet	Not yet decided, research data missing
VDM_2	AV drives in manual mode	1,25 (1,89)	1,25 (1,89)	0,75 (0,96)	2,5 (2,38)	Not yet	Not showing VDM_1 could be interpreted as manual mode
VDM_3	AV's SAE current automation level	0,75 (0,96)	0,75 (0,96)	0,5 (0,58)	0,75 (0,96)	Not yet	Too complex to understand
Next manoeuvre							
NM_1	AV accelerates	2,50 (2,89)	2,50 (2,89)	3,25 (3,95)	5,75 (4,35)	No	No explicit signal needed; indicated by vehicle movements
NM_2	AV decelerates	5,50 (4,04)	5,50 (4,04)	7,25 (2,99)	6,00 (4,32)	Yes, braking lights	Braking lights in the back
NM_3	AV stops	5,50 (4,04)	5,50 (4,04)	8,25 (1,26)	7,25 (2,22)	Yes, braking lights	Braking lights in the back
NM_4	AV turns right	5,00 (5,77)	5,00 (5,77)	7,50 (5,00)	7,25 (4,86)	Yes, turn indicator	Important but no new eHMI needed, see turn indicator
NM_5	AV turns left	5,00 (5,77)	5,00 (5,77)	7,50 (5,00)	7,25 (4,86)	Yes, turn indicator	Important but no new eHMI needed, see turn indicator
NM_6	AV drives forward	1,75 (2,36)	1,75 (2,36)	3,00 (4,76)	3,00 (4,76)	No	Not yet decided, research data missing

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Identifier	Category of information	Increase of trust	Increase of acceptance	Optimisation of traffic flow	Increase of safety	Required by law	Comments
NM_7	AV drives backward	5,00 (5,77)	5,00 (5,77)	6,50 (4,73)	6,50 (4,73)	Yes, reversing light	Reversing light in the back
NM_8	AV gets out of the way	3,25 (2,36)	5,75 (4,35)	5,75 (4,35)	2,50 (2,89)	No	Might be covered by other messages such as turn signals.
NM_9	AV will start moving	7,75 (2,06)	8,25 (2,36)	4,00 (3,37)	8,25 (1,26)	No	Very similar to NM_10, might be only one message
NM_10	AV will accelerate	1,00 (1,73)	1,00 (1,73)	1,00 (1,73)	3,67 (4,04)	No	Very similar to NM_9, might be only one message
NM_11	AV will stop	7,50 (1,73)	8,00 (2,16)	8,75 (1,98)	7,00 (2,58)	Yes, braking lights	See NM_2, “AV decelerates”
NM_12	AV will decelerate	5,67 (4,93)	5,67 (4,93)	6,00 (5,29)	4,67 (4,16)	Yes, braking lights	Braking lights in the back
NM_13	AV will turn right	5,00 (5,77)	5,00 (5,77)	7,50 (5,00)	6,50 (4,73)	Yes, turn indicator	No new eHMI needed, see turn indicator
NM_14	AV will turn left	5,00 (5,77)	5,00 (5,77)	7,50 (5,00)	6,50 (4,73)	Yes, turn indicator	No new eHMI needed, see turn indicator
NM_15	AV will drive backwards	5,00 (5,77)	5,00 (5,77)	6,50 (4,73)	6,50 (4,73)	Yes, reversing light	Reversing light in the back
NM_16	AV will park	6,25 (2,5)	7,50 (2,08)	9,25 (0,96)	4,50 (5,26)	No	Not yet decided, research data missing
NM_17	AV will create an emergency lane for emergency vehicles	2,5 (2,38)	2,75 (2,63)	6,00 (3,92)	6,75 (3,95)	No	Might be covered by other messages such as turn signals and vehicle manoeuvre.

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Identifier	Category of information	Increase of trust	Increase of acceptance	Optimisation of traffic flow	Increase of safety	Required by law	Comments
Environmental perception							
EP_1	AV has detected on other TP	9,5 (1,00)	8,5 (1,91)	5,25 (3,30)	4,25 (0,96)	No	Important from what we know from WP 2 results
EP_2	AV has detected more than one other TP	8 (4,00)	7 (3,83)	5 (3,56)	4 (1,41)	No	Not yet decided, research data missing
EP_3	AV has not detected other TP	1,5 (1,29)	2,25 (2,63)	0,75 (0,96)	5 (4,67)	No	Not needed, would be difficult to communicate explicitly
Cooperation capabilities							
CC_1	AV gives right of way	7,00 (2,45)	8,50 (1,00)	9,25 (1,50)	6,00 (4,32)	No	Important from what we know from WP 2 results
CC_2	AV informs it will not give right of way	2,00 (1,63)	2,25 (2,06)	3,00 (4,76)	4,25 (4,35)	No	Not yet decided, research data missing; message NM9 could be used instead
CC_3	AV commands that other TP should wait	2,67 (3,06)	4,33 (2,08)	5,00 (3,00)	4,00 (5,29)	No	Not needed, would be difficult to communicate explicitly
CC_4	AV commands that other TP should go	6,00 (1,41)	6,50 (3,11)	8,75 (2,50)	4,75 (3,40)	No	Not taken into account due to liability/legal issues
CC_5	AV will wait for someone	4,00 (2,65)	5,00 (3,61)	5,67 (4,51)	2,33 (3,21)	No	Similar to CC_1
CC_6	AV is able to cooperate / AV needs to negotiate	3,67 (5,51)	3,67 (5,51)	2,33 (3,21)	1,00 (1,00)	No	Not yet decided, research data missing
CC_7	AV informs that it will shortly re-take right of way	4,00 (1,41)	3,75 (1,50)	7,25 (2,22)	8,25 (2,36)	No	Similar to NM 9

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Identifier	Category of information	Increase of trust	Increase of acceptance	Optimisation of traffic flow	Increase of safety	Required by law	Comments
Other messages of lower priority							
CC_9	AV says "thank you"	5,00 (3,56)	8,75 (1,50)	0,50 (0,58)	0,50 (0,58)	No	Used in human-human communication, no research data for AVs
CC_10	AV indicates "irritation"	2,50 (2,08)	2,50 (2,08)	4,50 (4,80)	2,25 (3,86)	No	Used in human-human communication, no research data
CC_11	AV has technical problems	3,50 (4,12)	4,25 (2,87)	3,50 (3,70)	5,75 (3,86)	Yes, warning lights	Existing warning lights could be used
CC_12	AV makes a safe stop/emergency stop	5,75 (4,35)	7,75 (2,63)	5,75 (4,35)	9,00 (1,15)	No	Existing warning lights could be used
CC_13	AV informs about dangerous situations	3,25 (2,22)	4,25 (3,30)	3,50 (2,38)	6,00 (4,90)	No	Not in the focus of interACT

In a third stage, the partners then came together for a two-day design workshop in Munich and a follow-up workshop in Braunschweig (Figure 7 & Figure 8). Here we discussed the ratings and decided which messages should stay in the catalogue of potential messages sent by the AV. The comments in

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Table **3** give some insight in why a message was selected or deleted. In interACT we decided not to go for explicit advice-based messages such as "go first" for other traffic participants due to liability and legal issues, as well as potentially negative effects an advice could have on traffic safety (e.g. inattentive behaviour of pedestrians to other traffic participants).

