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

interACT D.4.2. Final interaction strategies for the interACT Automated Vehicles

Work package	WP4: Suitable HMI for successful human-vehicle interaction
Tasks	Task 4.1: Development of generic human-vehicle interaction strategies Task 4.2: Development of specific design solutions for the interaction with other TPs and the on-board user
Authors	**Florian Weber (BMW)**, Lenja Sorokin (BMW), Elisabeth Schmidt (BMW), Anna Schieben (DLR), Marc Wilbrink (DLR), Carmen Kettwich (DLR), Janki Dodiya (DLR), Michael Oehl (DLR), Marc Kaup (HELLA), Jan-Henning Willrodt (HELLA), Yee Mun Lee (ITS Leeds), Ruth Madigan (ITS Leeds), Gustav Markkula (ITS Leeds), Richard Romano (ITS Leeds), Natasha Merat (ITS Leeds)
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Table of contents

This report is part of interACT project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 723395.

This report is part of interACT project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 723395.

This report is part of interACT project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 723395.

Index of figures

This report is part of interACT project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 723395.

Index of tables

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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
eHMI/external HMI	External Human-Machine-Interface of the AV that is designed to communicate with surrounding traffic participants
iHMI/internal HMI	Internal Human-Machine-Interface of the AV that is designed to communicate with the user on-board
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
CLEPA	European Association of Automotive Suppliers
D	Deliverable
eHMI	External Human-Machine-Interface
iHMI	Internal Human-Machine-Interface
ISO	International Organization for Standardization
GRVA	Group on Automated/Autonomous and Connected Vehicles
GTB	Groupe de Travail Bruxelles 1952
HMI	Human-Machine-Interface
HRU	Human road user
LED	Light-emitting-diode
NGO	Non-governmental organisation
OEM	Original Equipment Manufacturer
OICA	Organisation Internationale des Constructeurs d'Automobiles
SAE	Society of Automotive Engineers
TP	Traffic participant
UNECE WP.x	Working Parties under United Nations Economic Commission for Europe. "x" stands for each party's number representatively.
VAS	Vehicle automation status
WP	Work package

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Executive summary

The interACT project aims to enable the safe deployment of automated vehicles (AVs) by developing novel software and hardware components for reliable communication between an AV, its on-board driver, and other road users. The project will place a particular focus on the design of innovative Human Machine Interfaces (HMIs) to replace current human-human communications in mixed traffic environments. It is expected that reaching the project's goals will facilitate the gradual integration of AVs in future transport networks.

Task 4.2 of Work Package (WP) 4 centred on the design of interaction strategies for AVs, which will be implemented into the interACT demonstrator vehicles being developed as part of WP5 of the project. Driving strategies for AVs were assessed and design principles were defined, guiding the design process. Suitable technologies for the development of external HMI (eHMI) solutions were assessed. Based on this assessment, the WP4 partners developed concrete HMI solutions, which were evaluated in simulator- and virtual reality- based user studies, and further refined. A main eHMI design was developed, consisting of an LED light-band wrapped around the body of the vehicle. This light-band communicated the intentions of the AV (such as giving way or starting to move). Two secondary eHMI solutions were also developed. A variant of the light-band, where specific segments were illuminated, was used to communicate the perception of another traffic participant; and a combination of a single lamp and the light-band were used to communicate both AV intention and perception at the same time. To improve trust and acceptance of the AV for the on-board user, internal HMI solutions (iHMI) were also developed and evaluated in simulator-based user studies. Following the external HMI approach a LED light-band was installed in the interior of the AV and tested also for the iHMI interaction with the on-board user against a state of the art textual head-down display. Participants preferred the communication via the LED light-band and rated the interaction strategy containing information regarding detected traffic participants higher compared to information regarding the intention of the AV.

This deliverable documents the process and results of the work conducted in WP 4 and serves as a basis for the technical development of the HMI solutions, which will be outlined in WP 4.3, as well as the implementation of the demonstration vehicles in WP 5.

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1. Introduction

1.1 Purpose and scope

One of the major challenges associated with the introduction of automated vehicles (AVs) into mixed traffic, is how to design appropriate interaction strategies for these vehicles. As human–human interaction is very complex, it is crucial to define which messages have to be exchanged in AV interactions and how to communicate these through both on-board / interior human machine interface (iHMI) and external human machine interface (eHMI) solutions. This deliverable gives an overview of the results that have been achieved in WP 4 of the interACT project since the last deliverable D 4.1 (Wilbrink et al., 2018). Task 4.2 deals mainly with the design and selection of concrete iHMI and eHMI solutions, and the selection of the appropriate technology to transmit chosen messages in an adequate way. For the iHMI design the main objective of the work was to keep the user on board adequately informed of AV interactions with surrounding traffic participants, in order to increase their trust level in all situations in which there is no need for intervention by the user. For other traffic participants the main objective was to come up with design solutions, including eHMI and vehicle movements that facilitate expectation-conforming and safe interactions with AVs. Interactions in today's traffic occur primarily through visual and acoustic modalities, and explicit communication through light based eHMI elements (such as turn indicators or brake lights) is common. Therefore, through several expert workshops, we chose to focus primarily on the design of a light based eHMI solution to communicate the "what"-messages developed in Task 4.1 of WP 4. Starting with a preliminary eHMI and iHMI design, we proceeded using an iterative approach consisting of several user studies to develop a final design. The design is described in this deliverable, and serves as a basis for the development of the iHMI and eHMI elements in Task 4.3.

1.2 Intended readership

This deliverable gives an insight into the design work of WP 4 and reports the results for the concrete HMI design of Task 4.2 based on the generic human-vehicle interaction strategies reported in Deliverable 4.1 (Wilbrink et al., 2018). Therefore, this document serves primarily as an input for all interACT partners from WP 2, 3 and 5, presenting relevant information on the concrete interaction design (iHMI, eHMI and vehicle movements) for the use-cases defined in D1.1 . It also serves as a documentation of the on-going work in WP 4 for our Project Officer, the reviewers and the European Commission.

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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 the 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 also influence the work of WP 4.

In addition, the work of WP 2 on psychological models of human-human interaction had a significant influence on the work done in WP 4. Insights from the observation studies were taken into account to understand which communication messages are relevant and how those can be designed. This deliverable continues the work described in D4.1 "Preliminary human vehicle interaction strategies" by adding concrete HMI (eHMI and iHMI) designs to the relevant use-cases, reviewing and evaluating technologies suitable for supporting the human vehicle interaction strategies, and reporting design choices.

All results presented in this deliverable will directly influence the future work of WP 4 and the related deliverable D4.3 "Final 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 deal with the integration of different components including HMI for the interACT test vehicles.

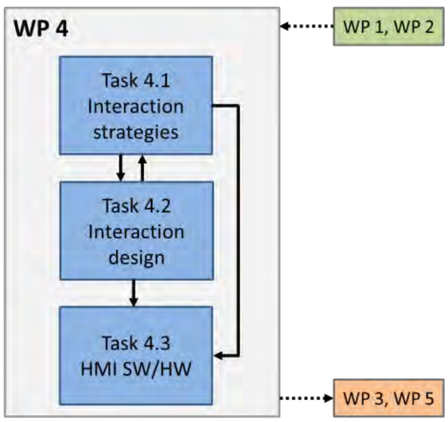

Figure 1: Connection of WP 4 to other work packages

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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 (Human on-board of the AV who acts as a driver or passenger), as well as that between the AV and other traffic participants, such as pedestrians and drivers of other vehicles. As shown in Figure 2 the interaction strategies are meant to support the AV in interacting safely and efficiently with the on-board user and other traffic participants, as current human-human interactions (see interACT D2.1 (Dietrich et al., 2018)) for a detailed analysis) will play less of a central role in the future, when AVs are present in traffic.

Figure 2: Automated vehicles in mixed traffic environments

In more detail, the objectives of this WP are summarized in Deliverable 4.1 of this WP. These objectives are to:

- Develop generic interaction strategies and general HMI (eHMI and iHMI) messages to enhance 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 concrete HMI messages to be sent by the AV towards other TPs. These will include explicit communication via eHMI, 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

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modules for controlling the HMI hardware elements for simulators and demonstrator vehicles via the “Cooperation and Communication Planning Unit” of WP 3.

All of this work was completed 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 3 shows the process followed within WP 4 of interACT.

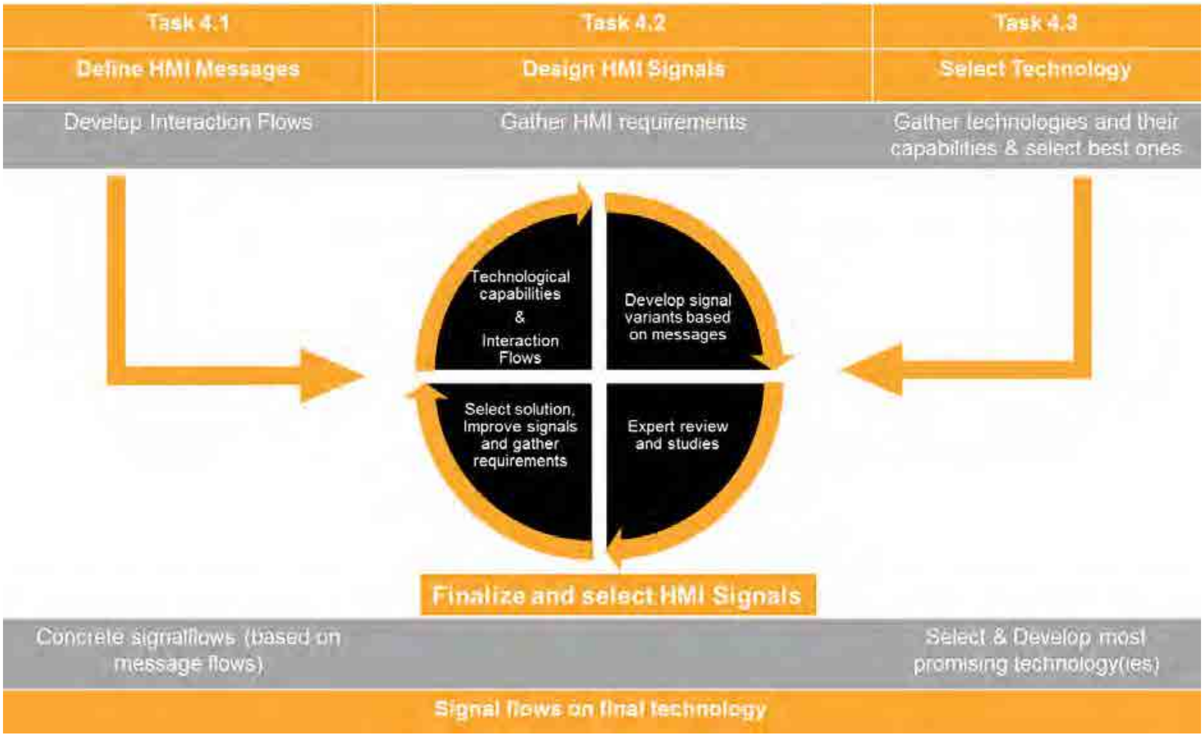

Figure 3: WP 4 working process in interACT

A detailed description of individual tasks within WP 4 can be found in D4.1 p.11ff.

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3. Interaction design

3.1 Preliminary interaction strategies and assumptions for the design work in WP 4

The basis of the current design work was set in D4.1 “Preliminary interaction strategies” (Wilbrink et al., 2018). In this deliverable, we documented the status of the design process and came up with a catalogue of interaction messages. The main purpose of the defined messages is to ensure that the on-board users and other traffic participants interact safely and efficiently with the AV. In addition, acceptance and trust should be increased by using the messages. As can be seen in Table 1: Refined interaction messagesTable 1, this list was further refined for D4.2.

Table 1: Refined interaction messages

Next manoeuvre (NM)	
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)	
EP_1 & EP_2	AV has detected (one or more) other/specific TP(s)
Cooperation capability (CC)	
CC_1	AV gives way *(Message was changed from “AV gives right of way” in D4.1)*
Other messages of lower priority	
VDM_1	AV drives in automated mode
-	Temporal indication (e.g. searching for a parking slot)
CC_9	AV says “thank you”
CC_10	AV indicates “irritation”
CC_11	AV has technical problems

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Evidence suggests (Rodríguez Palmeiro et al., 2018), that communicating the automation mode does not contribute to improved interactions and therefore has to be carefully considered. For this reason, we decided to not include the vehicle driving mode (VDM) in our baseline design and moved it to the messages with lower priority. The interaction strategies aim to use explicit as well as implicit AV communication with other traffic participants and the user on board.

Implicit communication is defined as: all parameters of the vehicle movement that do not have the sole purpose of communication, but can be used by on-board users as well as other TPs to extract information. Examples are the trajectory of the vehicle, its acceleration and deceleration patterns and speeds, or the stopping distance of the vehicle with respect to a pedestrian. The driving behaviour of the AV is a form of implicit communication (Fuest, Sorokin, Bellem, & Bengler, 2018) which exists at any given time (even when the AV is standing still this could be perceived as a message).

Explicit communication is defined as: additional measures to communicate with other TPs. This includes specific signals for communicating the driver's or the AV's awareness and intention, which are not necessary for the vehicle movement. Examples are driver head- and hand gestures, or the built in eHMI of manually driven cars (such as turn indicators or the reversing light). Furthermore additional eHMI elements of AVs might be used to replace head and hand gestures, or to illustrate implicit signals by highlighting, for instance, the braking movement of the car with additional visual cues.

This definition illustrates that implicit communication can occur without explicit communication. Explicit communication, however, never exists without implicit communication as all patterns of the vehicle movement can be perceived as a message.

For further classification purposes we came up with three classes of interaction strategies that have different main characteristics. The three classes are:

- **Perception-signalling design**: For this design variant we developed a message design that is mainly characterized by giving explicit information to other traffic participants that they have been 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. In this interaction strategy, the information identifying which interaction partner is detected by the AV is also given to the on-board user. As described in D4.1 "Prelininary interaction strategies" (Wilbrink et al., 2018) the message "AV has detected (one or more) other/specific TP(s)" is the characteristic message for this design.

- **Intention-signalling design**: In this message design variant we developed a design that shows the intentions of the AV by giving explicit information to other traffic participants and the on-board user about the current vehicle manoeuvres, about future manoeuvres of the AV,

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and/or the cooperation capability of the AV. Characteristic messages are the "AV gives way" or "AV will start moving".

• **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, along with communicating the intentions of the AV.

Other messages, such as the "AV drives in automated mode" or "AV says - thank you" do not fall into the above-mentioned interaction strategies and can be used in addition to all three strategies.

The interaction strategies have some implications for the concrete eHMI design. In mixed traffic environments it is very likely that more than one other traffic participants is present in the AV surroundings. This means that we can distinguish the format of the messages to be communicated in the following way:

- Addressed messages: Messages which are intended for only one traffic participant, and the traffic participant understands that the message is addressed to him or her. An example might be an acoustic message which includes the location of the traffic participant communicating him/her to cross the street, such as "pedestrian on the left side of the pedestrian crossing, please cross the street")
- Non-addressed messages: messages which are intended for everyone that can perceive them. An example might be an acoustic message communicating explicitly "everyone who can hear this message can now cross the street" or "this vehicle will now yield".

While the perception-signalling design should only work with addressed messages (one recipient for the message "AV has detected TP", the intention-signalling design can work with addressed as well as non-addressed messages.

In D4.1 we also documented how the interaction strategies are applied to the different scenarios of the interACT project. Over the course of Task 4.2 these strategies were tested and compared in user studies to know more about which strategy works best in which scenarios. Furthermore, the need to communicate messages in an addressed way was researched. The results of these studies are reported in section 4. Based on the outcomes of the studies, the most appropriate strategies were selected and further refined for application in the interACT demonstrator vehicles. In the following sections we will explain the concrete interaction design solutions for other traffic participants and the on-board user.

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3.1.1 Guiding principles for designing the interactions

For designing the concrete interactions we chose several design principles guiding the interaction design.

1) Implicit communication is the basis for the AV's communication. In today's traffic, driving behaviour is of high relevance to other road users. AV's should be designed to behave in an expectancy-conforming way, therefore implicit communication by means of driving behaviour can be a sufficient means of communication in most situations (see detailed analysis of human-human interaction reported in D2.1 (Dietrich et al., 2018)).
2) Explicit communication through eHMI might be necessary or beneficial when the AV is not moving, or cannot select a trajectory which is ideal for communication purposes, or additional information is needed by the other TP.
3) On-board communication through iHMI might be necessary or beneficial, when the on-board user needs a more detailed picture of the situation to trust the AV actions. This might be especially the case in ambiguous traffic situations that can be only solved through the interaction of the AV with other traffic participants (e.g. pedestrian detected with the intention to cross and AV gives way). The level of information detail for the iHMI might differ according to the level of user attention to the driving task.
4) As information overflow needs to be avoided, whenever possible the communication should primarily rely on implicit communication. Explicit communication by means of eHMI and iHMI should only be used if an additional need for communication is identified.

3.1.2 Updated assumptions and requirements from international consortiums

Besides the design principles chosen for guiding the design process, we have taken results and discussions of international consortiums into account to be able to integrate the resulting interaction concepts seamlessly into the interACT design.

With focus on international activities in Europe, the UNECE (United Nations Economic Commission for Europe) has the goal of coming up with a legal framework for AVs across Europe. Two Working Parties (UNECE WP) are mainly dealing with this overall topic. On the one hand UNECE WP.1 is responsible for the Vienna and Geneva road traffic convention, on the other hand UNECE WP.29 bears responsibility for all vehicle approval regulations under UNECE. UNECE WP.29 decided, due to the importance of the subject, to establish a new Group on Automated/Autonomous and Connected Vehicles (GRVA) in parallel to existing groups like GRE (working party on lighting and light-signalling). Further, the decision was made to launch the AVSR task force (Autonomous Vehicle Signalling Requirements) in October 2018. The initial scope of this task force is to evaluate and report on the safety needs for highly and fully automated vehicles to signal their status and communicate their next intended actions

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using visual or audible signals or a combination of both. This should result in a concerted recommendation. As this AVSR task force is a GRE activity, experts from governments (contracting parties to the UNECE 1958 and 1998 agreements) and NGOs (non-governmental organisations) such as CLEPA (Automotive suppliers, e.g. HELLA), GTB, ISO, OICA (OEMs, e.g. BMW), SAE participate. Furthermore, this task force takes care of upcoming results of conducted, ongoing and planned projects like interACT ("UNECE," n.d.).

In parallel, consortia like GTB (Groupe de Travail Bruxelles 1952) and SAE (Society of Automotive Engineers) are working on proposals of what AV signals can look like, if the need for those will be proven, and their implementation strategy decided. One important topic is the ongoing discussion about a special light colour for eHMIs of AVs. Cyan, turquoise and blue-green are used as terms describing the same colour within the CIE (Commission internationale de l'éclairage*)* diagram, which is to be the colour of choice while transferring any kind of message from an AV to a human road user (HRU). Figure 4 shows the colour area of interest, between already restricted blue and green. The final decision and delimitation of this feasible blue-green area is still open. interACT is following all discussions intensively and is contributing to the fora with latest project results.

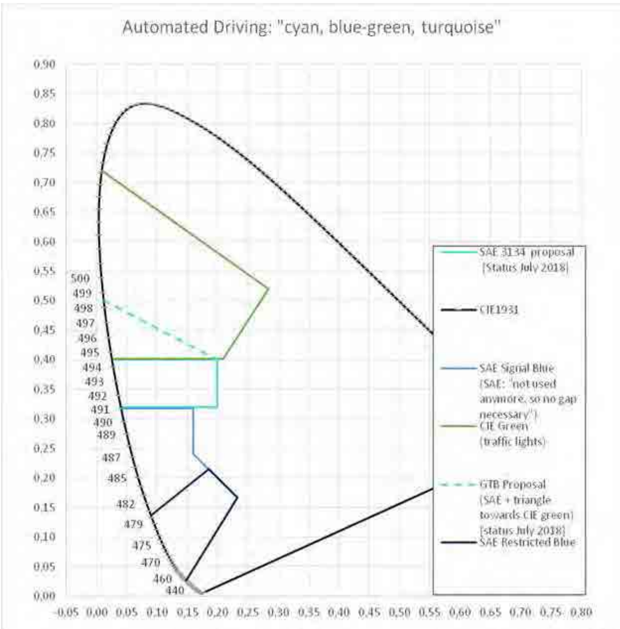

Figure 4: Colour definition "cyan, blue-green, turquoise" (Tiesler-Wittig, 2018)

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3.2 Implicit Communication – design of vehicle movements

The observations in WP2 (see interACT D2.1 (Dietrich et al., 2018) for further details) have shown that most potential traffic encounters are resolved kinematically by the involved traffic participants before they turn into interaction-demanding situations. Ideally, the AV should act in a comparable way – avoid conflicts by adapting the kinematic motion as early as possible, taking trajectories of other road users into account. Actual interaction mostly happens in low speed close proximity situations (see interACT D2.1 (Dietrich et al., 2018)) – in these situations adaptations of the vehicle kinematic is often used to communicate the individual intent. If, for example a driver wants to let someone turn onto his/her congested road, he/she would simply reduce the speed opening a gap, signaling his/her yielding intention this way.

Based on the results of the observation studies, we assume that the following vehicle behavior characteristics should be considered in the design process of the AV interaction:

Deceleration and gap size: For all information that is related to giving way, the AV should decelerate to decrease its approaching speed to make its yielding intentions clear. Based on literature as well as on the empirical and modelling work in interACT WP 2, one seemingly recommendable strategy is to decelerate so as to reach an apparent time to arrival (TTA = distance / speed) that is greater than typical gap acceptance thresholds (tentatively, in urban settings: typically 3-4 s for pedestrians, and 5-6 s for vehicles). For greatest interaction efficiency, this above-threshold TTA should be reached as quickly as possible, while of course at the same time considering the comfort of AV passengers and safety with respect to other vehicles behind.

Approach speed: Based on the findings from the observational studies on human-human behavior, the AV does not necessarily need to come to a full-stop. Slow driving with a speed of below 3 km/h* seems to be accepted, once the gap acceptance threshold was surpassed. Avoiding full stops keeps an interactive scenario dynamic: if the other road user does not respond in any way or rejects the created gap, the situation will resolve itself, as the relative distance decreases over time, until the yielding vehicle can pass the other road user safely and accelerate again. If the other road user decides to cross/merge late, the absolute velocity of the yielding vehicle is low enough to come to a full stop with a reasonable deceleration. In addition, in a situation where the AV is following another vehicle, it should be considered that the size of the yielding gap considered by the crossing road user is also affected by the leading vehicle.

Active pitch: An active pitch of the AV might support the indication that the AV gives way to a pedestrian, but requires an active suspension. A VR simulator study run in WP 2 found that if the AV actively pitches prior to decelerating or artificially pitches two times more strongly while decelerating, pedestrians crossed significantly sooner in comparison to a normal deceleration. As the results of this

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study are not generalizable to all traffic scenarios, the effects of vehicle pitch on crossing behavior should be further investigated.

Lateral distance: Furthermore, in a shared space situation such as a parking space the AV should slightly increase its lateral distance to other road users if it intends to bypass them.

3.3 Design of eHMI

3.3.1 Selection of output media

In order to limit the design-space, we first chose to analyse output media, and select the most suitable and most promising output media for eHMI. A collection of main target criteria was created as an extract from interACT's overall requirement list (Drakoulis, Drainakis, Portouli, Tango, & Kaup, 2017) to be used for evaluating and selecting the best fitting technologies. Table 2 shows a list of general evaluation criteria for eHMI, with a focus on the visual channel, and explanations of why each criterion is relevant. The visual channel was selected as the most promising communication channel, as the sender of visual messages is clearly identifiable by the light emitting surface on the car body. This might not be the case for acoustic signals. Visual signals are also discussed in the specific legislative and policy fora such as UNECE WP.29, GTB or SAE (see section 3.1.2). Acoustic signals can play an additional role in critical situations to avoid or minimise the impact of collisions, for meeting accessibility criteria for visually impaired groups, or for further improving the salience of the sent signal. Haptic and olfactory channels were excluded, as for haptic interaction a physical contact between the AV and the other TP would need to be established, which should be avoided at all costs. Olfactory interaction could only occur in odour free environments, and is, therefore, not suitable for interaction of any kind on public streets.

Table 2: Target criteria for eHMI selection

Target Criteria	Definition & reasoning
perceivable in daylight	If a clear perception of an eHMI's light signal is given in daylight conditions, it can be clearly distinguished from other reflections on the vehicle. The fact that a bright environmental luminance could disturb the visibility of a signal also needs to be taken into account.
perceivable at night	The communication concept should be independent from environmental conditions. Thus, a concept change between day, twilight and night is not necessary. The technical solution should adapt itself to different luminance conditions.

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Target Criteria	Definition & reasoning
perceivable in rain	The functionality of the eHMI has to be ensured during rain. Even if large puddles cover the road surface, a working communication is necessary.
perceivable in snow	At lower temperatures, snowfall worsens visibility. To realize a safe and reliable communication, this should be taken into account. Further it should be taken into account that a snow covered road in urban traffic is usually not a perfect diffuse projection surface.
perceivable > 50 km/h	For urban use cases this is not so relevant.
perceivable 20-50 km/h	This is a typical speed at urban scenarios, so it is an important requirement to realize perception at vehicle speeds of 20-50 km/h.
perceivable 5-20 km/h	At crossing scenarios, e.g. turning manoeuvres, the typical vehicle speed is reduced. At this speed, a possible communication between the vehicle and other traffic participants could take place.
perceivable 0-5 km/h	At parking spaces, where pedestrians, cyclists and other vehicles share one space, vehicles reduce the speed to walking pace. A perception should be realized also at a full stop.
Possibility to limit the visibility to only one TP	Depending on the message that should be transferred, the light signals could communicate information that refer to the vehicle itself as well as information that refers to certain TPs. The transfer of a piece of information that refers to the vehicle itself could be communicated to every TP (broadcast message). If information is addressed to one certain HRU, it could be an option to reduce the visibility to only that addressed person. Further, this could reduce overstimulation.
possible avoidance of other TP's distraction	To avoid overstimulation and unintended misbehaviour of other TPs, potentially distracting communication should be avoided.

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Target Criteria	Definition & reasoning
Compatibility with conventional external light units/functions	Conventional external light functions are well established in today's traffic. Upcoming manoeuvres like braking, turning or moving backwards are communicated by conventional light functions, depending on driver's actions. Novel eHMI units should form a completion (not a substitution) by adding messages that may not be communicated by the driver anymore. Therefore, the compatibility with conventional external light functions is important. This also means that danger of confusion with other external light units and functions has to be minimised.
external HMI range (up to 25 m)	The eHMI should enable an early communication between vehicle and TP. This will give TPs time to react. Taking the speed of a cyclist into account, the HMI range should be up to 25 m (Willrodt, Strothmann, & Wallaschek, 2017)
HMI visibility/perceivability horizontal (0-360°)	To cover different interaction strategies in several use cases a 360° eHMI has to be the aspiration. The simplest example is the indication of vehicle automation status (VAS) in all, or selected, directions.
HMI visibility/perceivability vertical	To address different HRUs in close distances, e.g. a truck driver on the one hand and a pedestrian on the other hand, an eHMI solution has to cover ±45° vertically (Willrodt et al., 2017)
Understanding of HMI signal	Aligned with international consortiums, especially GTB, the understanding of eHMI signals has to be "simple, clear and learnable" [Tiesler-Wittig, 2018]. Intuitiveness is a tough goal, but not a must-have.
applicable for visually impaired people	interACT does not focus on visually impaired people. For the sake of completeness, this criterion is listed.
applicable for hearing impaired people	interACT does not focus on hearing impaired people. For the sake of completeness, this criterion is listed.
independent from language skills/reading skills	To reduce communication barriers based on language skills, age, or culture, a reduction on light based message content is desirable. Therefore, the usage of text or symbols is avoided.

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Target Criteria	Definition & reasoning
potential to display different messages	If more than one message should be transferred via one single HMI, the signal design has to be adaptable, e.g. by changing luminous intensities, frequencies or to limit the visibility to specific TPs.

Some output media for eHMI have already been proposed and discussed in the past, e.g. visual displays, a light-band, and projection onto the road surface have been compared regarding their suitability as output media for the communication of AVs with other TPs (Schieben et al., 2019; Sorokin, Chadowitz, & Kauffmann, 2019; Sorokin & Hofer, 2017; Willrodt et al., 2017). In interACT, this list of output media was complemented with another light medium, the Directed Signal Lamp, and was evaluated based on the requirements listed above in Table 2. In the following section, a short overview of these output media is given. All the concepts mentioned below are also part of the "Innovation Management list" of WP 8, which is the central document for the Work-Package-overlapping literature and patent research of all interACT partners.

a) Signal lamp b) Light-band c) Display d) Projection

Figure 5: Examples of eHMI technologies ("BMW Vision Next 100," n.d.; Clamann, Aubert, & Cummings, 2017; Mercedes, 2015; Sorokin & Hofer, 2017)

Signal lamp: Signal lamps are firmly established to realize different kinds of safety-relevant functions around the vehicle. Usually these devices are responsible for one function, so they are often called Single Lamps. For examples "Daytime running light" [ECE Regulation R87], "Position light" for front and back [ECE Regulation R7], "Turn indicator" [ECE Regulation R6], etc. are already regulated with regard to mounting positions, size of light emitting surfaces, photometrical values, and colors. In the course of alignment on the need of novel lighting devices for AVs (see chapter 3.2.1) further functions, positions, colors, etc. are in discussion (Figure 5a).

Light-band: The Light-band (Figure 5b) is a direct light-emitting horizontal ring around the vehicle which can be illuminated completely or by segment only. It ideally covers 360 degrees and follows the contours of the car. The light-band can be realized by integrating several light-emitting surfaces in a

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row. By integrating different light-band types, the light-band is able to light up in different colors. An individual driving circuit for each light source allows the individual control of small segments.

Display: By integrating light-emitting surfaces in a matrix, display technology is realized. This enables the presentation of symbols (Figure 5c) and letters.

Projection: Figure 5d illustrates projection technology. A lighting unit projects information on the road or other surfaces around the vehicle.

interACT WP 4 focused on selecting a technology which is usable as a primary communication medium in any situation. Evaluations were based on an expert rating by WP4-related project partners. For documentation, a matrix (see Annex 2) was used, evaluating general eHMI technologies against target criteria (from Table 1).

In theory, with high definition projection systems, complex symbols or text could be displayed on the road in front of a certain TP. The main disadvantage is the low luminance that can be realized. In daytime conditions the perception will be limited, which is a knockout criterion for using this technology as the primary communication medium. Furthermore, dependencies on road surface conditions (e.g. wet road, snow covered road, rough road) have to be considered. Therefore, projection onto the road surface might be useful as an additional output media (Sorokin & Hofer, 2017) in certain situations to enhance communication. Displays, even with high resolution, can potentially implement complex symbols or text. Compared to projection systems, there is no dependency on road conditions as the information is displayed on the vehicle itself. Here, the perception depends on the display dimensions, the distance and the viewing angles of the observer. Each letter must be 15 cm tall to be readable at 100 feet distance (Clamann et al., 2017). Words or short sentences would require high display dimensions, which are extremely challenging to integrate into AVs. Communicating with iconography needs to ensure the cultural transferability of eHMI, which is difficult to achieve (Weber, Chadowitz, Schmidt, Messerschmidt, & Fuest, 2019). In addition, communicating by text on an in-car display requires the skill of reading and understanding the language. Display technology was therefore rated by the experts as not being best suited to explicit communication with other TPs.

For the reasons outlined above, abstract light signals were selected as being preferable to text or symbols for communicating the intention of the AV to other traffic participants. Within interACT, the light-band concept was rated as the most promising solution for conveying the messages defined in WP 4.1. The light-band around the whole vehicle allows the communication of signals visible from any perspective. By presenting short light segments separately, the light-band can additionally reflect the detection of one or more traffic participants, and restrict visibility, so that the signal can only be perceived by traffic participants in a similar direction. Thus for short distances, presenting light

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segments separately could also be used to realize a perception-based interaction strategy (Nissan, n.d.; Sorokin et al., 2019) Depending on the visibility of a signal lamp (see example Vision Next 100 in Figure 5a), different messages could also be communicated. If it is a signal lamp that can be seen by everybody at 360° around the vehicle, it could be used to communicate the automation status or next maneuvers, because the light signal does not refer to specific TPs. When the visibility needs to be adaptively reduced to TPs in a certain area, a light signal could be placed in a position that would only be visible by specific TPs, thus becoming “directed”. A directed signal lamp concept is able to communicate that a specific person has been seen by the vehicle sensors, as soon as they see the light signal (Willrodt et al., 2017). This would require the knowledge by the TPs that a light signal really refers to her- or himself, as soon as they perceive that signal. As a directed signal lamp can communicate to TPs at larger distances individually, this technology is rated as promising, too.