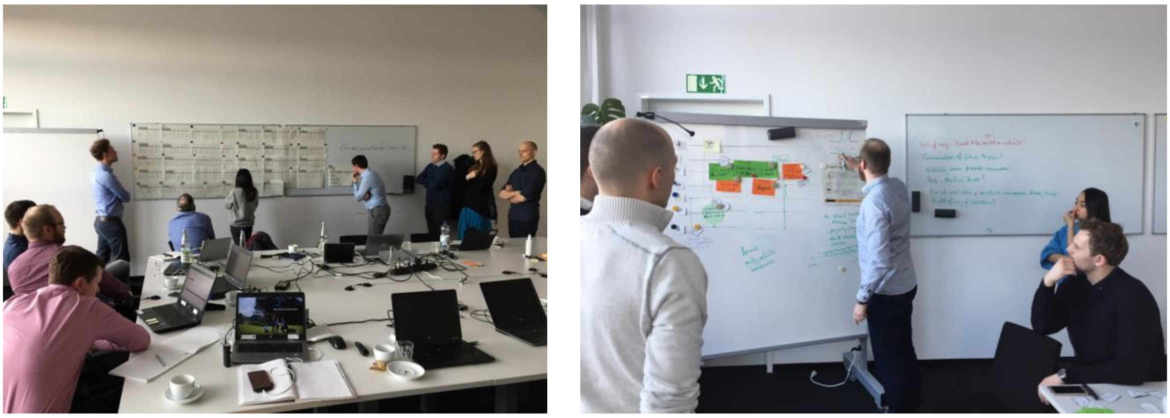

Figure 7: Design workshop in Munich

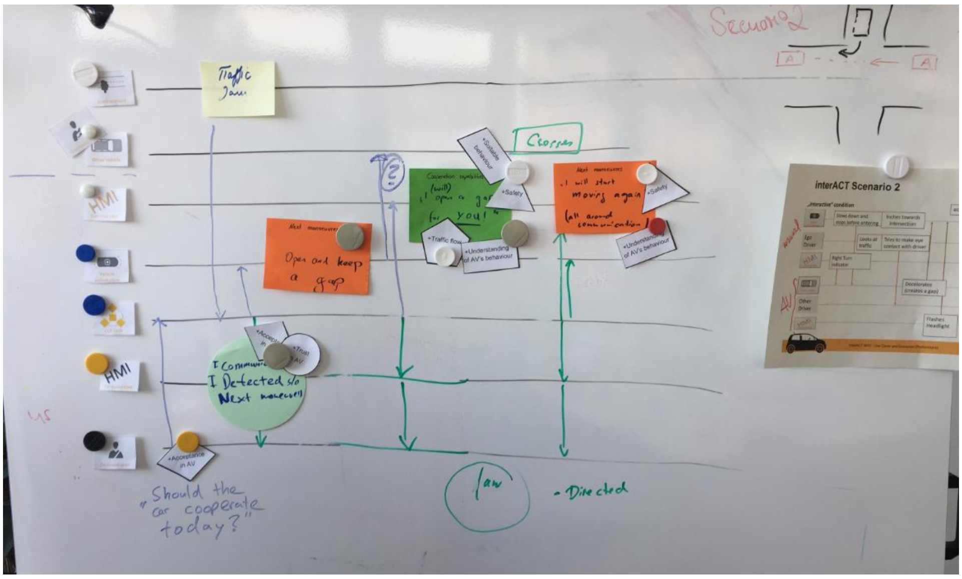

Figure 8: Sketch of sequence diagram from the design workshop in Munich

As an outcome of this process it was decided that only the following messages are going to be used within interACT for the selected scenarios (see table 4). For future, more complex scenarios we might need to include other messages in addition. These messages will be documented in D4.2 on final interaction strategies.

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Table 4: Selected interaction messages in interACT for preliminary interaction strategies

	Vehicle driving mode
VDM_1	AV drives in automated mode
-	Temporal indication (e.g. searching for parking slot)
	Next manoeuvre
NM_13 & NM_14	AV will turn
NM_4 & NM_5	AV turns
NM_9	AV will start moving
-	AV starts moving
	Environmental perception
EP_1 & EP_2	AV has detected (one or more) other/specific TP
	Cooperation Capability
CC_1	AV gives right of way
	Other messages of lower priority
CC_9	AV says "thank you"
CC_10	AV indicates “irritation”
CC_11	AV has technical problems

3.3 Documentation of results

In the workshops in Munich and Braunschweig and in several conference calls, the interaction strategies were discussed for the four must-have scenarios. For this, we took the selected messages into account and designed the potential message flows for each of the scenarios. Message for the other TPs as well as messages for the driver on board were take into account. The results of these discussions were depicted in form of sequence diagrams. The sequence diagrams help us to document a flow of messages in a timely based manner and document the information that is exchanges between involved agents and technical components. The sequence diagrams can be read as follows:

- All relevant entities are presented on the left side of the sequence diagram. The time elapse from left to right and the flow of information is illustrated by arrows from the source of information to the receiver of the information.
- A short description of the information is placed next to the arrow.
- The used sequence diagrams include boxes with different colours. The blue boxes present messages on vehicle manoeuvres, green boxes presents messages on the cooperation capabilities of the AV; red boxes stand for messages on the perception of the environment of the AV while the orange boxes are used for displaying the next manoeuvres planed by the AV.

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Finally, the yellow boxes represent the decisions of the CCPU regarding the AV behaviour (**Figure 9** gives an example).

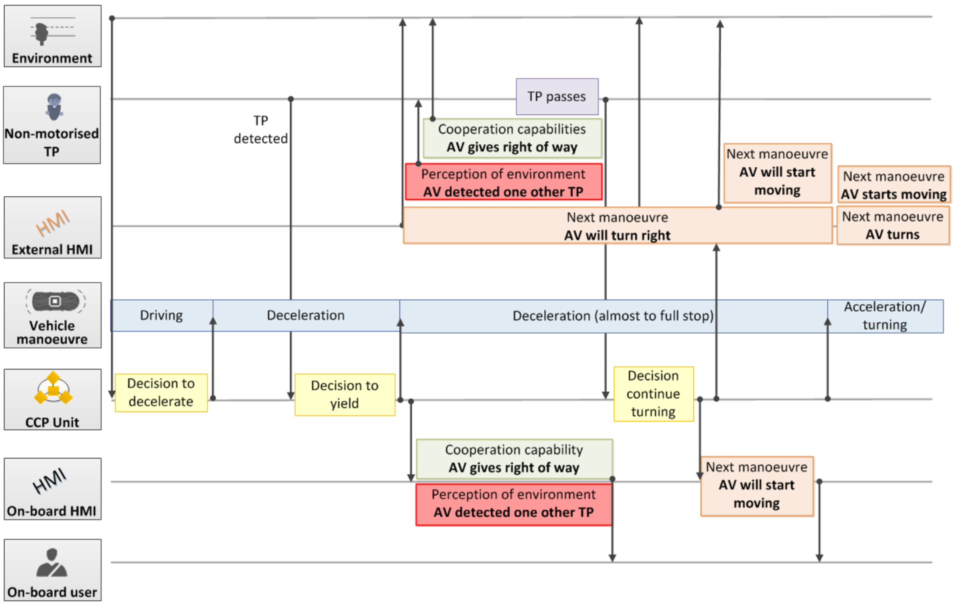

Figure 9: Example of a sequence diagram for a scenario of use case 1

For each scenario three design variants were selected in the iterative design process. These are documented in section 4. The current sequence diagrams do not cotain any information on how the messages will be transferred, that means no information on specific HMI and eHMI design is given. This design work is part of Task 4.2 and will be documented in D 4.3.

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4. Preliminary interaction strategies per scenario

4.1 Variants of interaction strategies defined for interACT

In the design work for WP4 we came up with different "What" messages that can be communicated by the AV (see section 3.2.2). We used these messages to develop three interaction strategies that are described in this section. The interaction strategies are using explicit as well as implicit communication of the AV with other traffic participants and the user on board. However, for the classification of the interaction strategies only the differences in the explicit communication of the AV were taken into account.