Light-band and Directed signal lamps were selected as the most promising technologies to cover the interACT requirements, selected interaction strategies, and use cases. Signal lamp and light-band imply two different approaches to sending the message: While the light-band sends a message so that it is visible for all, the message of the signal lamp is visible only for a specific traffic participant.

In studies and evaluations, these eHMI technologies were evaluated against each other regarding their effectiveness for different interaction strategies (Perception-signalling vs Intention-signalling vs. a combination). Further, a combination of both technologies was also tested. Acoustic signals were evaluated as add-ons. The results of those studies are reported in chapter 4. The evaluation will follow in WP6.

3.3.2 Design of output media

Having selected the appropriate output media and most promising technologies to be used for explicit communication, design parameters used in previous work were gathered for selecting a baseline design. For the baseline design the specific parameters of the signal lamp and the light-band were considered. The signal lamp has the potential of sending signals which are only visible for one individual traffic participant, as the view can be restricted. The light-band has the potential to send signals which can be perceived by all traffic participants involved. A comparison of these solutions, and their matching to the three selected interaction strategies can be found in Table 3.

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Table 3: Comparison of interaction strategies

	Perception-signalling design	Intention + Perception signalling design	Intention-signalling design
Visible-for-one (only selected traffic participants can perceive signal)	**Signal lamp** sends "AV has detected (one or more) other/specific TP." so that it is visible only for this TP/these TPs.	**Signal lamp** (If TP is aware, that only he can see it) sends "AV gives way." and "AV has detected (one or more) other/specific TP." so that it is visible only for (a) certain TP/TPs.	**Signal lamp** (If TP is not aware, that only he can see it) sends "AV gives way." so that it is visible only for certain TP/TPs.
Visible-for-all (everybody can perceive signal)	**Light-band** sends "AV has detected (one or more) other/specific TP(s)." so that it is theoretically visible for everybody	**Light-band** sends "AV gives way." And " AV has detected (one or more) other/specific TP(s)." so that it is visible only for certain TP/TPs	**Light-band** sends "AV gives way." so that it is theoretically visible for everybody

3.3.2.1 Description of the light-band: eHMI "visible-for-all"

The light-band concept used in interACT was derived from previous work by BMW, which proposed a light-band 360° around the vehicle (Sorokin et al., 2019; Sorokin & Hofer, 2017).

The BMW analysis of traffic situations had shown that there was a wide range of view angles on AVs, in which interaction could occur (see examples in Figure 6). An ideal solution was, therefore, one that would allow 360 degree communication to enable interaction in all scenarios and allow maximum flexibility. Two options are stated to potentially achieve this: several single communication elements (with a horizontal position similar to the ones of the light elements for the turning signal), one element in the middle of the vehicle or one continuous element (see Table 4). The different types of traffic participants also imply a wide range of vertical positions for the viewpoint of the TP (from children to truck drivers). In combination with a range of distance from few meters to farther distances typical for vehicle-vehicle interaction this implies a wide range of vertical angles from which the communication signals need to be visible.

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Based on this premise and the decision to use direct light, Sorokin et al. (2019) developed a direct light-emitting element which horizontally spans the whole vehicle, the "Light-band". To ensure visibility in traffic, and from a range of vertical viewing angle, the vertical position may not be too low. A position close to the roof may result in an additional risk of being outshined by reflections. As traffic participants usually communicate with the driver through the windshield, a vertical position close to this height is preferred. The light-band proposed by Sorokin et al. (2019) was able to either be lit fully, for instance to convey the intention of the AV, or have only a segment lit, for instance, to reflect the detection of a traffic participant.

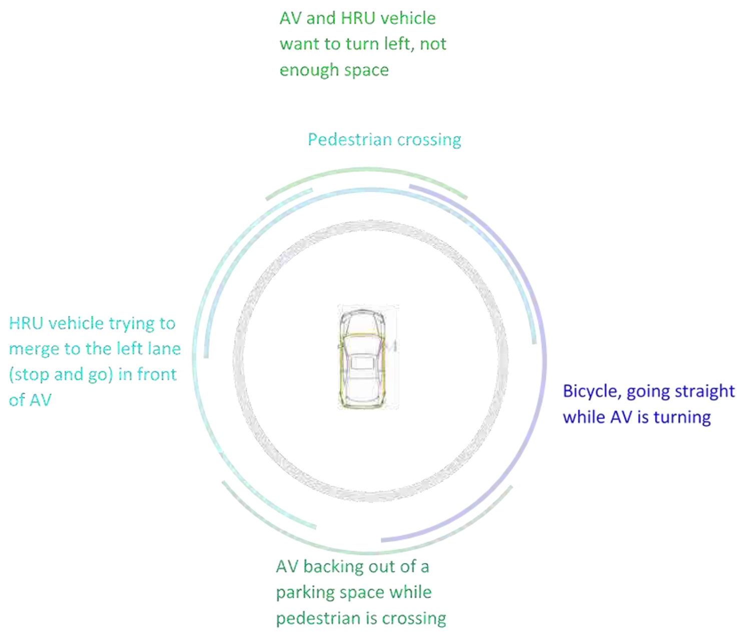

Figure 6: Examples on perspectives on AV in traffic situation with high potential of a need of interaction covered by the 360° light-band

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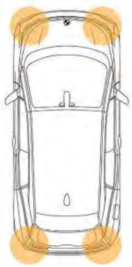
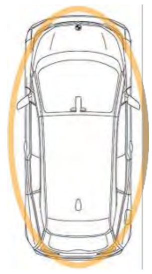
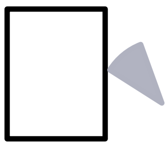
Table 4: Positioning of light emitting elements and assessment of visibility for 360° communication

	Several light elements at the corners of the vehicle	**Light element on the roof of the vehicle**	**One continuous light element encompassing the vehicle**
			
Pros/Con	Disadvantage: Signal might be too close to turn signal (danger of confusion, outshine)	 Disadvantage: Due to viewing angles (low vertical eye position of HRU + close to AV, e.g. in children crossing the path of the AV) it might not be visible in certain situations	Advantage: Continuous signal possible

The interACT partners agreed to work further on the light-band concept to design the appropriate eHMI messages for the message catalogue of the project. The main properties of the light-band concept are summarized as follows:

- Direct light allows signaling in any weather and light condition in which existing optical signals of vehicles (brake light, turn signal) work too
- Visible from every viewing angle
- Size of lit area is large
- Due to large area in horizontal dimension it is less likely that it is confused with other signals (unlikely that existing light signals or reflections will outshine the whole area)

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- It is also possible to light only a segment of 360 degree display area (in horizontal dimension), allowing it to:
  - Display spatial relationship to HRU
  - Follow main dimension of HRU movement.

3.3.2.2 Description of the directed signal lamp: eHMI "visible-for-one"

The "Directed Signal Lamp" idea was developed (during investigations at HELLA) while dealing with the question of if and how addressed messages could be transferred only to specific relevant HRU recipients. The concept of the directed signal lamp is as follows: Every detected and relevant traffic participant sees a light signal that lets him/her know that he/she has been detected and that the vehicle is aware of him/her, while other, possibly not detected or not relevant classified traffic participants do not see any light signal at all. Figure 7 illustrates the idea behind this in an abstract way. Further the small photos in this figure show the possibility to address more than one channel (above) and how the light signal appears to an addressed TP (below). (Willrodt et al., 2017)

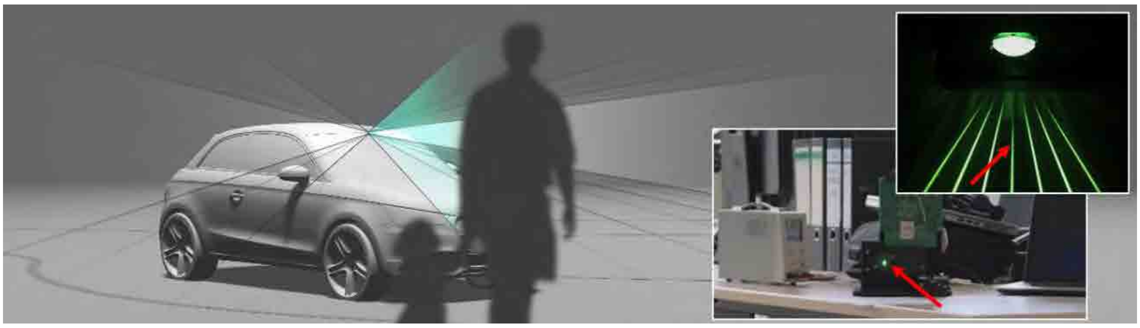

Figure 7: Directed signal lamp idea [Willrodt et al., VDI, 2018].

The Directed Signal Lamp is a new concept in the context of novel eHMI for Automated Driving Systems. Thus, this concept is realized and implemented for the first time within the interACT project. A detailed technical description of this approach will be carried out in the future deliverable D4.3.

In alignment with the light-band concept, a 360° solution for the Directed Signal Lamp to cover all use cases and specific scenarios would be ideal too. However, the goal of integrating eHMI into the car body of the interACT demo vehicles requires multiple Signal Lamp devices to cover 360°. Given the time constraints of the project, during WP4 and WP5 the decision was made to implement one very first prototype of this Signal Lamp at the vehicle's front to cover ca. 70°. This will be sufficient to cover most of the interACT scenarios and to provide a first evaluation of this approach.

The main properties of the Directed Signal lamp concept are summarized as follows:

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- Direct light allows signaling in any weather and light conditions in which existing optical signals of vehicles (brake light, turn signal) work too
- Addressed messages only visible for relevant TPs
- Size of lit area is small
- Variable mounting position realizable (see chapter 3.3.3)

3.3.3 Analysis of hardware variants for in car integration

Having selected the appropriate technologies to proceed with the project, several variants for integrating the HMI elements into the BMW demonstrator vehicle had to be assessed. Two potentially conflicting requirements had to be integrated: Requirements from a research and design point of view as well as the technical feasibility of the integration. We therefore conducted an expert workshop on the potential mounting positions for the eHMI elements in the BMW i3 demonstrator vehicle with experts from all relevant domains (Design, Technical development, Human factors and Integration). The workshop took place at the BMW lighting lab in Munich. Different mounting positions for the different eHMI elements were assessed by prototyping with light strips as well as design-tape on the vehicle.

Preliminary mounting positions for the different eHMI elements were defined, based on the assessment of all involved experts. These preliminary mounting positions are shown in Table 5.

Figure 8: interACT expert workshop in Munich

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Table 5: Preliminary mounting positions of eHMI elements discuss in interACT

Mounting position FRONT			
	Variant 1	Variant 2a	Variant 2b
Light-band			
Signal lamp		---	
Mounting position SIDES			
	Variant 1	Variant 2	
Light-band			
Signal lamp	---		
Mounting position REAR			
	Variant 1a	Variant 1b	Variant 2
Light-band			
Signal lamp	---		

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During the workshop, all experts decided to integrate the "Directed Signal Lamp" only in the front of the BMW demonstrator vehicle (see Table 5) to communicate with other road users in front of the car. For this purpose, the signal lamp will be installed close to the interior mirror in the car's interior. A position behind the windshield was chosen, where eye contact with a driver would be expected, but without significant limitation of driver's view during evaluation. In addition to the signal lamp, the light-band will be integrated in the front of the car as well. In principle two mounting variants in the exterior at the front of the car are possible:

1. Light-band mounted on the top of the windshield
2. Light-band mounted above/into the radiator grille

On the sides of the BMW i3s two mounting positions have also been preliminarily decided. Firstly, an integration of the light-band above the car doors (Variant 1), and, as an alternative, the integration below the side windows (Variant 2).

As the goal is to have a 360° light-based eHMI, the mounting positions at the rear of the vehicle were discussed as well. Thereby three different variants were discussed, which mainly depend on the mounting position of the light-band at the sides of the car. The first two variants, mounting on the rear window (Variant 1a) and integration in the rear spoiler (Variant 1b) are suitable if Variant 1 on the sides is chosen. The integration at the bottom of the rear window (Variant 2) is an alternative variant when the light-band courses below the side windows.

Based on the preliminary mounting positions of the eHMI elements, each variant of the different positions had to be further evaluated. The main focus here was on the specific assembly space investigations of concerned body parts in the BMW i3s demonstrator vehicle. After a detailed analysis of the CAD – data, and due to the limited assembly space in specific body parts of the BMW i3s, the following mounting positions of the light-band have been decided:

- Front: Variant 1 or 2b
- Sides: Variant 1 – Integration above the car doors
- Rear: Variant 1b – Integration in the rear spoiler

The mounting positions of the light-band in the rear and on the sides of the car have been finally decided, based on the available assembly space. To decide the final mounting position in the front (Variant 1 or Variant 2b), several advantages and disadvantages have been collected by experts of the relevant fields (design, technical development, human factors, body shop).

In particular, the missing optical isolation between the light-band for communication with other traffic participants and the main headlamps have been seen as very critical. As the project has set the light color for the eHMI elements to both "cyan" and "white", a potential risk of misinterpretation by

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communicating with “white” light signals, was seen in Variant 2b. Due to the strict isolation between main light functions and eHMI elements in Variant 1, this mounting position of the light-band has finally been selected. The final mounting positions of the interACT eHMI elements are summarized in Table 6.

Table 6: Final mounting positions of eHMI elements 360° light-band and directed signal lamp in interACT

Mounting position FRONT	Mounting position SIDES	Mounting position REAR
		

Furthermore, first rough construction data of the the eHMI elements have been transferred into virtual reality for further assessments of the final mounting positions (Figure 9 + Figure 10) and to get a better impression of the first signal designs of the eHMI elements.

Figure 9: CAD-data of BMW i3s with highlighted eHMI positions for interACT

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Figure 10: VR-model of BMW i3s with eHMI elements for interACT studies

The VR model of the BMW i3s has been set as basis for all upcoming simulator studies in WP4, described within chapter 4. Furthermore, the development process for the final eHMI hardware components in the demonstrator vehicles have been started based on the final mounting positions. This development process as part of Task 4.3 in WP 4 will be described in detail within Deliverable 4.3.

3.4 Design of iHMI

3.4.1 Selection of suitable on-board media

interACT develops a holistic approach towards communication between the AV and other road user(s). In addition to the communication to road users outside of the AV, it is important to also take the on-board user of the AV into account. The main purpose of an on-board HMI during automated driving, is to ensure that the user on board of the AV trusts the AV, and feels safe when traveling. In highly demanding interaction situations in particular, on-board users need additional information regarding the situation to understand and anticipate the AV's behaviour. Information on the on-board HMI needs to be easily understandable for the user, and enhance the transparency of the AV actions. It is important to avoid any uncertainty of the on-board user that might lead to a take-over of control in situations that are well handled by the AV.

For the selection of suitable on-board HMI technologies the following list of criteria was set up (Table 7). Based on this list, the visual channel was selected as the most promising communication channel.

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Table 7: Target criteria for iHMI selection

Target Criteria	Definition & Reasoning
Well perceivable for on-board user	Perceivable in various seating positions that can occur in an automated vehicle.
Perceivable in daylight	If a clear perception of an on-board HMI's light signal is given in daylight conditions, it can be clearly distinguished from other reflections inside the vehicle. The fact that a bright environmental luminance could disturb the visibility of a signal also needs to be taken into account.
Perceivable at night	The communication concept should be independent from environmental conditions. Thus, a concept change between day, twilight and night is not necessary. The technical solution should adapt itself to different luminance conditions.
Compatibility with conventional on-board HMI signals	Conventional internal HMI functions are well established in today's traffic. Novel on-board HMI should be compatible by adding information regarding automated driving functions to enhance the transparency. The novel HMI functions need to be harmonised with existing on-board HMI signals.
Not disturbing when user is involved in other tasks than monitoring	The on-board HMI needs to deliver information when the driver is searching or interested in it. The HMI signals should not distract the user when engaged in other tasks.
Potential to display different messages	If more than one message should be transferred via one single HMI, the signal design has to be adaptable, e.g. by changing luminous intensities and frequencies.

3.4.1.1 Description of the 360° light-band: iHMI

The 360° light-band is installed in the interior of the AV, surrounding the on-board user from all sides (Figure 11). The 360° approach uses the peripheral vision of the on-board user to transfer messages and information in an unobtrusive way. Therefore, the light-band can display animations, change its colour, or pulse at a certain frequency. Users are able to perceive information communicated via the light-band regardless of their seating position, and without focusing on the light-band.

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In several research studies the 360° light-band showed very promising results regarding the communication of relevant information to the user on board (Dziennus, Kelsch, & Schieben, 2016b). Further, the 360° light-band was well accepted for displaying additional information during automated driving (Dziennus, Kelsch, & Schieben, 2016a).

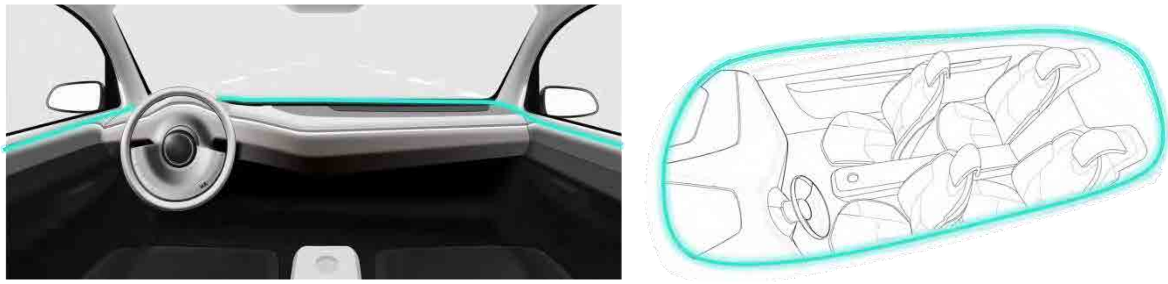

Figure 11: Positioning of the 360° light-band in the interior of the AV

3.4.1.2 Description of the automation display: iHMI

The automation display is an additional display positioned at the middle of the dashboard (Figure 12). This display provides the on-board user with additional information regarding the behaviour of the AV. Therefore it uses symbolic and textual communication to enhance the transparency of the AV behaviour. The main goal of this on-board HMI is to gain the users trust in the AV by presenting information in a format that is already known from the cluster display. In fact, this additional information could also be integrated into an existing cluster display or displayed on a handheld device.

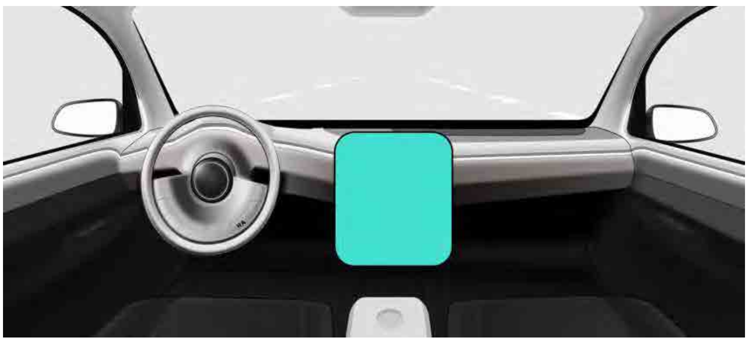

Figure 12: Positioning of the automation display in the interior of the AV

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3.5 Concrete signal design

Having selected appropriate output media, which were transferred for further development to Task 4.3, we developed several signal designs for the messages defined in D 4.1, as well as the preliminary design described in 0. Design Variants were created in several expert workshops. The most suitable ones were defined in detail and included into a signal design catalogue which can be found in Annex 1. A preliminary signal design was used as a baseline for further refinement and extension throughout this design step.

3.5.1 Preliminary signal design for eHMI

Signal design for the light-band: "eHMI visible for all"

Two basic types of signals are described by (Sorokin et al., 2019): A fully pulsing light-band ("Pulsing") to convey the intention of the AV regarding who goes first; and a moving light-segment, reflecting the detection of an AV ("Position light") (see Figure 13). The "Position light" signal was designed to be used when the AV respects the spatial needs of the TP or will give way to it. The light-segment of the "Position light" follows the movement of the TP to reflect detection, and the size of the light segment in the "Position light" signal changes iteratively over time to enhance visibility. The Pulsing signal uses a slow frequency for conveying that the AV gives way and a fast frequency for conveying that the AV expects the other TP to let the AV go first. The whole signal catalogue which had been used in the preliminary work by BMW can be found in Annex 1.

Figure 13: 360° intention-based communication via Light-band: "Pulsing" (left) and "Position-light" (right) (Sorokin et al., 2019)

The preliminary signal design by BMW described above did not conclusively answer the following questions, which were addressed in the next iteration of the interACT signal design:

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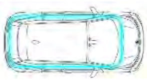
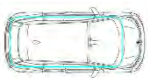
- Use of colour and which colour to be used.
- Details regarding frequency, brightness, and surface of light elements.
- Detailed comparison of Intention-based “Pulsing” vs. the detection-based “Position light” for conveying the intention that the AV will give way to another TP/other TPs.
- Definition of additional situations in which the detection based “Position light” could be advantageous.
- Definition of whether the AV should convey when it expects another TP to give way.
- The timing of the eHMI signals.
- The interplay between implicit and explicit communication.

Table 8: Signal design for light-band

Message	**Signal image**	**Signal name** ***Signal number***	**Signal Description**	**Applicability/Use Case Type**
AV gives way		Slow pulsing *#eHMI_LB_7*	Full light-band is pulsing slowly between low light (never completely off) and bright light	Indicating that there are currently other traffic participants which the AV yields to.
AV will start moving		Fast pulsing *#eHMI_LB_3*	Full light-band is pulsing fast between low light (never completely off) and bright light	AV decides to stop yielding e.g. due to - HRU whom AV intended to let pass has passed Update on intention of HRU, whom AV intended to let pass (e.g. pedestrian changes walking direction)

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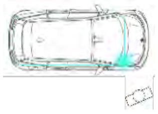
AV detected other TP		Position light *#eHMI_LB_11*	Light segment indicating position of detected TP. Light-band-Segment in direction of TP is lit. The size of the segment changes slightly over time (pulsing) to enhance visibility.	When indicating that the AV will respect the spatial needs of the HRU could be beneficial (e.g. to enhance acceptance or improve traffic flow)

Signal design for the directed signal lamp: "eHMI visible for one"

As already mentioned in chapter 3.3.2.2, the Directed Signal Lamp was developed and investigated to transfer messages to relevant TPs exclusively. In parallel, the initial idea arises to reduce the message catalogue to only one explicit message – 'AV has detected (one or more) other/specific TP' – to implement a pure perception-based interaction strategy in complex, dynamic scenarios, and larger distances up to 25m. As a baseline signal design, a steady light into the relevant TP's direction was chosen. Tests under real world conditions will show, what, if any kind of modification (e.g. flashing) can improve the perceptibility, especially the distinguishability, from the ambient light reflection on the vehicle.

Table 9: Signal design for signal lamp

Message	**Signal image**	**Signal name** ***Signal number***	**Signal Description**	**Applicability/Use Case Type**
AV detected other TP		Detection light *# eHMI_SL_3*	Light signal indicating a relevant TP explicitly, that he/she is detected. Steady light signal in the direction of relevant TP. Flashing or pulsing as an option.	When indicating that the AV will respect the spatial needs of the HRU could be beneficial (e.g. to enhance acceptance or improve traffic flow).

Based on the interACT message catalogue, the target criteria, and the previous work from BMW and HELLA described above, the interACT consortium developed a signal design catalogue. This signal catalogue (see Figure 14 and Annex 1) contains information on signal variants besides the baseline design, addressing of the messages (if one or multiple traffic participants are addressed), if it is an intention and/or perception-based signal, a detailed signal description including brightness, surface

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and frequency as well as information on the research concerning this signal. Regarding colour, interACT took a general decision, based on the proposals from international consortia, to use the colour cyan/turquoise/blue-green.

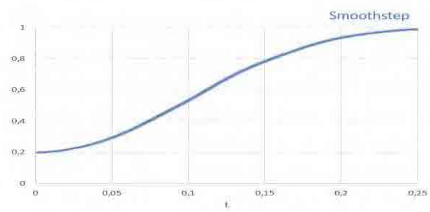
Signal Design	Number of TPs	Description	Research Resu
Light band: Calmly pulsing Signal lamp: no signal Included as baseline in the studies	Same for “single TPs” and “multiple adressed TPs” 	The full light band pulses calmly when the AV gives way. The signal lamp is “off” Light emitting surface of LED band: 10mm Colour: Cyan Frequency of light band: 0,4 Hz Brightness: 20% - 100% (smooth step interpolation) 	

Figure 14: Example of signal design catalogue for the message “AV gives way to one or multiple TPs”

Table 10 illustrates how the signals are mapped to the interaction strategies with the visible-for-one technology signal lamp and the visible-for-all technology light-band. The Signal design catalogue was used as a base for refining the signals throughout the iterative, user-centered, development process. The most promising signals were chosen for the final interaction design described in Chapter 0, and transferred to WP 3 and WP 4.3 for final integration into the interACT demonstrator vehicle. Several studies reported in Chapter 4 were conducted for refining and selecting the concrete final signal design for implementation in the prototype.

Table 10: Assignment of signals on interaction strategy

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	Perception-signalling design	Intention + Perception signalling design	Intention-signalling design
Visible-for-one	**Signal lamp** "Detection-light"	**Signal lamp** (combined strategy including Signal Lamp within WP4 studies only realized by combination of Signal Lamp and Light-band)	**Signal lamp** (not investigated because of mismatch between intention-based strategy and aimed limitation of visibility to one specific TP – Exception: "AV gives way" as implicit message to specific relevant TP)
Visible-for-all	**Light-band** "Position light" (visible only for those in a similar direction as the detected TP, but with a wide angle) To be investigated: does it make sense to have a pure perception-signaling, or is this confusing and it should always include an intention (e.g. giving way or respecting spatial needs)?	**Light-band** "Position light" (visible only for those in a similar direction as the detected TP, but with a wide angle)	**Light-band** "Pulsing"

3.5.2 Additional signal design variants

Additional signal design variants which were developed within task 4.2 and which were used for further studies can be found in Annex 1.

3.5.3 Preliminary design for iHMI

When displaying additional information to the on-board user, messages need to be clearly understandable and easy to discriminate from one another. Further, the interaction strategies should be easy to learn and in line with already known signal designs. Therefore, interACT uses the same interaction approaches developed for external communication for communication with the on-board user (intention and perception-based signals).

Design for the 360° light-band

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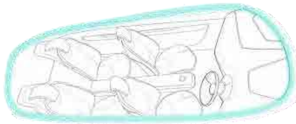
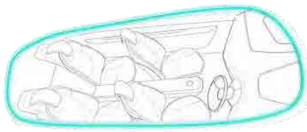
Intention-based information was communicated consistently with the external HMI (see Table 11). When the AV gives way, the 360° light-band starts pulsing slowly. If the AV starts moving again the light-band informs the on-board user through fast pulsing before the AV starts. The perception-based communication works in a way that an illuminated segment on the light-band indicates the position of the interaction partner in the real world. Due to the 360° light-band it is possible to highlight the spatial position of the interaction partner by a blue bar on the light-band. When the AV starts moving again, there is no relevant interaction partner highlighted on the light-band. Indications on the light-band do not vary between different traffic participants. This means that the interaction strategy is the same while interacting with vehicles or pedestrians.

Table 11: Signal design for light-band: iHMI

Message	**Interaction strategy**	**Signal image**	**Signal name, Signal number**	**Signal description**	**Applicability/Use Case Type**
AV gives way	Intention based		Slow Pulsing *#iHMI_LB_3*	Slow pulsing 360° light-band	Indicating that there are currently other traffic participants which the AV yields to.
AV will start moving	Intention based		Fast pulsing *#iHMI_LB_1*	Fast pulsing 360° light-band	AV decides to stop yielding e.g. due to - HRU whom AV intended to let pass has passed - Update on intention of the HRU whom AV intended to let pass (e.g. pedestrian changes walking direction)

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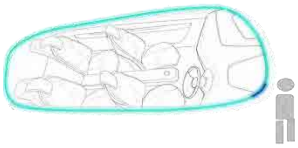
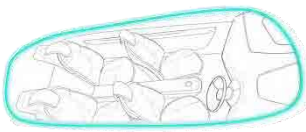
Message	Interaction strategy	Signal image	Signal name, Signal number	Signal description	Applicability/Use Case Type
AV detected other TP	Perception-based		Position light *#iHMI_LB_4*	Indication of relevant interaction partner by blue bar on light-band	When indicating that the AV will respect the spatial needs of the HRU could be beneficial (e.g. to enhance acceptance or improve traffic flow)
AV will start moving	Perception-based		Fading position light *#iHMI_LB_2*	Exiting/vanishing information about relevant interaction partner on light-band	AV decides to stop yielding e.g. due to - HRU whom AV intended to let pass has passed Update on intention of HRU, whom AV intended to let pass (e.g. pedestrian changes walking direction)

Design for the automation display

The automation display shows additional information regarding the behaviour of the AV to the on-board user. Therefore it uses symbolic and textual communication. Consistent with the light-band the information display provides information using the intention-based and perception-based communication approaches (Table 12). The intention-based communication will focus on communicating the next manoeuvre of the AV while displaying text and symbols. The perception-based approach communicates that the AV has detected other traffic participants with text and symbols. The automation display did not vary its symbols depending on the type of traffic participant (vehicle or pedestrian).

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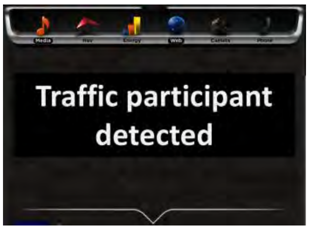
Table 12: Signal design for additional display

Message	Interaction strategy	Signal image	Signal name, Signal number	Applicability/Use Case Type
AV gives way	Intention based		Intention brake *#iHMI_AD_2*	Indicating that there are currently other traffic participants which the AV yields to.
AV will start moving	Intention based		Intention start *#iHMI_AD_1*	AV decides to stop yielding e.g. due to - HRU whom AV intended to let pass has passed - Update on intention of HRU, whom AV intended to let pass (e.g. pedestrian changes walking direction)
AV detected other TP	Perception based		Perception TP *#iHMI_AD_3*	Indicating that the AV will respect the spatial needs of the HRU could be beneficial (e.g. to enhance acceptance or improve traffic flow)

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4. Results of user studies for the selection of the final interaction strategies

To evaluate and improve the eHMi/iHMI design in an iterative manner such as defined for WP 4, we conducted 7 studies in various setups. These studies are reported in brief in this section of the report and detailed further in the Annex 3.

4.1 Studies for defining the final interaction strategies for vehicle movements

Within the interACT project, vehicle movements and interactions are investigated within WP 2. As the results from WP 2 are affecting the interaction strategy within WP 4 as well, Table 13 gives a brief overview about the studies which were conducted in WP 2. The studies mentioned in the following table are described in detail in Deliverable 2.2. The results of those studies are taken into account for designing the final interaction strategy for the interACT prototypes (see chapter 5.1 of this deliverable).

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Table 13: Overview of conducted studies within interACT for vehicle movement

Study no	Study name	Main research questions	Tested scenarios	No of participants	Test environment	Responsible partner
1	Pedestrians' Gap Acceptance	Investigating the Gap Acceptance of pedestrians	React to crossing non-motorised TP at crossings without traffic lights	14	VR pedestrian simulator	ITS Leeds
2	Effect of Driver on crossing decisions and behaviour in VR	How does driver behaviour / presence of driver influence the crossing decision?	React to crossing non-motorised TP at crossings without traffic lights	20	VR pedestrian simulator	ITS Leeds
3	Leeds-Keio D2P+D2D VR study	How is the decision to cross a lane with an approaching vehicle (e.g., AV) affected by (1) the kinematics of the approaching vehicle, (2) being a crossing pedestrian versus being a crossing car driver, and (3) being used to English versus Japanese traffic?	React to crossing non-motorised TP at crossings without traffic lights. React to an ambiguous situation at an unregulated 4-way intersection	80	VR pedestrian simulator	ITS Leeds
4	Effects of pitch and deceleration on crossing behavior	Which implicit communication do we need for the AV?	React to crossing non-motorised TP at crossings without traffic lights	32	VR pedestrian simulator	TUM

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Study no	Study name	Main research questions	Tested scenarios	No of participants	Test environment	Responsible partner
5	Effects of deceleration and eHMI on crossing behaviour	Do we need eHMI at all or is implicit communication enough? How does the presence of eHMI affect pedestrians' gap acceptance?	React to crossing non-motorised TP at crossings without traffic lights.	32	VR pedestrian simulator	TUM

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4.2 Studies for defining the final interaction strategies for eHMI

The studies conducted within WP 4 to investigate interaction strategies for the eHMI are described in the following sub-chapters. The following Table 14 gives an overview about all WP 4 studies which are described more in detail in Annex 3.