The following preliminary interaction strategies were developed:

- **Perception-signalling design**: For this design variant we developed a design that is mainly characterized by giving explicit information to other traffic participants that they were detected by the AV. This is meant to replace information that is normally exchanged by interpreting eye contact or head rotation in human-human communication. The information about the perception of the environment is also given to the user on board.
- **Intention-signalling design**: In this design variant we developed a design that mainly gives explicit information to other traffic participants and the on-board user about the current vehicle manoeuvres, about future manoeuvres of the AV and/or the cooperation capability of the AV to show the intentions of the AV. This design variant is very much related to the movement-signalling behaviour that was described in WP 2 results.
- **Combination of perception-signalling and intention-signalling design:** In this design variant we combine both interaction strategies from above. This means that the AV explicitly communicates that TPs were detected and in addition the intentions of the AV.

While the perception-signalling design should work with addressed messages, the intention-signalling design can work with addressed as well as non-addressed messages.

Over the course of the WP 4 duration these strategies will be tested and compared in user studies to know more about which strategy works best in which scenarios. Based on the outcomes of the studies the most appropriate strategies will be selected and further refined for application in the interACT demonstrator vehicles. In addition, these strategies will be enhanced for other more complex traffic scenarios. The results of this work will be documented in D 4.2.

4.2 Description of interaction strategies per scenario

In the following each of the interaction strategies is applied to one scenario per selected use-case. For the detailed description of the interaction strategies the scenario template, introduced in D1.1, are used (see D1.1. for further details).

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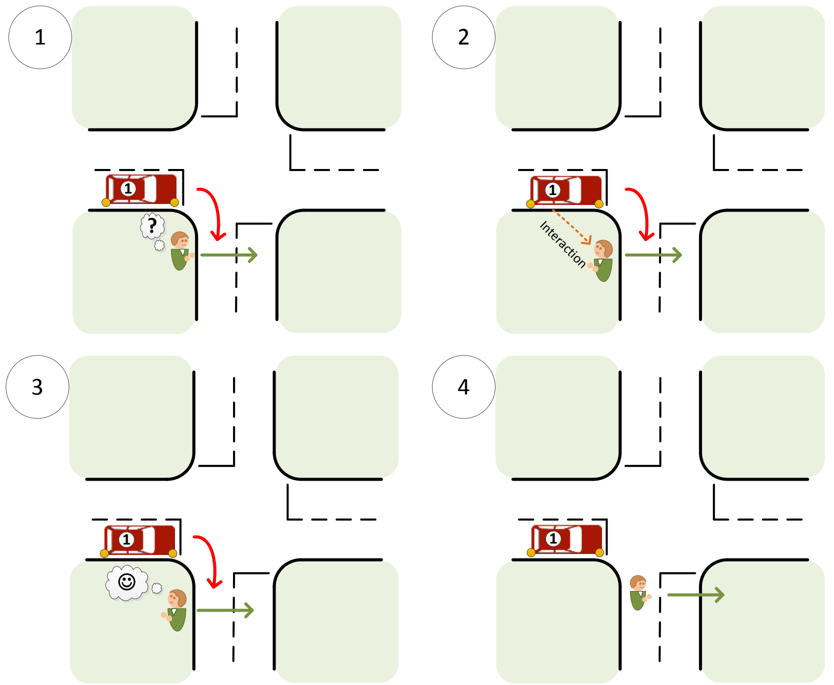
4.2.1 Interaction strategies for scenario 1

Scenario	React to a single pedestrian crossing at a distance from 3m-10m from right to left at a crossing without traffic lights	
Related Use case	React to crossing non-motorised TP at crossings without traffic lights	
Use case Priority	☒ Must ☐ Optional	
Use case Environment	☒ Intersection ☐ Parking space	
Graphical representation		
Verbal description	The AV is approaching an intersection, intending to turn right. It detects a pedestrian who wants to cross the street. The AV decides to yield for the pedestrian. The AV signalise its perception of environment and/or intention and waits for the pedestrian to cross. The pedestrian crosses and the AV continues turning.	
Traffic & Environment	Right of way	☐ AV ☒ other TP ☐ Undefined
	Longitudinal distance (headway)	☒ < 3m ☐ 3-10m ☐ > 10m

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	Lateral distance	☐ 0m ☒ ≤ 3m ☐ > 3m
	Speed AV	☐ 0 km/h – 5 km/h ☒ 5km/h - 30 km/h ☐ 30km/h- 50 km/h
	Speed other TP	☒ 0 km/h (standstill) and ☒ 5 km/h (Ø Pedestrian) ☐ 17.5 km/h (Ø Bicyclist) ☐ 30 km/h ☐ 50 km/h
	Time of day	☒ Day ☐ Night
	Lighting conditions	☒ Photopic (daylight) ☐ Mesopic (twilight) ☐ Scotopic (night)
AV related attributes	Driving direction AV	☒ Driving forward ☐ Reverse
	Perspective (from the perspective of the AV)	☒ Ahead ☒ Sideways / Diagonal ☐ Backward
	AV's intention regarding right of way	☒ Let other TP go first ☐ Go first
	Attention of on-board user	☒ Yes, attentive ☐ No, distracted ☐ No on-board user inside
TP related attributes	Interaction partner (other TP character)	☐ Driver of other vehicles ☐ Cyclist ☒ Pedestrian
	Number of traffic participants	_1_ AV _1_ Non-motorised TP _0_ Vehicles

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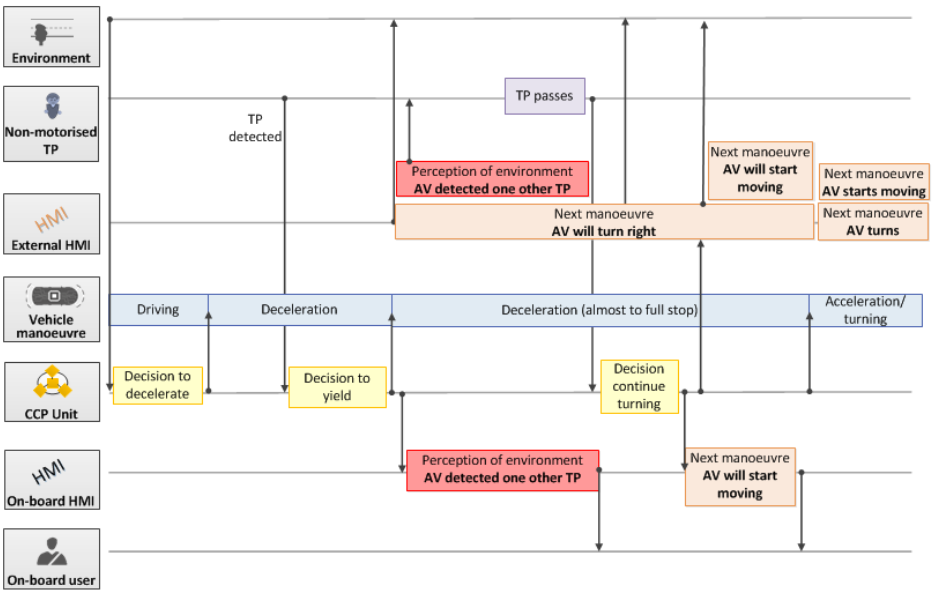
<table>
<tr><td></td><td>Other TP’s intention regarding right of way</td><td>☐ Let AV go first
☒ Go first</td></tr>
<tr><td></td><td>Age of HRU</td><td>☒ Not in focus
☐ 3-17 years
☐ 18-60 years
☐ > 61 years</td></tr>
<tr><td></td><td>Impairment of the HRU’s perception</td><td>☒ No impairment
☐ View
☐ Acoustic
☐ Both (view and acoustic)</td></tr>
<tr><td></td><td>Attention other TP</td><td>☒ Yes
☐ No</td></tr>
<tr><td>Sequence diagram</td><td colspan="2">Variant 1: Perception-signalling design