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Table 14: Overview of conducted studies within interACT WP4 for eHMI

Study no	Study name	Main research questions	Tested interaction strategies	Tested scenarios	No of participants	Test environment	Responsible partner
1	Comprehension of eHMI	Which signals best convey which messages?	Intention based	-	20	VR Head Mounted Display	ITS LEEDS
2	To yield vs. not to yield	Is there a benefit in using eHMI? Does an AV need to communicate if it does not yield?	Intention based	1. React to crossing non-motorised TP at zebra crossings 2. React to crossing non-motorised TP at crossings without traffic lights 3. React to non-motorised TP at a parking space	30	VR pedestrian simulator	BMW
3	Addressing messages to a single pedestrian	Is there a benefit in addressing signals to a pedestrian? Is there a benefit in using coloured signals?	Intention and perception based	1. React to an ambiguous situation at an unregulated 4-way intersection 2. React to non-motorised TP at a parking space	23	VR pedestrian simulator	BMW

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Study no	Study name	Main research questions	Tested interaction strategies	Tested scenarios	No of participants	Test environment	Responsible partner
4	Comparision of intention vs perception-based eHMI design	Are there any differences in user acceptance for intention-based vs. perception-based vs. a combination of the two designs? Do pedestrians prefer different design concepts for different scenarios?	Intention and perception-based; combination	1. React to crossing non-motorised TP at crossings without traffic lights 2. React to non-motorised TP at a parking space	27	VR pedestrian simulator	DLR
5	Addressing messages to multiple drivers	Which interaction strategy is is best in a multiactor scenario with several drivers present?	Intention and perception based	React to an ambiguous situation at an unregulated 4-way intersection	60	Driving Simulator	BMW

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4.2.1 eHMI Study 1: Comprehension of eHMI

Research question / Objective

Section 3.3 provides an overview of the different eHMI designs proposed and the messages they aim to convey. It is important to gain an understanding of whether participants interpret these eHMI signal designs as we intended, and to what extent. Merat et al. (2018) found that participants interacting with an AV would like to have information on the automated status of the vehicle, along with its intended behaviours. The study at the University of Leeds aimed to address this issue by investigating which of these signal designs best conveys the messages ‘I am giving way’, ‘I am in automated mode’ and ‘I will start moving’ using two methods (Lee et al., 2019). The other two proposed interACT messages were not tested in this study mainly because the signal design proposed for ‘AV will turn/AV turns’ is the existent turn indicator, and the nature of the virtual environment used in these experiments precluded an evaluation of any interactions with other vehicles for the ‘AV has detected (one/more) other/specific TPs’.

Method

A VR HMD study was conducted. Twenty participants, with a mean age of 26.85 (S.D. = 4.74) took part in this study. This study compared responses to 10 different eHMI signal designs (Table 15), and focused on 3 messages ‘I am giving way’, ‘I am in automated mode’ and ‘I will start moving’.

Table 15: 10 eHMI signal designs

No.	eHMI signal design based on Section 3.2.1	Description of the eHMI signal design
1	#eHMI_LB_3	Fast pulsing light-band (2 Hz)
2	#eHMI_LB_7	Slow pulsing light-band (0.4 Hz)
3	#eHMI_LB_9	Light-band disappears from front to back
4	#eHMI_LB_5	Light-band appears from back to front
5	#eHMI _SL_1	Fast pulsing single lamp (2 Hz)
6	#eHMI_ SL_2	Slow pulsing single lamp (0.4 Hz)

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No.	eHMI signal design based on Section 3.2.1	Description of the eHMI signal design
7	-	Flashing headlights • This signal design was not described in Section 3.2.1 but was included because flashing headlights is one of the social interactions we observed in society which indicates 'I am giving way' or 'Do not pull out in front of me' based on situations and contexts (citation)
8	#eHMI_AC_2	Slow beeping sound (Pulsing frequency: f=0.4 Hz)
9	#eHMI_AC_1	Fast beeping sound (Pulsing frequency: f=2 Hz)
10	#eHMI_LB_3 #eHMI_AC_1	Multiple modality (Fast pulsing light-band with fast beeping sound) (Puling frequency: 2 Hz)

This study consisted of two main tasks. A paired comparison forced choice task was used in Task 1 in which participants were asked to choose which of two eHMI signal designs best conveyed a particular message (Figure 15). Images of the designs were presented through a head mounted display and participants used a click pointer to select their chosen vehicle.

All 10 eHMI signal designs were paired with each other, resulting in a total of 45 comparisons for each of the three messages. Therefore, Task 1 consisted of 135 trials. The presentation of these trials were randomised and counterbalanced, using a technique described by Wells (1991), to ensure adequate distance between the appearance of the same signal, and an approximately equal number of times that each signal would appear on the left or right vehicle.

Figure 15: The experimental setup of Part 1, paired comparison forced choice task

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The same eHMI options were then rated in Task 2, with participants being asked to rate the extent to which each of the 10 eHMI signals conveyed each of the three desired messages on a 6 point scale (Figure 16). This was a PC-based task.

Figure 16: The experimental setup of Part 2, rating task

Main results

For the message 'I am giving way', data from Task 1 and Task 2 of the studies revealed consistent findings and showed that the Top 3 rated eHMI designs for conveying this message are (7) Flashing headlights, (1) Fast pulsing light-band and (10) Multiple modality (Fast pulsing light-band with fast beeping sound).

For the message 'I am in automated mode', the findings from Task 1 and Task 2 revealed the two top-rated eHMI designs for conveying the message are (2) Slow pulsing light-band and (6) Slow pulsing signal lamp.

Finally, for the message 'I will start moving', the results indicated that the most popular eHMI design is (10) Multiple modality (False pulsing light-band with fast beeping sound); followed by (9) Fast beeping sound and (1) Fast pulsing light-band.

Conclusions / recommendations

Overall, these findings seems to suggest that:

(1) A 360° light-band seems to be more likely to be chosen and to receive a higher rating compared to single lamp.
(2) Faster animation seems to be more likely to be chosen when compared to slower animation, such as fast pulsing as compared to slow pulsing. This finding was especially true for messages which were intended to convey a change in the vehicle's behaviour such as 'I am giving way' and 'I will start moving'. Overall, the pulsing light-band was also more likely to be chosen and receive a higher rating compared to any other animated light-band.
(3) Multiple modality and auditory cues seem to be more likely to be chosen and receive a higher in general, particularly for the message 'I will start moving'.

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This study was conducted to investigate the comprehension of each eHMI signal designs in isolation, without providing any context. Therefore, future studies should focus on the comprehension of these different eHMI signal designs in different environments, as well as exploring the effect of these eHMI signal designs on pedestrians' crossing decisions and behaviour.

4.2.2 eHMI Study 2: To yield vs. not to yield (Weber et al., 2019)

Research question / Objective

We conducted a study on the effects of two eHMIs vs. a baseline. The main research question addressed in this study was the benefit eHMI can bring in respect to baseline - if we need to have eHMI to communicate that the AV yields or does not yield and if there are differences between traffic scenarios.

Method

A VR pedestrian simulator study was conducted. N=30 (16 females) took part in this study (m = 43 years; SD = 13 years). 2 eHMIs were included. The eHMIs consisted of light-band, showing signals in white colour and a display, showing icons in the windscreen in white colour. Only one eHMI was displayed at one time. 2 types of AV intentions (give way, pass) were included. When the AV gave way, the light-band displayed a slow pulsing light. The Icon displayed was a car with a stop line in front Three different traffic scenarios (Zebra crossing, 2 lane streets, and parking space) were included. The pedestrian had to wait on the edge of the curb and decide when he recognized the intention of the AV and press a button at this moment in time. A brief interview was conducted after each scenario

Figure 17: Different eHMI concepts in study 2

Main results

When the AV is communicating the intention to give way, eHMI (slow pulsing light-band) improves intention recognition rates compared to a baseline without eHMI. eHMI (fast pulsing light-band) deteriorates intention recognition when the AV's intention is to pass the pedestrian and go first. Intention recognition times remain constant across scenarios. The light-band seems to be a more fruitful approach than a display showing Icons.

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Conclusions / recommendations

The authors conclude that explicit communication should not be used when the AV is not giving way. Implicit communication through constant speed seems to be enough communication in this case. The slow pulsing light-band is recommended to be used for communicating the intention to give way. It was therefore decided to include the slow pulsing light-band as a baseline signal in the interACT message catalogue. As the fast pulsing light-band was subjectively understood well it should be used for a different message but does not work / is not needed in the context used in this study.

4.2.3 eHMI Study 3: Addressing messages to a single pedestrian

Research question / Objective

A VR pedestrian simulator study was conducted to assess the effect of including detection information in signals and addressing signals towards a pedestrian. Three different eHMIs were included in this study. The aim was to assess if addressing signals to a pedestrian adds information to the signal and improves intention recognition and overall interpretation of the respective signal. Furthermore colour was added to one signal to test if colour holds the potential to improve intention recognition.

Method

A VR pedestrian simulator study was conducted. N=23 (10 females) took part in this study (m = 41.4 years; SD = 12.4 years). 3 eHMIs were included. The eHMIs consisted of light-band variants for conveying the intention to yield. These included a slow pulsing light-band in white colour, a partially lit up light-band aimed at the addressed pedestrian also in white colour, as well as the partially lit light-band with a green colour. A baseline without eHMI was included. When the intention of the AV was not to give way, no eHMI was displayed. Two different traffic scenarios (The 4-way crossing and the parking space scenario from the interACT must-have scenarios) were included. The pedestrian had to wait on the edge of the curb and decide when he recognized the intention of the AV and press a button at this moment in time. A brief interview was conducted after each scenario.

Figure 18: Different eHMI concepts in study 3

Main results

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The eHMI significantly improved intention recognition. No differences between eHMI variants were found. This was interpreted in a way that the pedestrian always feels addressed when he is already in an interactive position with the AV. The green coloured light-band was preferred by the study participants compared to other variants

Conclusions / recommendations

The eHMI significantly improved intention recognition. No differences between eHMI variants were found. This was interpreted as showing that the pedestrian always feels addressed when he is already in an interactive position with the AV. The green coloured light-band was preferred by the study participants compared to other variants

Conclusions / recommendations

From these results, it can be concluded that an intention-based communication alone might be sufficient. It would therefore be best to realise the technically simplest solution by only transmitting the intention of the AV without having to process and display any detection information. It can, however, also be concluded that results might be due to the study setting in which the pedestrian attributed the signal always to himself, as only one pedestrian and only a singular AV were present in the study. Furthermore the preference for the green coloured light-band can be interpreted as an indication to use coloured signals. This was included in the interACT baseline design with the decision to use cyan blue coloured signals.

4.2.4 eHMI Study 4: Intention vs perception based eHMI for different scenarios

Research question / Objective

The aim of the study was to test different eHMI concepts based on the perception-based vs intention-based interaction strategy in different urban scenarios. The main research questions were a) if there is a preference of pedestrians for one of the interaction strategies and b) if there is difference in the preferences of the interaction strategies across different urban driving scenarios (see Figure 19)

Figure 19: Different eHMI interaction strategies

Method

A Virtual Reality pedestrian simulator study was carried out to investigate the interaction of an automated vehicle with a pedestrian. 27 participants (14 males, 13 females) aged 20-67 (mean= 34.4, SD=13.0) took part in the study. Six different light-based designs for eHMI were tested: two related to the interaction-based design strategy, two related to the perception-based design strategy and two related to a combination of both design strategies. The eHMI comprised of a light-band installed at the outside of the vehicle and a directed signal lamp [Willrodt, 2018] installed behind the windshield in the position of the rear-view mirror. The intention-based design was characterized by the AV providing information about its next maneuvers, while the perception-based design focused on signaling detected traffic participants in the environment surrounding of the AV. All designs were tested in three urban scenarios. Those were a crossing scenario, an intersection scenario and a parking scenario. After the participants had seen the eHMIs in Virtual Reality they were asked to rate each eHMI variant in terms of understandability and preference. Furthermore they ranked the different designs for each scenario.

Main results

The tested scenarios had no influence on the preferred eHMI. In all scenarios the perception-based eHMI designs were ranked higher in the subjective ratings compared to the intention-based designs. The eHMI strategy “Combined 2”, comprising a pulsing light-band and a directed signal lamp, was the most preferred eHMI in all scenarios. The second most preferred eHMI design was the HMI “Combined 1” consisting of a dispersing light-band and an animated light-segment realized through the light-band. The eHMI strategies “Combined 2” and “Perception1”, both using a pulsing light-band for the communication with the pedestrian, were rated as most intuitive by the participants.

Conclusions / recommendations

From the study results we conclude that there is no significant difference in the eHMI preference in different urban scenarios and thus, that the same eHMI design could be used in different scenarios. A combination of intention- and perception-based eHMI led to the highest preference ratings compared to design solutions using one of the components – light-band or directed signal lamp.

4.2.5 eHMI Study 5: Addressing messages to drivers in multi-actor scenarios

Research question / Objective

As no significant differences between addressed or non-addressed eHMI variants were found in the previous study which included only one pedestrian, a further AV interaction study was set up to further assess the impact of addressing messages towards specific traffic participants. We decided to run a study with multiple actors, meaning other – simulated – traffic participants besides the actual study participant. To address the other perspectives besides the pedestrian, we conducted the study

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in a car driving simulator including different traffic scenarios. The baseline interaction concepts developed in WP 4.2 including the full light-band, the addressed light-band, and the signal lamp were included in this study (see Figure 20).

Figure 20: Different eHMI concepts in study 5

Method

A driving simulator study was conducted. N=60 (7 females) took part in this study (m = 31.6 years; SD = 10.9 years). Three eHMI variants as well as a baseline were compared in a between groups analysis. One group was presented with the full light-band, only communicating the AVs intention to give way. The second group saw the detection based communication, the addressed light-band pointing in the direction of the addressed driver that the AV yielded for. Group three interacted with an eHMI variant which was only visible when they were addressed, the signal lamp. Participants could only see a signal on the signal lamp, when the AV was yielding to them. Group 4 was the baseline group without any eHMI. All 4 groups were controlled for driving style. Eight traffic scenarios with differing priorities and different viewing angles between the respective participants were included. For instance 3 actors (participant, AV and a third car) arrived at the same 4 way crossing at the same point in time. The participant and the other AV were positioned either in opposite or in similar viewing angles. The legal priority could be on the participants', the AV's, or the other manually driven cars' side.

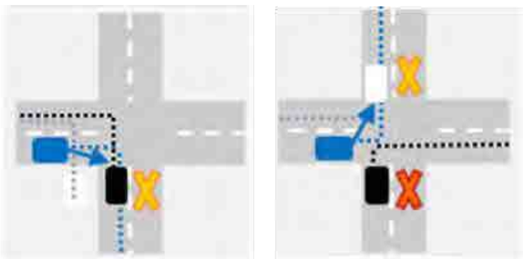

Figure 21: Tested scenario in study 5

Main results

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No effects of eHMI on crossing time were found. Subjective clarity was not significantly improved throughout the course of the whole experiment. However, if only the second half of all trials were analyzed, to account for learning effects occurring in the first half of the trials, eHMI improved subjective clarity significantly for the fully pulsing light-band as well as the single lamp. Furthermore, participants judged the AV equipped with the full light-band as well as the AV equipped with the signal lamp to be more efficient and more reliable than the baseline AV without any eHMI.

Conclusions / recommendations

It can be stated that both the intention-based light-band and the detection based signal lamp help in improving subjective assessment of an AV interaction situation, once the interaction pattern has been established. As crossing times were not improved we cannot draw the conclusion that any of these eHMI variants has the potential to improve traffic flow. The results of this study might be limited to driver-AV interaction. This issue has to be researched further in pedestrian settings to derive a conclusion on the best suitable interaction patterns.

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4.3 Studies for defining the final interaction strategies for iHMI

The studies conducted within WP 4 to investigate interaction strategies for the iHMI are described in the following sub-chapters. The following Table 16 gives an overview about all WP 4 studies which are described more in detail in Annex 3.

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Table 16: Overview of conducted studies within interACT WP4 for iHMI

Study name	Main research questions	Tested interaction strategies	Tested scenarios	No of participants	Test environment	Responsible partner
iHMI expectation assessment	What kind of iHMI do users prefer? Does the preference differ for different scenarios? Does the preference differ according to the distraction level of the user?	Perception-based Intention-based	2. React to crossing non-motorised TP at crossings without traffic lights 3. React to non-motorised TP at a parking space	12	Questionnaire and interview study	DLR
iHMI design evaluation	Which HMI design variant do users prefer? Which kind of HMI hardware do users prefer? Does the preference differ according to the traffic scenarios?	Perception-based Intention-based	2. React to crossing non-motorised TP at crossings without traffic lights 3. React to non-motorised TP at a parking space	33	VR simulator	DLR

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4.3.1 iHMI Study 1: iHMI expectation assessment

Research question / Objective

The aim of the study was to understand the expectations and preferences of on-board users with regards to their information needs.