The sequence diagram of variant 1 describes AV’s main manoeuvres in chronological sequence (blue boxes). Firstly, AV decelerates due to traffic. After the detection of the traffic participant who wants to cross the road the AV decides to yield for the pedestrian. The AV slows down further to almost a full stop. In parallel, the AV indicates to turn right and indicates that it detected one other traffic participant via external HMI (red box). Further, the on-board user is informed that the AV has detected an other traffic participant to interact with. After the traffic participant has crossed the road, the AV decides to</td></tr>
</table>

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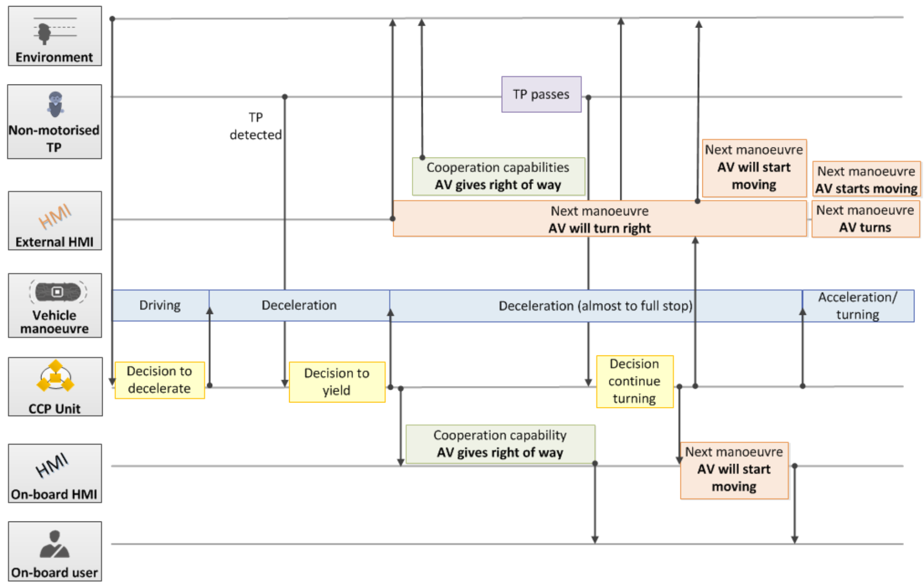
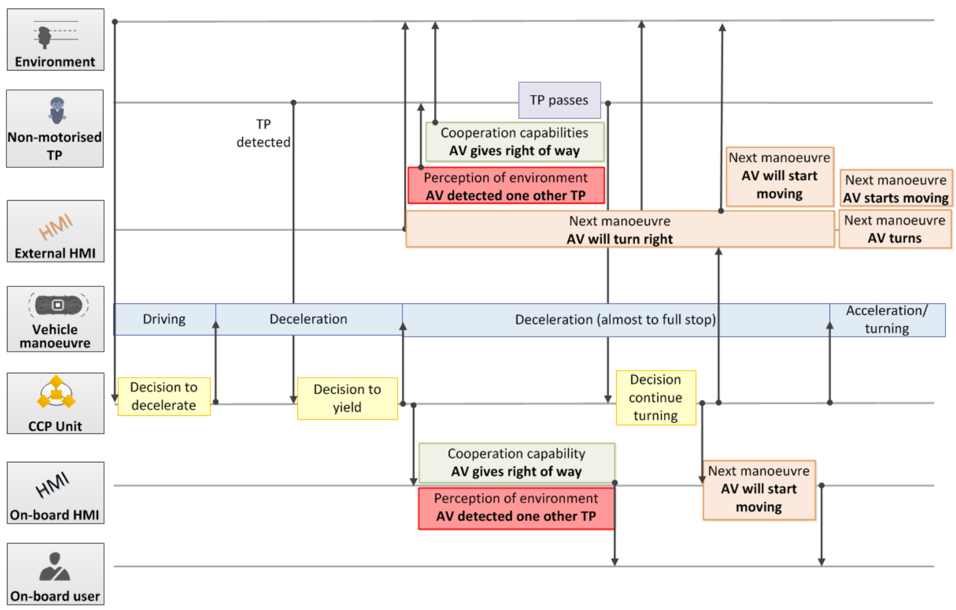
continue turning. Again, other TPs and the on-board user are informed about the next manoeuvre of the AV (turning and start moving).

Variant 2: Intention-signalling design



Variant 2 describes the same scenario but focusses on indicating the AV's cooperation capability. The main difference to variant 1 is that the AV indicates to give right of way to the other traffic participant via external HMI (green box). There is no information regarding the detection of the other traffic participant.

Variant 3: Combination of Perception-signalling and Intention-signalling design



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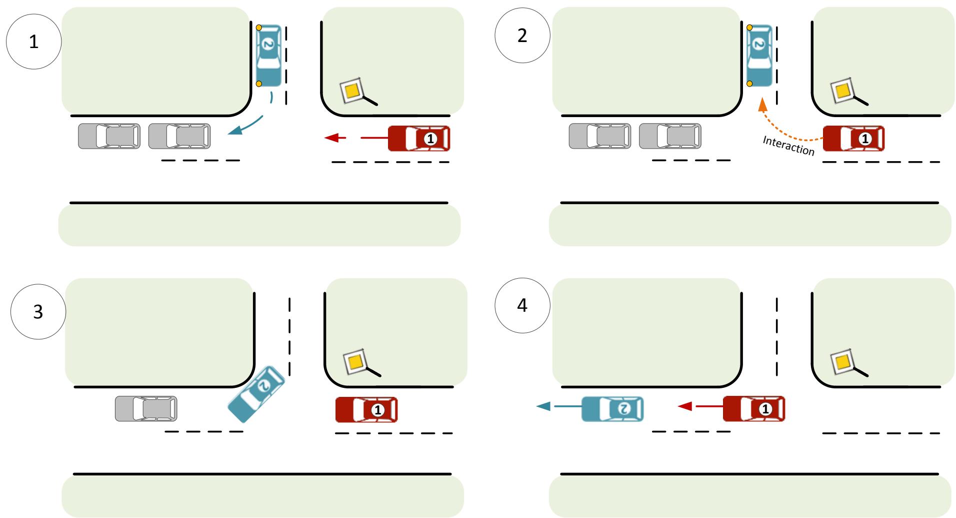
	Variant 3 describes the same scenario including the AV's cooperation capability and the perception of environment. This is a combination of the message that the AV has detected one other traffic participant the message that the AV gives right of way.

4.2.2 Interaction strategies for scenario 2

Scenario	Open a gap for a motorized vehicle at a T-intersection	
Related Use case	React to an ambiguous situation at an unsignalised intersection	
Use case Priority	☒ Must	☐ Optional
Use case Environment	☒ Intersection	☐ Parking space
Graphical representation		
Verbal description	The AV (red) is approaching an intersection, intending to go straight. A traffic jam forces the AV to decelerate. Further, the AV detects another motorised traffic participant (blue) who wants to merge into the main road. The AV is deciding to open a gap for the TP.	
Traffic & Environment	Right of way	☒ AV ☐ other TP ☐ Undefined
	Longitudinal distance (headway)	☐ < 3m ☒ 3-10m ☐ > 10m
	Lateral distance	☐ 0m