In order to achieve that we conducted a study to understand the following:

- The importance of information about traffic participants (TP) in 2 different urban traffic situations for manual driving, automated non-distracted and automated distracted driving.
- The information richness needed for the iHMI in interaction-demanding situations
- Furthermore, we evaluate 4 (paper-pencil) HMI design prototypes, for 3 different interfaces namely Head-Up display (HUD), Head-Down display (HDD) and light-band

Method

A 3 step qualitative study was conducted, with a focus group of N = 12 participants (m = 48 years SD = 23.9), with a balanced distribution of gender (6 males, 6 females) and age (6 young m= 25.17 years SD = 1.9 and 6 old, m = 70.83 years SD = 3.4). The two traffic situations tested were a right turn at a non-signalised intersection (RT) and a parking space (PS) respectively. The first part of the study focused on understanding the importance of different surrounding Traffic Participants (TPs) for the on-board user when driving manually, and how, and whether, this importance changes in different scenarios. The study participant was seated in a simulator acting as a driver, and video from driver's perspective was presented to them. The second part assessed the significance of TPs when driving fully automated without distraction, compared to driving automated with distraction by engaging in a secondary task (reading a magazine). The second part included a simulation of an automated driving experience. The importance of surrounding TPs for the on-board user was measured for significant phases of traffic situations (photos from the video) on a Likert scale of 1 to 7, and followed by interviews to gain deeper insights. Within the third part of the study we evaluate 4 HMI (paper-pencil) design prototypes, presenting 4 levels of information richness using 3 interfaces, HUD, HDD and light-band. The 4 levels of information richness consisted of Baseline (Automation status and speedometer), Baseline+ Environment information –i.e., Detection of a TP (pedestrian/car), Baseline + Environment + informing about the intention (here braking) and Baseline + Environment + Intention + Next maneuver (AV will turn left). The usability was first assessed by measuring, the comprehensibility (naïve run asking what participants understand from design), and after understanding the design we measured usability (van der Laans scale and questionnaire), and finally ranked intuitiveness and general preferences (using card sorting). The differences between gender and age were also analysed.

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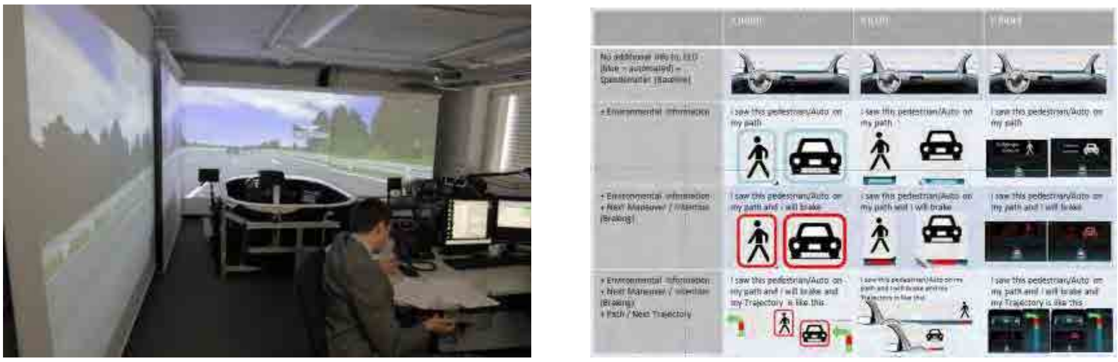

Figure 22: Experimental setup of iHMI study 1

Main results

Not surprisingly, the importance of surrounding traffic participants for the on-board user decreases from manual driving to automated driving. Also information about surrounding TPs was more important in automated driving when the on-board user was not distracted, compared to driving automatically when being distracted. The most important TPs were the ones who had the right of way or, alternatively speaking, whose path the vehicle crossed. There might be an effect of age and gender, showing that older women tend to require more information. In the first, naïve run, the light band was ranked the least intuitive because participants found some parts especially the "next maneuver" difficult to understand. However once the design was explained, the light-band was one of the most preferred designs ranked best by majority of the participants for both automated drive - distracted and non-distracted. The baseline including information on the automation status and speedometer, was sufficient information richness level among all, but male participants in particular would prefer more information on detected objects in the environment (Baseline + Environment (TPs)).

Conclusions / recommendations

In general, the main conclusion/recommendation is that the iHMI interface and design should not be too visually demanding. Especially while automated driving, drivers will most probably be engaged in other visually demanding tasks. Therefore the information on HMI should be minimal and not distracting. The automation status and speedometer usually provide sufficient information for automated driving especially when the user of an AV is involved with a secondary task. Additional information about TPs directly in the AV's path can be provided. The use of red colour is not recommended for HMI messages apart from conveying warning or danger information. The user requirements in terms of age and gender should be considered when designing an HMI for optimal usability.

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4.3.2 iHMI Study 2: iHMI evaluation

Research question / Objective

Based on the results and recommendations of our previous iHMI expectation assessment study, we conducted a second iHMI usability study focusing on the light-band with rather minimal information provided for the on-board user compared with a Head-Down Display (HDD) as benchmark. The experimental setting was realized in a virtual reality simulation (VR). The main research questions addressed in this study were whether different iHMI interaction approaches (light-band vs. HDD), delivering additional information about an AV's interaction with a pedestrian (perception- vs. intention-based vs AV's automation level only), are perceived more or less favorably, and whether they thereby enhance the on-board user's acceptance in different use cases?

Method

We conducted a VR-simulated on-board user study. *N* = 33 (14 females) participants with a mean age of 34.06 years (*SD* = 11.37 years; *range* = 19 – 58 years) took part in this experimental usability study with a 3x2x2 within-subjects design. Participants experienced 12 simulated AV rides each with a single AV - pedestrian interaction in either of two different use cases (parking lot vs. left turn). Information was provided on a light-band or on a Head-Down Display (HDD), with three different iHMI interaction approaches (baseline, i.e., only showing the automation mode, vs. perception-based, i.e., showing the pedestrian detected by the AV, vs. intention-based, i.e., showing AV's acceleration or deceleration). For the intention-based approach, the Light-band communicated acceleration with a fast pulsing and deceleration with a slow pulsing turquoise light signal. For the perception-based approach, the Light-band communicated the perception of a pedestrian by a highlighted bar on the Light-band following the pedestrian (see Figure 23). The HDD communicated all text- and icon-based information on a display located at the AV's central console. Participants were instructed about the different iHMI versions before the test runs and rated their perceived safety and comfort using the AV and its iHMI as well as its usability.

Figure 23: Perception- (left) and intention-based (right) light-band iHMI in the interior of the AV in a parking lot use case

Main results

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In general participants significantly preferred light-band-based iHMI versions, and perception-based interaction approaches both for the light-band and HDD. The baseline only was the least preferred interaction approach for both output media. In both use cases, we observed that the perception-based versions for light-band and, to some extent, HDD were rated as pleasurable. This seems to be slightly pronounced in the parking lot use case. With regard to ease of information access provided by the iHMI versions, no differences were found for the HDD, but differences for the light-band-based interaction approaches emerged for both use cases. The intention-based, and especially the perception-based, interaction approach were rated as significantly easier to understand, i.e., to access the provided information, compared with the baseline.

Conclusions / recommendations

Bringing together the findings with regard to AV's iHMI design, a perception-based interaction design conveyed via light-band output media is recommended. This confirms our previous results out of the iHMI expectation study. However, after summarizing the study results, some further research issues came up. As participants' arousal levels were low in both use cases it might be of interest to establish if subjective ratings would change for more critical use cases or scenarios? Additionally, conveying information to the on-board user about the AV's interaction with multiple other traffic participants is an open research question. Last but not least, the combination of a perception- and intention-based iHMI interaction approach and its possible adaption to different use cases or on-board users, e.g., like elder users or unexperienced users, might be a crucial issue to be addressed for on-board user's acceptance and user experience.

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5. Interaction strategies to be implemented in demonstrator vehicles

The design principles chosen in WP 4.2 were applied to the interaction strategies which will be implemented into the interACT demonstrator vehicles. One major design principle is the avoidance of information overflow. Therefore, optimized driving behaviour is the basis of clear communication and clear interaction. eHMI is used in situations where additional benefit is expected.

5.1 Interaction strategy for driving behaviour

The interACT demonstrator vehicles should communicate their intentions clearly through driving behavior. The WP 4 partners decided that clear driving behavior should correspond to optimal driving behavior observed in current, manually driven traffic. Therefore WP 2 results were considered for implementing an optimal driving strategy in the demonstrator vehicles. The recommended strategy is therefore to adapt deceleration behavior so that deceleration is clearly recognizable, and the expected time to arrival shall be greater than 3-4 s for pedestrians and 5-6 s for vehicles. The AV does not need to come to a full stop as slow driving below 3km/h seems to be accepted. In shared space scenarios lateral distance should be maximized without impeding other passing traffic.

5.2 Interaction strategy for eHMI

eHMI Design: One main interaction design and two secondary designs

Having completed the planned studies, the WP4 partners decided to reduce the design space further and implement the most suitable solutions into the interACT demonstrator vehicles for final evaluation within interACT. It was decided to implement one main eHMI interaction design and two secondary designs, as the findings of the WP 4 studies were not conclusive enough to discard all other designs.

The intention-based baseline design described throughout chapter 3 and 4 was found to be a very fruitful approach and will be implemented as main design. The signals used in the intention-based baseline design were shown to be matched well to the messages that should be communicated to the TPs (Study 1) (e.g. rapid pulsing for “AV will start moving” or slow pulsing for showing “AV will give way”). Study 1 also showed that a multimodal approach will be beneficial. We will solve this by displaying an artificial engine noise changing with velocity which is emitted by the BMW i3 already today and combine this acoustic signal with the eHMI signals. It was furthermore confirmed (study 2) to refrain from communication in situations, which do not require interaction (such as communicating that the AV will not give way). We therefore decided to not pursue a specific signal for displaying the

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AV's automation status permanently. The interACT AV will only signal that it is driving in automated mode in situations where interaction is necessary, by communicating with specific signals (such as slow pulsing for communicating the intention to yield).

In the studies described in chapter 4 it could not be shown that the perception-based design variants led to benefits in TP behaviour in the scenarios where the AV yielded to other TPs (studies 3 and 5). However TPs in study 4 preferred perception-based, and in particular, a combined interaction strategy, over a purely intention-based strategy. We therefore decided to include a design variant for both of these strategies in the Interact demonstrator vehicle. For the perception-based interaction strategy the signal #eHMI_LB_11 (secondary design 1) on the light-band will be included. For the combined strategy a sequence of the intention-based slow-pulsing light-band, as well as the illumination of the signal lamp for the TP who is addressed (secondary design 2), will be implemented. Details can be seen in the detailed signal flows in section 5.4. These additional design variants are considered to be the secondary designs which will not be thoroughly evaluated in WP 4, but can serve as an additional design if the interACT researchers discover shortcomings of the selected intention-based design in the WP 6 evaluation.

All other signal designs for the interact messages besides the main design and secondary designs 1 and 2 were dropped and will not further be pursued. An adapted catalogue of messages and the respective signal designs can be found in Table 17.

Table 17: interACT message catalogue and the respective signal design for eHMI

Intention communication: Next manoeuvre		**Signal design chosen**	**Signal #**
NM_13 & NM_14	AV will turn	Turn indicator	#eHMI_TI_1
NM_4 & NM_5	AV turns	Turn indicator	# eHMI_TI_1
NM_9	AV will start moving	Fast pulsing light-band	#eHMI_LB_3
-	AV starts moving	Fast pulsing light-band	# eHMI_LB_3
Intention communication: Cooperation Capability			
CC_1	AV gives way *(Message was changed from "AV gives right of way" compared to D4.1)*	Slowly pulsing light-band	#eHMI_LB_7

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Secondary design			
Environmental perception			
EP_1 & EP_2	AV has detected (one or more) other/specific TP	Lit up light-segment on light-band	#eHMI_LB_11
Combined design: cooperation capability + perception of TP			
	AV gives way AV has detected (one or more) other/specific TP	Slowly pulsing light-band and signal lamp lights up shortly afterwards	#eHMI_LB_7 #eHMI_SL_2
Dropped messages for further implementation			
Other messages of lower priority			
VDM_1	AV drives in automated mode		
-	Temporal indication (e.g. searching for a parking slot)		
CC_9	AV says "thank you"		
CC_10	AV indicates "irritation"		
CC_11	AV has technical problems		

Interactions between driving behaviour and eHMI: Display point in time

Throughout implementation of the eHMI into the interACT demonstrator vehicles, the exact display parameters of the eHMI will be refined and tested again before undergoing thorough evaluation in WP 6.

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5.3 Interaction strategy for iHMI

Based on the results of the participant studies, the WP4 partners decided to follow the following strategies:

First of all, one common HMI strategy could be used for all interACT scenarios, as there were no differences in the preference ratings from our participant studies. Further, the information provided to the user on-board could be reduced to the most essential messages to avoid overload and distraction by too salient signal which catch attention (unintentionally) of the user. Having this in mind, no iHMI design for the message “AV will start moving” was used since this message was not identified as essential and would have to be communicated very often, causing a disturbance. Additionally, the information richness could be adjusted to the user state in a way that the non-attentive user receives less information than an attentive user. With regards to the user preferences shown in the results of our studies, we decided to use perception-based design solutions for either the light-band or the automation display.

Table 18: interACT message catalogue and the respective signal design for iHMI

Environmental perception			
EP_1 & EP_2	AV has detected (one or more) other/specific TP	Lit up light-segment on light-band or Indication of TP on display	#iHMI_LB_4 or #iHMI_AD_3

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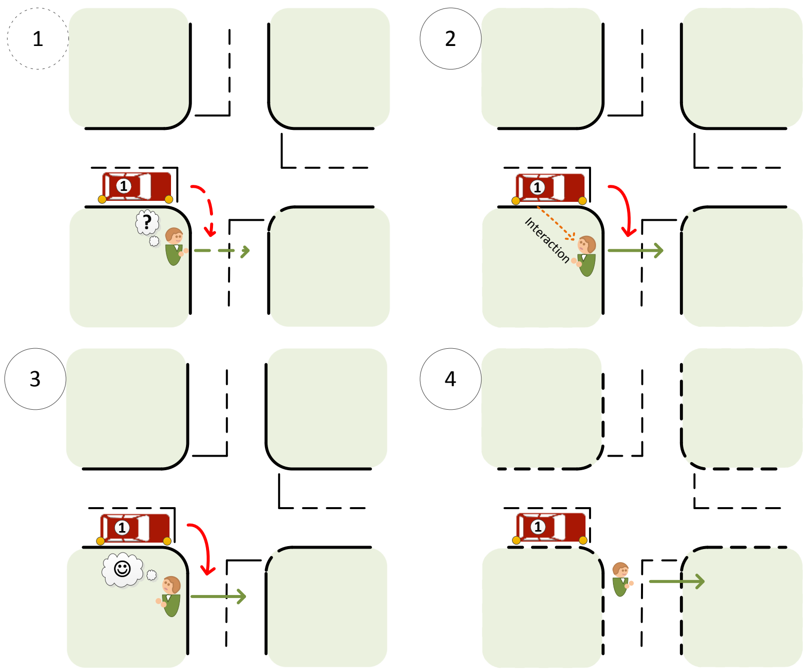
5.4 Description of interaction strategies per scenario

5.4.1 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 signalises its perception of the environment and/or intention and waits for the pedestrian to cross. The pedestrian crosses and the AV continues turning.	
Traffic &	Right of way	☐ AV

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Environment		☒ 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
	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

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		☒ 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
	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)
	Attention other TP	☒ Yes

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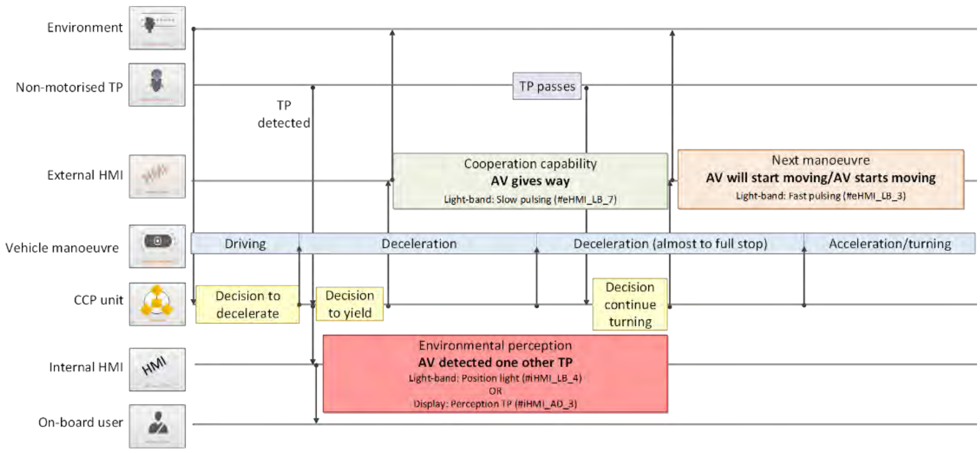
<table>
<tr><td></td><td></td><td>☐ No</td></tr>
<tr><td>Sequence diagram</td><td colspan="2">
Main design: Intention- based eHMI; perception-based iHMI



The sequence diagram of the main design describes the AV’s main manoeuvres in chronological sequence (blue boxes). Firstly, the 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 that it will give way to the pedestrian with a slow pulsing of the light-band (signal #eHMI_LB_7). Further, the on-board user is informed that the AV has detected the traffic participant. This can be indicated by a position light (signal #iHMI_LB_4) on the light-band or the message “TP detected” (signal #iHMI_AD_3) on the display. After the traffic participant has crossed the road, the AV decides to continue turning. The other TPs are informed about the next manoeuvre of the AV by illuminating the light-band with a fast pulsating flashing (signal #eHMI_LB_3).