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		☒ ≤ 3m ☐ > 3m
	Speed AV	☐ 0 km/h – 5 km/h ☒ 5km/h - 30 km/h ☐ 30km/h- 50 km/h
	Speed other TP	☒ 0 km/h (standstill) ☐ 5 km/h (Ø Pedestrian) ☐ 17.5 km/h (Ø Bicyclist) ☐ 30 km/h ☐ 50 km/h
	Time of day	☒ Day ☐ Night
	Lighting conditions	☒ Photopic (daylight) ☐ Mesopic (twilight) ☐ Scotopic (night)
AV related attributes	Driving direction AV	☒ Driving forward ☐ Reverse
	Perspective (from the perspective of the AV)	☒ Ahead ☒ Sideways / Diagonal ☐ Backward
	AV's intention regarding right of way	☒ Let other TP go first ☐ Go first
	Attention of on-board user	☒ Yes, attentive ☐ No, distracted ☐ No on-board user inside
TP related attributes	Interaction partner (other TP character)	☒ Driver of other vehicles ☐ Cyclist ☐ Pedestrian
	Number of traffic participants	_1_ AV _0_ Non-motorised TP _1_ Vehicles
	Other TP's intention regarding right of way	☒ Let AV go first

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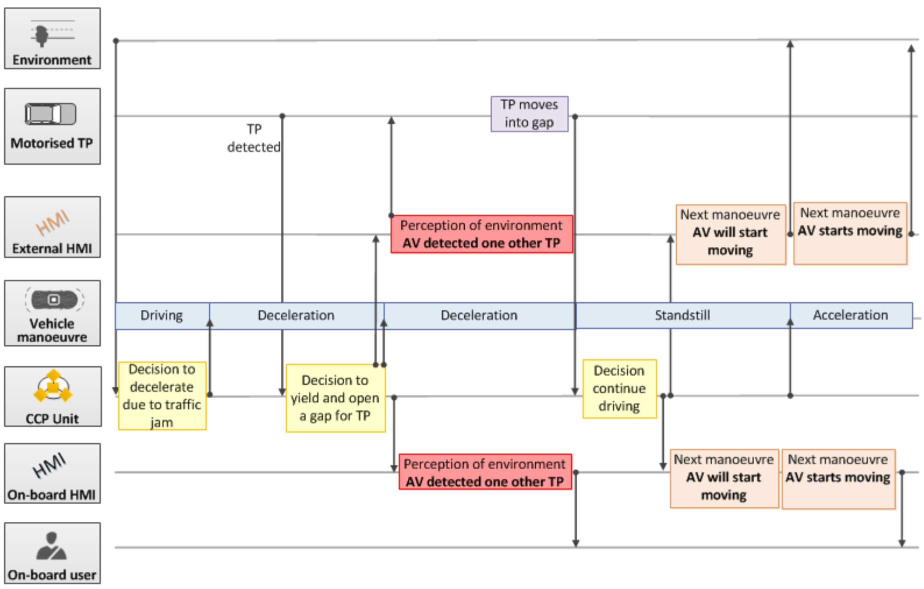
		☐ Go first
	Age of HRU	☐ Not in focus ☐ 3-17 years ☒ 18-60 years ☒ > 61 years
	Impairment of the HRU’s perception	☒ No impairment ☐ View ☐ Acoustic ☐ Both (view and acoustic)
	Attention other TP	☒ Yes ☐ No
Sequence diagram	**Variant 1: Perception-signalling design**  The sequence diagram of variant 1 describes AV’s main manoeuvres in chronological sequence (blue boxes). Firstly, AV decelerates due to traffic. After the detection of another vehicle that wants to merge, the AV decides to yield for the other traffic participant. The AV slows down to a full stop. In parallel AV shows that the other vehicle was detected by the AV via external HMI (red box). In parallel the AV informs the on-board user that it detected the other vehicle. After this, the addressed vehicle moves into the open gap. Before continue driving the AV signalises its intention to start moving.	

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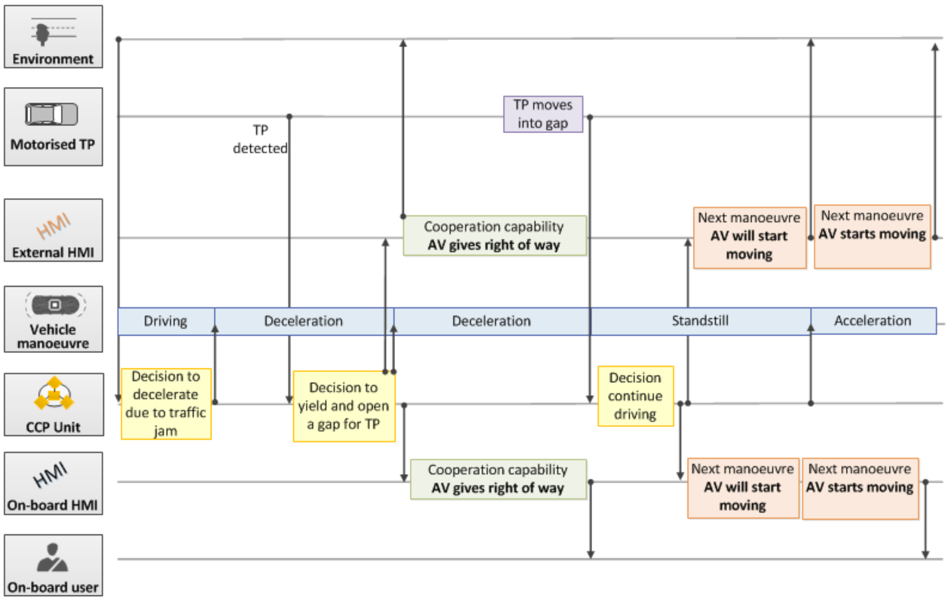
	Variant 2: Intention-signalling design  The sequence diagram of variant 2 describes AV's main manoeuvres in chronological sequence (blue boxes). Firstly, AV decelerates due to traffic. After the detection of another vehicle that wants to merge, the AV decides to yield for the other traffic participant. The AV slows down to a full stop. In parallel AV shows it's cooperation capability (green box) and demonstrates via external HMI that it will give right of way to the other road user. In parallel the AV informs the on-board user that it will give right of way. After this, the addressed vehicle moves into the open gap. Before continue driving the AV signalises its intention to start moving. While acceleration the AV displays the manoeuvre "AV starts moving".

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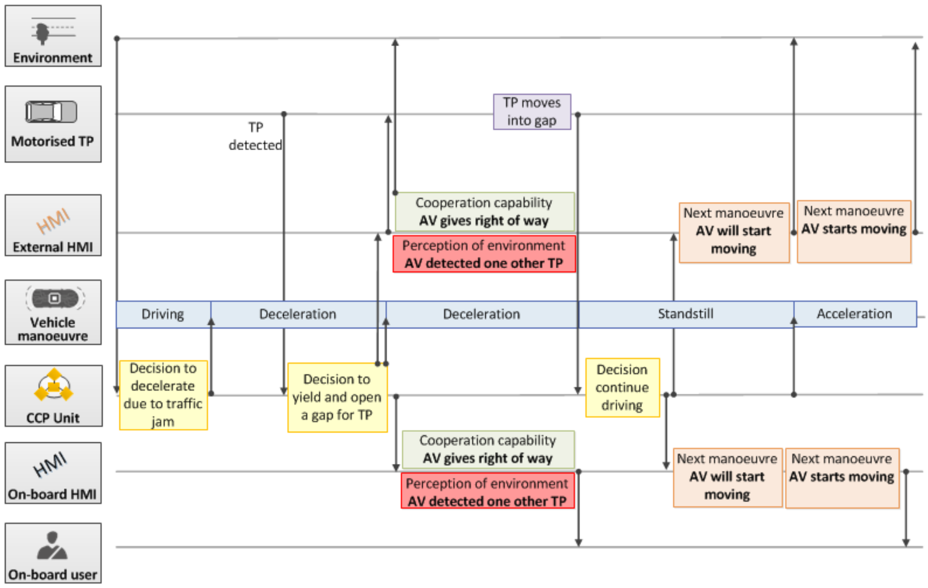
<table>
<tr><td></td><td>

Variant 3: Combination of Perception-signalling and Intention-signalling design



Variant 3 describes the same scenario including the AV's cooperation capability. Main difference here is that the AV communicates that it will give right of way and that it detects the other traffic participant via external HMI.

</td></tr>
</table>

4.2.3 Interaction strategies for scenario 3

Scenario	React to multiple non-motorised TP (two from left one from right) at a parking space	
Related Use case	React to non-motorised TP at a parking space	
Use case Priority	☒ Must	☐ Optional
Use case Environment	☐ Intersection	☒ Parking space

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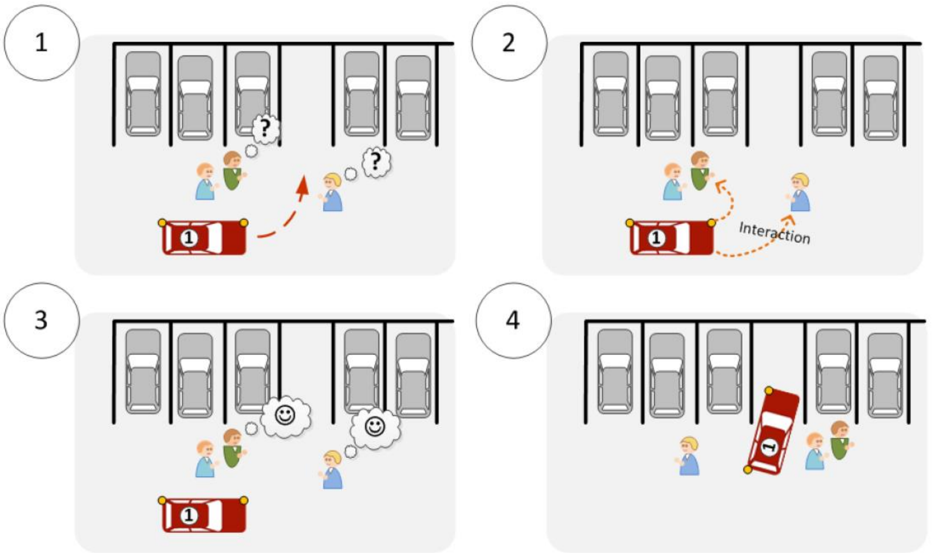
Graphical representation		
Verbal description	The AV is driving on a parking space, searching for a parking slot. The AV arrives at a free parking slot, but multiple pedestrians block the way. The AV interacts with the pedestrians to its left and right side to communicate that it will yield and wait until the pedestrians have crossed. Once the way into the parking slot is free, the AV enters the parking slot.	
Traffic & Environment	Right of way	☐ AV ☐ other TP ☒ Undefined
	Longitudinal distance (headway)	☒ < 3m ☐ 3-10m ☐ > 10m
	Lateral distance	☐ 0m ☒ ≤ 3m ☐ > 3m
	Speed AV	☒ 0 km/h – 5 km/h or up to ☒ 5km/h - 30 km/h ☐ 30km/h- 50 km/h
	Speed other TP	☐ 0 km/h (standstill) ☒ 5 km/h (Ø Pedestrian) ☐ 17.5 km/h (Ø Bicyclist) ☐ 30 km/h

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		☐ 50 km/h
	Time of day	☒ Day ☐ Night
	Lighting conditions	☒ Photopic (daylight) ☐ Mesopic (twilight) ☐ Scotopic (night)
AV related attributes	Driving direction AV	☒ Driving forward ☐ Reverse
	Perspective (from the perspective of the AV)	☒ Ahead ☒ Sideways / Diagonal ☐ Backward
	AV's intention regarding right of way	☒ Let other TP go first ☐ Go first
	Attention of on-board user	☒ Yes, attentive ☐ No, distracted ☐ No on-board user inside
TP related attributes	Interaction partner (other TP character)	☐ Driver of other vehicles ☐ Cyclist ☒ Pedestrian
	Number of traffic participants	_1_ AV _3_ Non-motorised TP _0_ Vehicles
	Other TP's intention regarding right of way	☐ Let AV go first ☒ Go first
	Age of HRU	☒ Not in focus ☐ 3-17 years ☐ 18-60 years ☐ > 61 years
	Impairment of the HRU's perception	☒ No impairment ☐ View ☐ Acoustic ☐ Both (view and acoustic)

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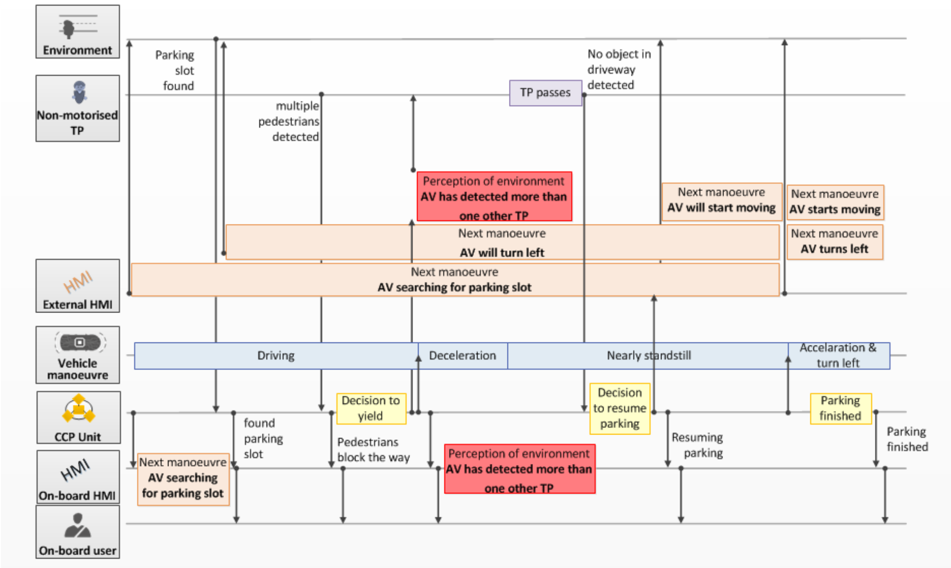
	Attention other TP	☒ Yes ☐ No
Sequence diagram	**Variant 1: Perception-signalling design**	



The Sequence diagram of variant 1 describes AV's main manoeuvres in chronological sequence (blue boxes). First the AV is driving slowly while it shows that it is searching for a parking slot via external HMI. Once the parking slot has been found, it starts communicating that it will park and will turn left to enter the detected parking space. This message is also communicated to the on-board user. While still proceeding onwards, multiple pedestrians are detected. The AV communicates via internal and external HMI the detection of these TPs (red box). Thereby, this message is directly addressed to the detected TPs. The AVs decides to yield to the pedestrians. The AV therefore starts decelerating. The AV then comes to a standstill and waits for the pedestrians to pass. Once the pedestrians have passed, the AV takes the decision to resume parking. The AV communicates via internal and external HMI to the environment that it will start moving. It then starts actually moving and parking, while still communicating the intention to park as well as the intention to turn left into the parking space until the manoeuvre is finished and the car is safely parked. Finally the on-board user is informed about the finished parking manoeuvre.