Secondary design 1: perception-based design eHMI and iHMI
</td></tr>
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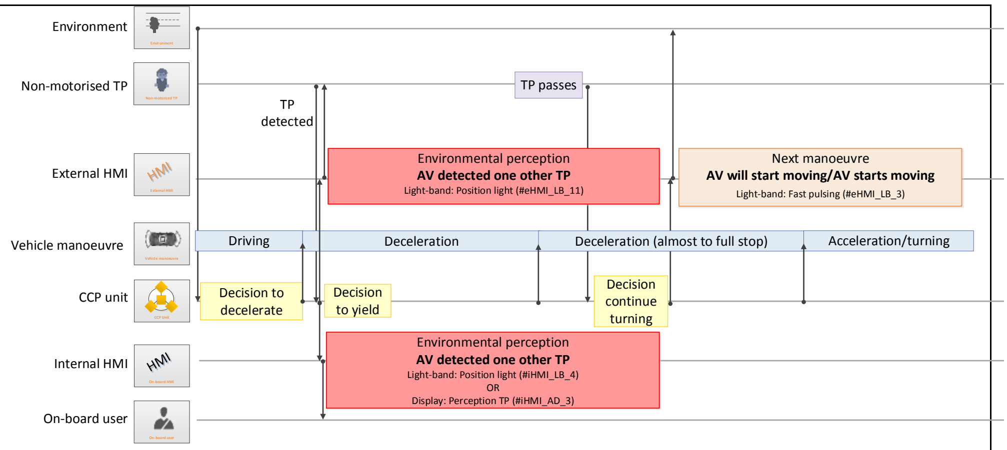
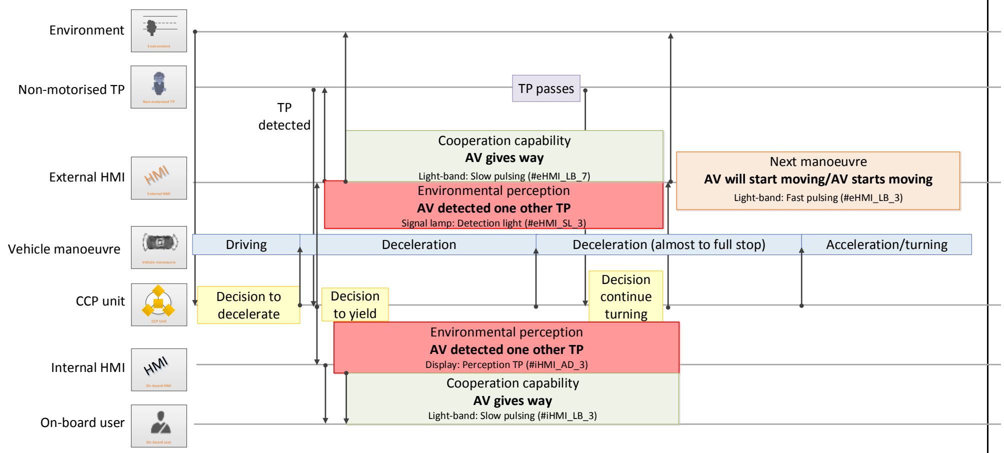


The sequence diagram of the secondary design 1 describes the AV's main manoeuvres in chronological sequence (blue boxes). Firstly, the AV decelerates due to traffic. After the detection of the traffic participant who wants to cross the road the AV decides to yield for the pedestrian. The AV slows down further to almost a full stop. In parallel the AV indicates that it has detected one other traffic participant by illuminating a segment on the light-band facing in the direction of the pedestrian (signal #eHMI_LB_11). Further, the on-board user is informed that the AV has detected the traffic participant. This can be indicated by a position light (signal #iHMI_LB_4) on the light-band or the message "TP detected" (signal #iHMI_AD_3) on the display. After the traffic participant has crossed the road, the AV decides to continue turning. The other TPs are informed about the next maneuver of the AV by illuminating the light-band with a fast pulsating flashing (signal #eHMI_LB_3).

Secondary design 2: combination perception + intention- based design eHMI + iHMI



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	The sequence diagram of the secondary design 2 describes the AV's main manoeuvres in chronological sequence (blue boxes). Firstly, the 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. Shortly after the onset of the intention, the signal lamp switches on communicating the perception of the pedestrian (signal #eHMI_SL_2). Thereby, this message is directly addressed to the detected TPs. The AV slows down further to almost a full stop. In parallel, the AV indicates that it will give way to the pedestrian with a slow pulsing on the light-band (signal #eHMI_LB_3). Further, the on-board user is informed that the AV has detected another traffic participant by the text message "TP detected" (signal #iHMI_AD_3) on the display. In addition a slow-pulsing light-band in the interior informs the one-board user, that the AV gives way to the pedestrian (#iHMI_LB_3). After the traffic participant has crossed the road, the AV decides to continue turning. The other TPs are informed about the next manoeuvre of the AV by illuminating the light-band with a fast pulsating flashing (signal #eHMI_LB_3).

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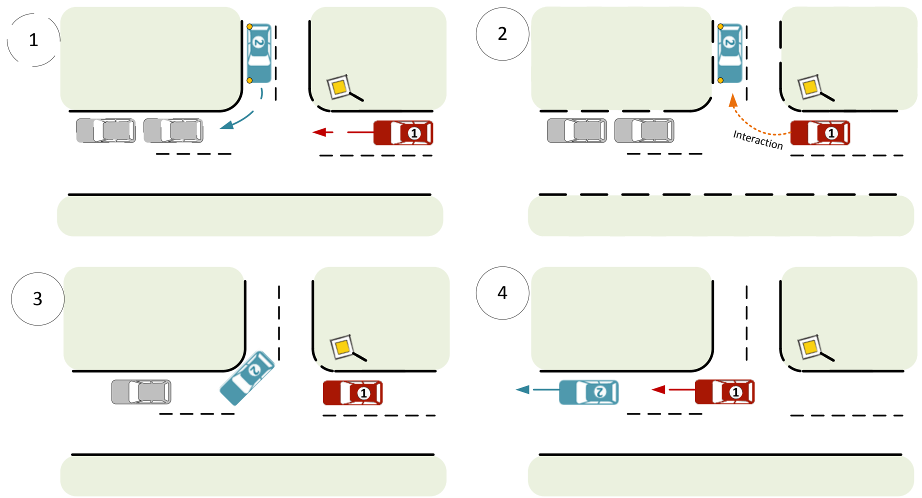
5.4.2 Interaction strategies for scenario 2

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

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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) ☐ 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

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		☐ 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
	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

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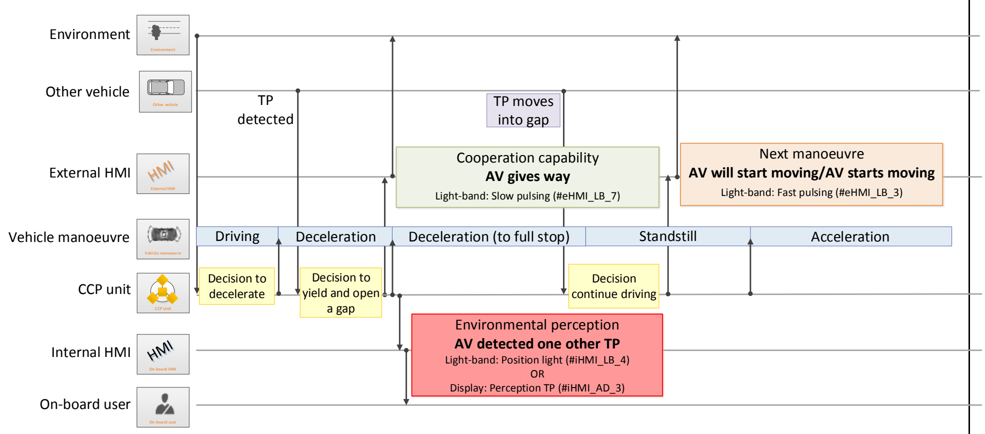
Sequence diagram	Main design: Intention-based design eHMI; perceptionbased design iHMI
	 The sequence diagram of the main design describes the AV's main manoeuvres in chronological sequence (blue boxes). Firstly, the AV detects another vehicle and decelerates due to its decision to open a gap for this vehicle. The AV slows down further to almost a full stop. In parallel the AV indicates that it will give way to the vehicle with a slow pulsing on the light-band (signal #eHMI_LB_7). Further, the on-board user is informed that the AV has detected the traffic participant. This can be indicated by a position light (signal #iHMI_LB_4) on the light-band or the message "TP detected" (signal #iHMI_AD_3) on the display. After the vehicle has merged in, the AV decides to continue driving. The other TPs are informed about the next manoeuvre of the AV by illuminating the light-band with a fast pulsating flashing (signal #eHMI_LB_3).

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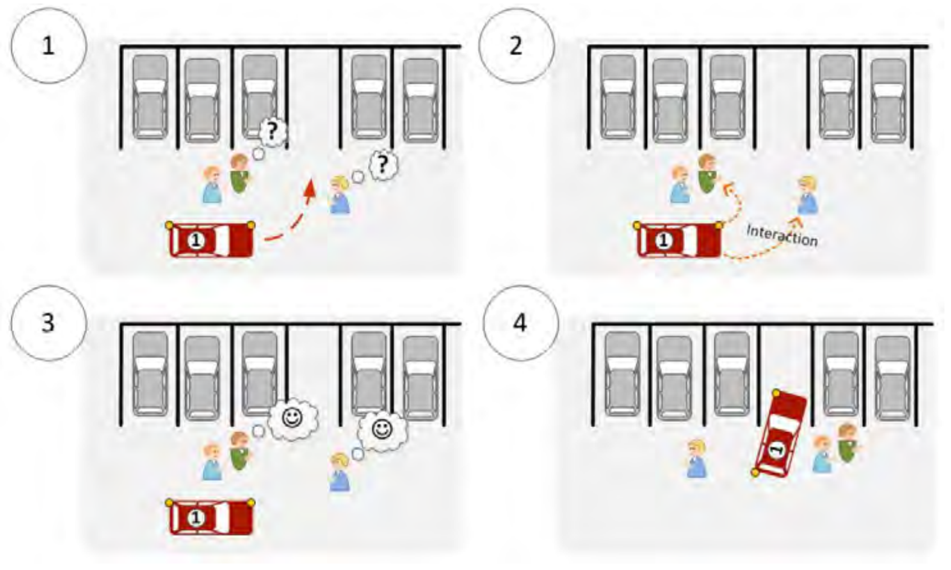
5.4.3 Interaction strategies for scenario 3

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
Graphical representation		
Verbal description	The AV is driving on a parking lot, searching for a parking space. The AV arrives at a free parking space, 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 space is free, the AV enters the parking space.	
Traffic & Environment	Right of way	☐ AV ☐ other TP ☒ Undefined
	Longitudinal distance (headway)	☒ < 3m

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		☐ 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 ☐ 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

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		☐ 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)
	Attention other TP	☒ Yes ☐ No
	Main design: Intention-based eHMI; perception-based iHMI design	

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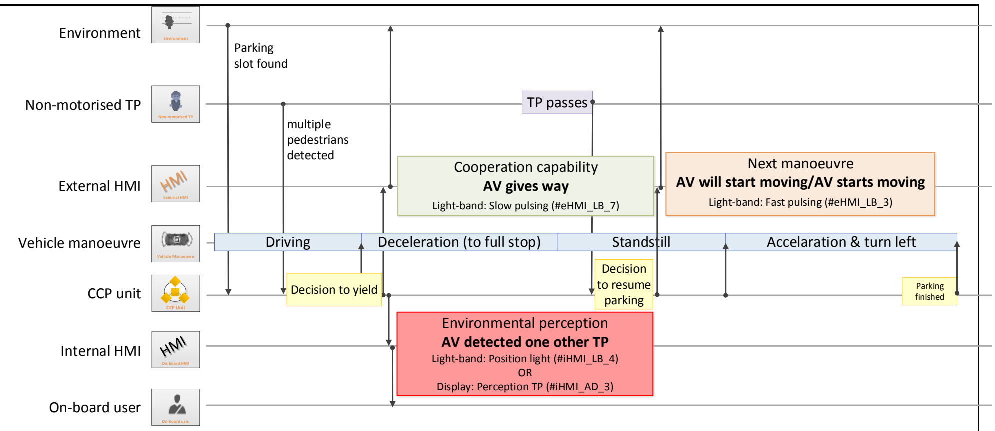
<table>
<tr>
<td>Sequence diagram</td>
<td>


The Sequence diagram of the main design describes the AV’s main manoeuvres in chronological sequence (blue boxes). First, the AV is driving slowly while it is searching for a parking space. Once the parking space has been found, it will park and will turn left to enter the detected parking space. While still proceeding onwards, multiple pedestrians are detected. The AV decides to decelerate and to yield for the pedestrians. The AV slows down further to almost a full stop. In parallel the AV indicates that it will give way to the pedestrian with a slow pulsing on the light-band (signal #eHMI_LB_7). Further, the on-board user is informed that the AV has detected the traffic participant. This can be indicated by a position light (signal #iHMI_LB_4) on the light-band or the message “TP detected” (signal #iHMI_AD_3) on the display. Once the pedestrians have passed, the AV takes the decision to resume parking. The AV communicates via external HMI to the environment that it will start moving by illuminating the light-band with a fast pulsating flashing (signal #eHMI_LB_3). It then starts actually moving and parking, until the manoeuvre is finished and the car is safely parked.
</td>
</tr>
</table>

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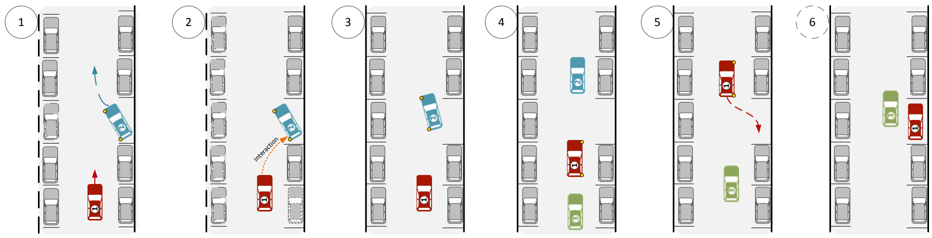
5.4.4 Interaction strategies for scenario 4

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 lot while searching for a parking space. The AV approaches a vehicle which wants to leave a parking spot. The parking space 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 space.	
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) ☐ 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

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	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
	Age of TP	☒ Not in focus ☐ 3-17 years ☐ 18-60 years ☐ > 61 years
	Impairment of the TP's perception	☒ No impairment ☐ View ☐ Acoustic ☐ Both (view and acoustic)
	Attention other TP	☒ Yes ☐ No

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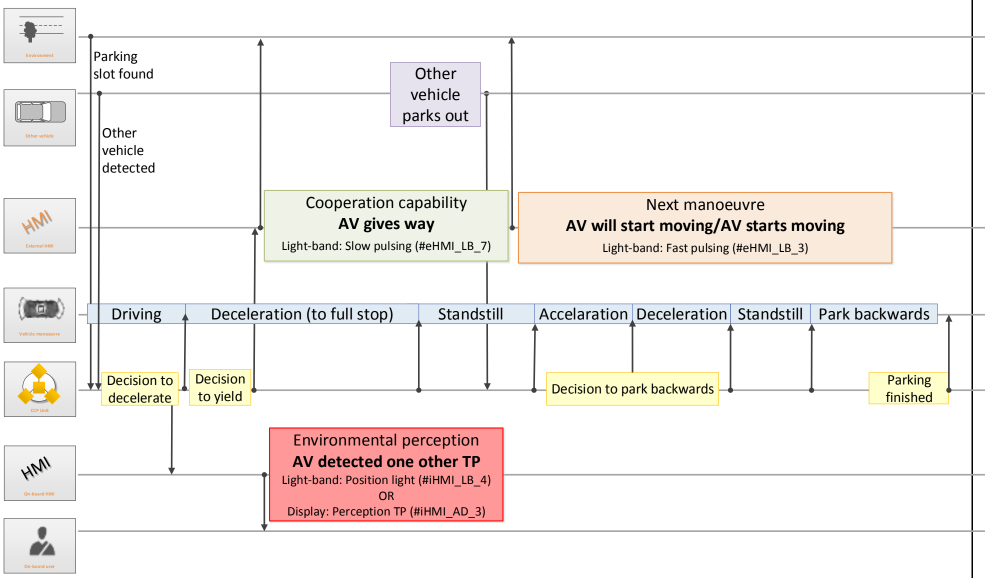
<table>
<tr>
<td>Sequence diagram</td>
<td>

Main design: Intention-based eHMI; perception-based iHMI design



The sequence diagram of the main variant describes the AV's main manoeuvres in chronological sequence (blue boxes). First, the AV is driving slowly on a parking lot. The AV approaches another vehicle which wants to pull out of a parking space. The AV slows down to a full stop. In parallel the AV indicates that it will give way to the other vehicle with a slow pulsing on the light-band (signal #eHMI_LB_7). Further, the on-board user is informed that the AV has detected the other vehicle. This can be indicated by a position light (signal #iHMI_LB_4) on the light-band or the message "TP detected" (signal #iHMI_AD_3) on the display. Once the other vehicle has successful pulled out the AV communicates via external HMI to the environment that it will start moving by illuminating the light-band with a rapidly pulsating flashing (signal #eHMI_LB_3). It then starts actually moving and parking backwards, until the manoeuvre is finished and the car is safely parked.