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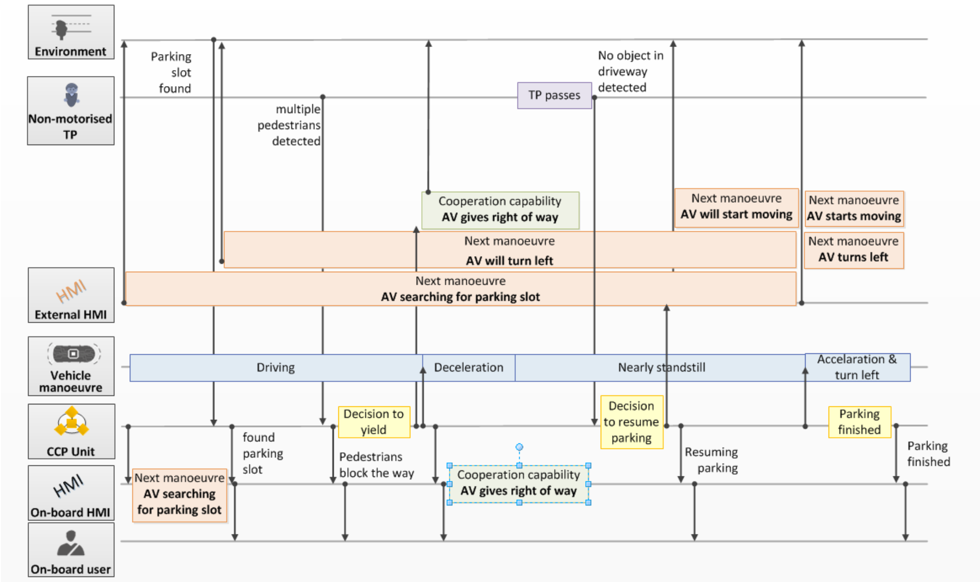
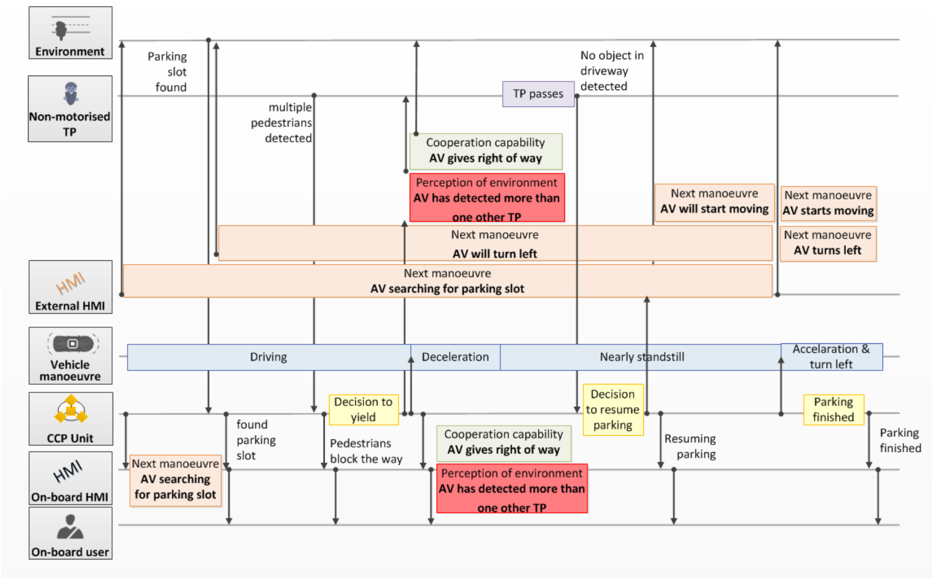
Variant 2: Intention-signalling design



In variant 2 the driving characteristics are identical to variant 1. The main difference to variant 1 is that AV signalises that it gives right of way to the environment via external HMI (green box). Further the AV is not signalising that it has detected other TP via external HMI.

Variant 3: Combination of Perception-signalling and Intention-signalling design



In variant 3 the driving characteristics are identical to variant 1. The main difference to variant 1 is that the AV signalises that it has detected the pedestrians and gives right of way via external HMI.

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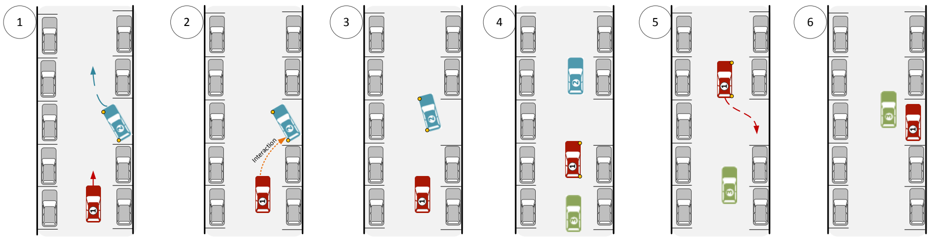
4.2.4 Interaction strategies for scenario 4

Scenario	React to a vehicle while reverse parking in a parallel parking slot	
Related Use case	React to other vehicles in parking situations	
Use case Priority	☒ Must ☐ Optional	
Use case Environment	☐ Intersection ☒ Parking space ☐ On the road	
Graphical representation		
Verbal description	The AV drives on the parking space while searching for a parking slot. The AV approaches a vehicle which wants to leave a parking spot. The parking spot is in parallel to the driving direction and the other vehicle needs some space to successfully move out. The AV communicates that it will wait for the vehicle to move out and keep a gap. The other vehicle moves out and continues driving. After that the AV parks into to the free parking slot.	
Traffic & Environment	Right of way	☒ AV ☐ other TP ☐ Undefined
	Longitudinal distance (headway)	☐ < 3m ☒ 3-10m ☐ > 10m
	Lateral distance	☐ 0m ☐ ≤ 3m ☒ > 3m
	Speed AV	☐ 0 km/h – 5 km/h ☒ 5km/h - 30 km/h ☐ 30km/h- 50 km/h

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	Speed other TP	☐ 0 km/h (standstill) ☐ 5 km/h (Ø Pedestrian) ☐ 17.5 km/h (Ø Bicyclist) ☒ 30 km/h ☐ 50 km/h
	Time of day	☒ Day ☐ Night
	Lighting conditions	☒ Photopic (daylight) ☐ Mesopic (twilight) ☐ Scotopic (night)
AV related attributes	Driving direction AV	☒ Driving forward ☐ Reverse
	Perspective (from the perspective of the AV)	☒ Ahead ☒ Sideways / Diagonal ☐ Backward
	AV's intention regarding right of way	☒ Let other TP go first ☐ Go first
	Attention of on-board user	☒ Yes, attentive ☐ No, distracted ☐ No on-board user inside
TP related attributes	Interaction partner (other TP character)	☒ Driver of other vehicles ☐ Cyclist ☐ Pedestrian
	Number of traffic participants	_1_ AV _0_ Non-motorised TP _1_ Vehicles
	Other TP's intention regarding right of way	☒ Let AV go first ☐ Go first

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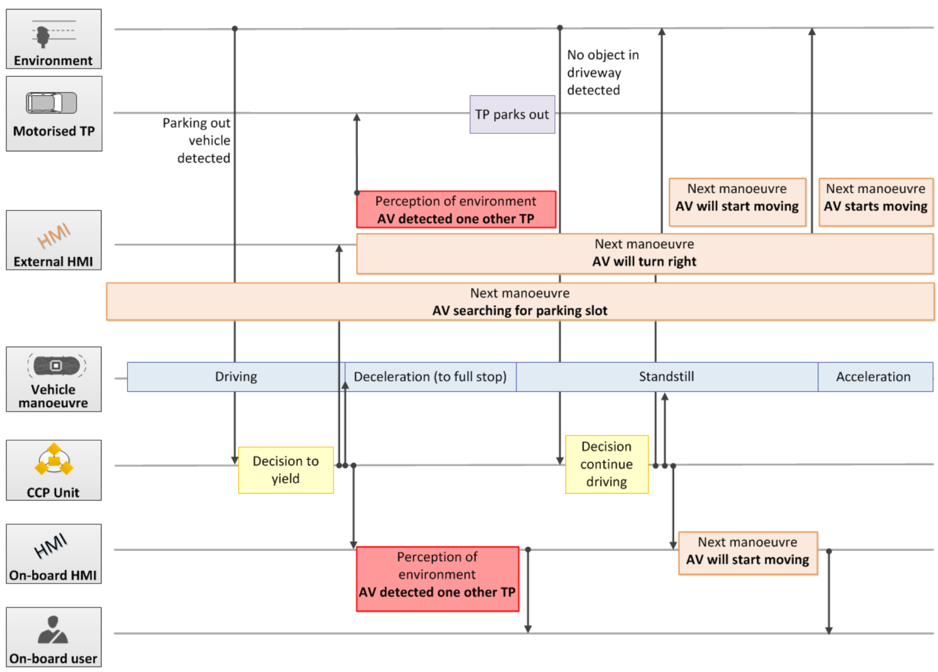
<table>
<tr><td></td><td>Age of TP</td><td>☒ Not in focus
☐ 3-17 years
☐ 18-60 years
☐ > 61 years</td></tr>
<tr><td></td><td>Impairment of the TP’s perception</td><td>☒ No impairment
☐ View
☐ Acoustic
☐ Both (view and acoustic)</td></tr>
<tr><td></td><td>Attention other TP</td><td>☒ Yes
☐ No</td></tr>
<tr><td>Sequence diagram</td><td colspan="2">Variant 1: Perception-signalling design