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

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6. Conclusions

interACT developed several interaction designs as well as concrete signal design variants within task 4.2. These variants were thoroughly evaluated in participants studies and optimized in an iterative manner within task 4.2. It can be concluded that eHMI improves interaction over a solely optimized driving behaviour, and should be implemented into the interACT demonstrator vehicle. Further, information for the on-board user helps to increase the awareness and trust of the use about the AV environment detection and reaction to it. Therefore a main eHMI and iHMI design and two secondary designs were chosen to be developed in task 4.3, and implemented into the interACT demonstrator vehicle in WP 5. The design choices made in this document are based on a limited number of scenarios, and there might be a need to communicate perception- information in other situations which have not been tested in the evaluation studies under WP 4. However, the results of the participant studies showed no main differences for the scenarios tested and it can be assumed that the chosen interaction strategies could be applied to other scenarios as well. There are also other research questions which could not be fully answered within WP4. For instance, although the results of the WP4 studies suggest that only situation specific communication is needed and other studies suggest that automation status indication is not beneficial (Rodríguez Palmeiro et al., 2018), it is still unknown if a permanent display of an automation status is beneficial in certain scenarios and which scenarios this will be.

In the further course of the project, the main interaction design strategies will be implemented in the interACT demonstrators (WP5) and will be part of all of the evaluation studies within WP 6. They will be thoroughly evaluated in simulator studies and real life test to establish if it is suitable for deployment in real traffic, and where further improvements can be made. If shortcomings of the main design are found in the WP 6 evaluations the secondary designs have to be tested in these scenarios and further design improvements can be made based on the final evaluation results.

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Annex

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Annex 1: interACT – signal design catalogue eHMI: Message "AV drives in automated mode"

Signal No.	Signal Design	Number of TPs	Description
No.: eHMI_LB_1	Light-band: Static active Signal lamp: no signal	Same for "single TPs" and "multiple adressed TPs" 	The full light-band is "on" when AV drives in automated mode. Signal lamp is "off" Light emitting surface of light- band: 10mm Colour: Cyan Brightness: 100%

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No.: eHMI_LB_2	Light-band: no signal Signal lamp: no signal	Same for “single TPs” and “multiple adressed TPs” 	The full light-band is “off” when AV drives in automated mode. Signal lamp is “off”

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interACT – signal design catalogue eHMI: Message “AV will turn” and “AV turns”

Signal No.	Signal Design	Number of TPs	Description
No.: eHMI_TI_1	Light-band: no signal Signal lamp: no signal Included as baseline in the studies	Same for “single TPs” and “multiple adressed TPs” 	The full light-band and the signal lamp are “off” when AV will turn/turns. The turning manoeuvre will be indicated through the conventional turning indicators. Frequency of turn indicator: 1,5 Hz ± 0,5 Hz (prescribed by law)

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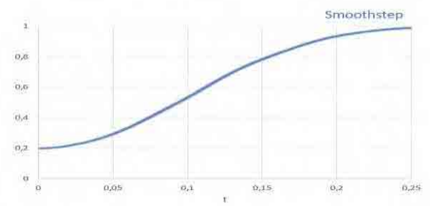
interACT – signal design catalogue eHMI: Message “AV will start moving” and “AV starts moving”

Signal No.	Signal Design	Number of TPs	Description
No.: eHMI_LB_3	Light-band: Fast pulsing Signal lamp: no signal Included as baseline in the studies	Same for “single TPs” and “multiple adressed TPs” 	The full light-band pulses fast when the AV will start moving/starts to move. The signal lamp is “off” Light emitting surface of light-band: 10mm Colour: Cyan Frequency of light-band: 2,0 Hz Brightness: 20% - 100% (smooth step interpolation) 

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No.: eHMI_LB_5	Light-band: appears from back to front Signal lamp: no signal	Same for “single TPs” and “multiple adressed TPs” 	While standstill the light-band is turned off. When AV will start moving the light-band is filled very quickly with cyan (beginning at the back filling from both sides to the front). When all LEDs are cyan again the AV (waits 1sec) and starts moving. Light emitting surface of light-band: 10mm
No.: eHMI_LB_6	Light-band: “filled” partially with cyan Signal lamp: no signal	Same for “single TPs” and “multiple adressed TPs” 	While standstill the light-band is turned off. When AV will start moving the light-band is filled partially cyan (beginning at section starting point). When all LEDs are cyan again the AV (waits 1sec and) starts moving. Size and distance: to be defined

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No.: eHMI_SL_1	Light-band: no signal Signal lamp: fast pulsing	Same for “single TPs” and “multiple adressed TPs” 	The signal lamp is pulsing fast while the light-band is “off” when the AV will start moving. The signal lamps allows an early communication due to the higher visibility in larger distance. Colour: Cyan Frequency of signal lamp: 2,0 Hz
No.: eHMI_AC_1	Auditory signal : Fast beeping sound Light-band: no signal Single lamp: no signal	Same for single and multiple TP’s 	Auditory signal extracted from https://freesound.org/people/datwilightz/sounds/194283/ The auditory signal beeping fast when the AV will start moving/starts to move. The light-band and signal lamp are “off” Frequency of beeping sound : 2,0 Hz

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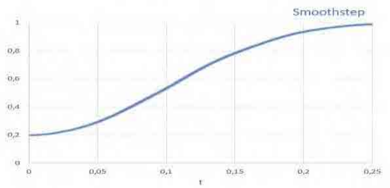
interACT – signal design catalogue eHMI: Message “AV gives way”

Signal No.	Signal Design	Number of TPs	Description
No.: eHMI_LB_7	Light-band: Calmly pulsing Signal lamp: no signal Included as baseline in the studies	Same for “single TPs” and “multiple adressed TPs” 	The full light-band pulses calmly when the AV gives way. The signal lamp is “off” Light emitting surface of light-band band: 10mm Colour: Cyan Frequency of light-band: 0,4 Hz Brightness: 20% - 100% (smooth step interpolation) 

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No.: eHMI_LB_8	Light-band: position light Signal lamp: no signal	Single TP  Multiple TPs 	Segment of light-band in direction of HRU lit up (calmly breathing to improve detection). Segment moves to stay directed to HRU, when AV and HRU change their relative position. Frequency: 0,4Hz Brightness: 100% Size: approx. 40cm Colour cyan Surface: 10mm

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No.: eHMI_SL_2	Light-band: no signal Signal lamp: calmly pulsing	Same for “single TPs” and “multiple adressed TPs” 	The signal lamp is pulsing calmly while the light-band is “off” when the AV gives way. The signal lamps allows an early communication due to the higher visibility in larger distance. Longer range to communicate early? Then switch to light-band? Colour: Cyan Frequency of signal lamp: 0,4 Hz
No.: eHMI_LB_9	Light-band: disappears from front to back Signal lamp: no signal	Same for “single TPs” and “multiple adressed TPs” 	While approaching a situation where the AV wants to give way, the light-band slowly turns off beginning at the front and slide back to the rear end of the AV. simultaneously on both sides. Colour: Cyan Duration: 8s until light-band is completely off

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No.: eHMI_LB_10	Light-band: slowly turns "off" Signal lamp: no signal	Same for "single TPs" and "multiple adressed TPs" 	While approaching a situation where the AV wants to give way, the light-band slowly turns off **(each section partially)** simultaneously at all sections. Size and distance: to be defined Colour: Cyan Duration: 8s until light-band is completely off
No.: eHMI_AC_2	Auditory signal : Slow beeping sound Light-band: no signal Single lamp: no signal	Same for single and multiple TP's 	Auditory signal extracted from https://freesound.org/people/datwilightz/sounds/194283/ The auditory signal beeping slow/calmly when the AV gives way. The light-band and the signal lamp are ''off''. Frequency of beeping sound : 0,4 Hz

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interACT – signal design catalogue eHMI: Message “AV has detected (one or more) other/specific TPs”

Signal No.	Signal Design	Number of TPs	Description
No.: eHMI_LB_11	Light-band: position light Signal lamp: no signal	Single TP  Multiple TPs 	Segment of light-band in direction of HRU lit up. Segment moves to stay directed to HRU, when AV and HRU change their relative position. Brightness: 100% Size: 30cm -40cm Colour: cyan

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No.: eHMI_SL_3	Light-band: no signal Signal lamp: steady light	Same for “single TPs” and “multiple adressed TPs” 	Signal lamp shows steady light signal (only visible for addressed TP). Signal is only visible for HRUs in an angular range of approx. 70 degree. Colour: Cyan

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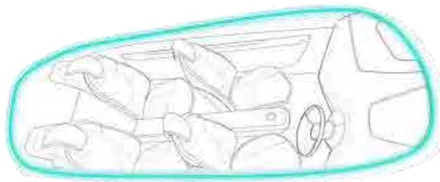
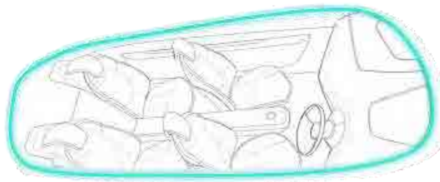
interACT – signal design catalogue iHMI: Message "AV will start moving" and "AV starts moving"

Signal No.	Signal Design	Number of TPs	Description
No.: iHMI_LB_1	Light-band: Fast pulsing Additional Display: no signal		Fast pulsing of the 360° interior light-band. Brightness: 100% Frequency: 2 Hz Colour: cyan
No.: iHMI_LB_2	Light-band: Fading position light Additional Display: no signal		Exiting/vanishing information about relevant interaction partner on light-band

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No.: iHMI_AD_1	Light-band: no signal Additional Display: Text		Indicating that the AV starts moving

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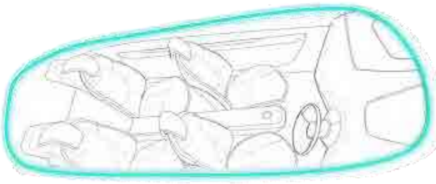
interACT – signal design catalogue iHMI: Message “AV gives way”

Signal No.	Signal Design	Number of TPs	Description
No.: iHMI_LB_3	Light-band: slow pulsing Additional Display: no signal		Slow pulsing of the 360° interior light-band. Brightness: 100% Frequency: 0.5 Hz Colour: cyan
No.: iHMI_AD_2	Light-band: no signal Additional Display: Text		Indicating that the AV will brake via static text message and icon

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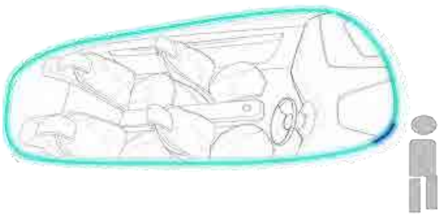
interACT – signal design catalogue iHMI: Message "AV has detected (one or more) other/specific TPs"

Signal No.	Signal Design	Number of TPs	Description
No.: iHMI_LB_4	Light-band: position light Additional Display: no signal	Single TP 	Segment of interior light-band in direction of HRU lit up. Segment moves to stay directed to HRU, when AV and HRU change their relative position. Brightness: 100% Size: 30cm -40cm Colour: cyan

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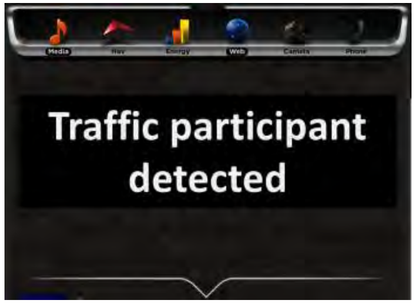
No.: iHMI_AD_3	Light-band: no signal Additional Display: Text	Same for “single TPs” and “multiple adressed TPs”  	Indicating that the AV has detected other traffic participants by a static text message

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Annex 2: Evaluation of eHMI technologies as result of WP 4-internal interdisciplinary expert rating

Technology	Lightband		Single Lamps/LEDs			Projection			External Display			Acoustic signals	
	LED-Array around the vehicle	partial LED-Array	visible for everybody 360°	visible for everybody within a certain solid angle	high resolution single lamp only visible for adressed persons	Projection Icon	Projection Trajectory	Projection text message	Display Icon/image/virtual driver	Display text message	Display animation/light patterns	spoken text	sound signals
percievable at daylight	+	+	+	+	+	-	-	-	0	0	0	+	+
percievable at night	+	+	+	+	+	+	+	+	+	+	+	+	+
percievable at rain	+	+	+	+	+	-	-	-	0	0	0	+	+
percievable at snow	+	+	+	+	+	0	0	0	0	0	0	+	+
percievable > 50 km/h	+	+	+	+	+	-	-	-	0	-	0	-	0
percievable 20-50 km/h	+	+	+	+	+	-	-	-	0	-	0	-	0
5-20 km/h	+	+	+	+	+	0	0	0	0	0	+	0	+
0-5 km/h	+	+	+	+	+	+	+	+	+	+	+	+	+
Possibility to limit the visibility to only one TP	0	0	0	0	+	-	-	-	-	-	-	-	-
possible avoidance of other TP's distraction	0	0	0	0	+	0	0	0	0	0	0	-	-
Compatibility with conventional external light units/functions	?	?											
external HMI range (-25m)	+	+	+	+	+	0	+	-	0	-	+	-	0
HMI Visability/perceivability horizontal (0-360°)	+	0	+	0	0	0	0	0	0	0	0	+	+
HMI visability/perceivability vertical	+	+	+	+	+	0	0	0	0	-	0	+	+
~~intuitive~~ understanding of HMI signal	+	+	+	+	+	-	0	-	-	-	0	-	0
applicable for visually impaired people	-	-	-	-	-	-	-	-	-	-	-	+	+
applicable for hearing impaired people	+	+	+	+	+	+	+	+	+	+	+	-	-
Independet from language skills/reading skills	+	+	+	+	+	0	+	-	0	-	+	-	+
potential to disply different messages	color, direction, animation, light intensity	color, direction, ?animation?, light intensity	color, light intensity	color, light intensity	color, light intensity, ?direction?	color, light intensity, direction, animation	color, light intensity, direction, animation	color, light intensity, direction, animation	color, light intensity, animation	color, light intensity, animation	color, light intensity, animation		
Rating of different messages	+		0			++			+			+	0

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For more information:

interACT Project Coordinator

Anna Schieben

DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT e.V. (DLR)

Lilienthalplatz 7

38108 Braunschweig, Germany

Anna.Schieben@dlr.de

interact-roadautomation.eu/

interACT

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