The sequence diagram of variant 1 describes AV’s main manoeuvres in chronological sequence (blue boxes). First the AV is driving slowly on a parking space. The AV approaches another vehicle which wants to park out of a parking slot. The AV slows down to a full stop. In parallel the AV shows that the other vehicle was detected via external HMI (red box). In parallel the AV informs the on-board user that it detected the other vehicle. The AV then comes to a standstill and waits for the other vehicle to park out. Once the other vehicle has</td></tr>
</table>

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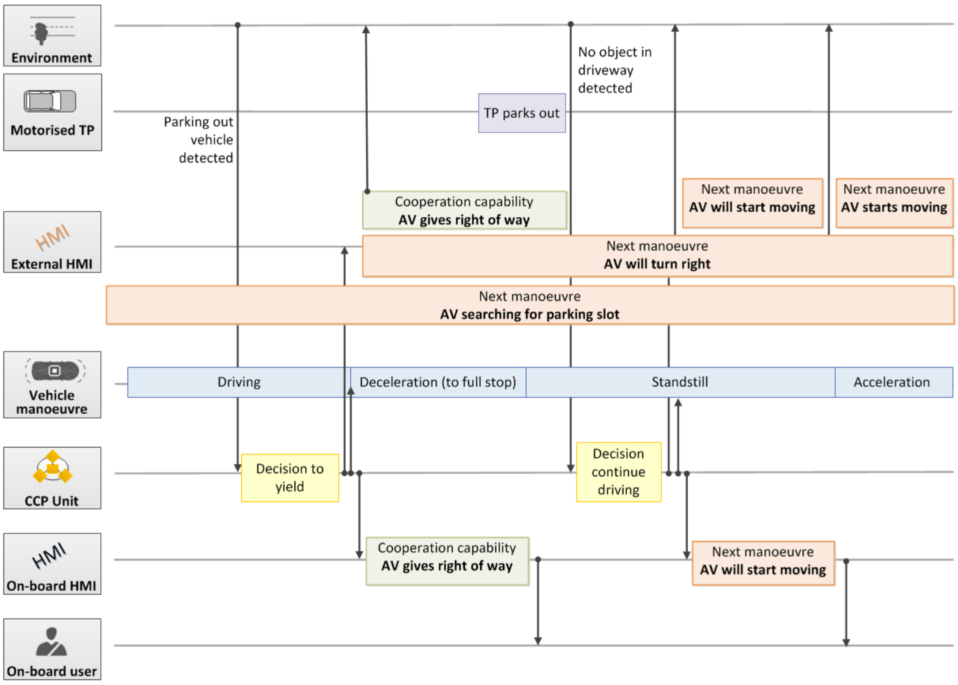
successful parked out the AV continoues driving.

Variant 2: Intention-signalling design



In variant 2 the driving characteristics are identical to variant 1. The main difference to variant 1 is that AV signalises that it gives right of way to the environment via external HMI (green box). Further the AV is not signalising that it has detected the other vehicle via external HMI.

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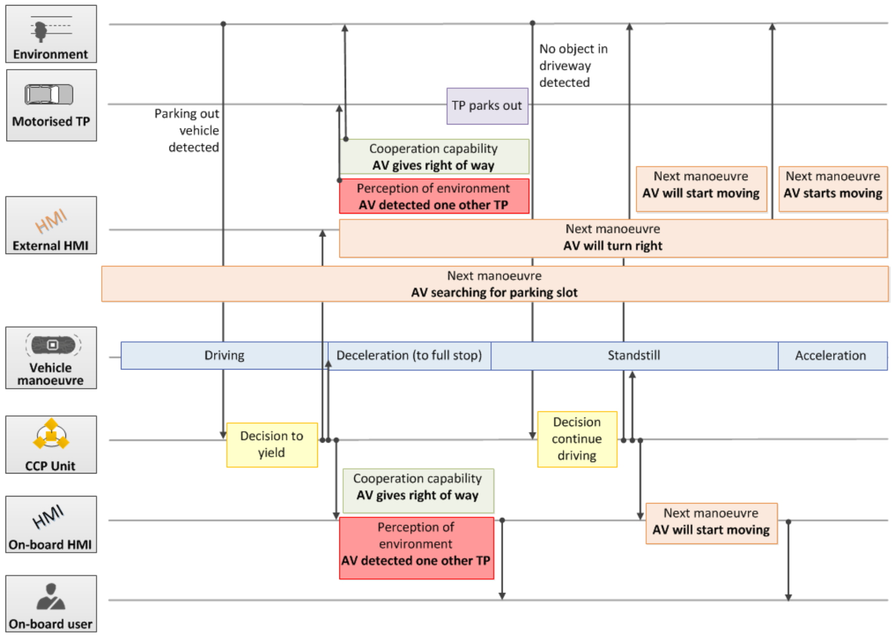
Variant 3: Combination of Perception-signalling and Intention-signalling design



In variant 3 the driving characteristics are identical to variant 1. The main difference to 1 is that AV signalises that it has detected the other vehicle and that it gives right of way via external HMI.

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5. Summary and outlook

The aim of this deliverable was to provide insight into the design process of WP 4 and document the preliminary interaction strategies for the interACT must-have scenarios.

Initially, we presented the objectives of the WP that are to define the “what” messages (task 4.1), to design “how” these messages are transferred (task 4.2) and to specify and built the needed HMI components as prototypes (task 4.3). Secondly, we gave an overview on the design process including the presentation of the used design framework, the potential messages for explicit communication and a first rating of those as well as the used sequence diagrams as documentation format. Finally, as the core of this deliverable we documented the preliminary interaction strategies defined for the four interACT must-have use cases in sequence diagrams. These strategies contain the information what should be communicated to other traffic participants and the user on board. We came up with three different design variants; these are the perception-signalling design, the intention-signalling design and a combination of those two.

As one of the next steps the interact strategies and their representation in HMI will be tested with users to find out which variant of the interaction strategies is most suitable and check for potential advantages/disadvantages of the variants in different scenarios and for different user groups. Based on the results of these user studies the interaction strategies will be further improved and refined. Further, we are including other and more complex scenarios into the design work and transfer the interaction strategies on a more abstract level to make them applicable to a larger number of scenarios. The result of this work will be documented in Deliverable 4.2 on final interaction strategies.

Based on the interaction strategies described in this deliverable, we are working on the specific HMI design to transfer the information (“how should the information be transferred”, see task 4.2.). This task includes explicit eHMI design for other TPs, HMI design for the on-board user as well as implicit manoeuvre based design. There are several options on how transfer information on eHMI components such as visual signals, light patterns, auditory signals etc. This is why we analyse the advantages and disadvantages of technological solutions in a next step and decide on which technologies are most promising for the interACT project. This work will be documented in D 4.3.

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Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments