Design of an external communication system for expressive automated vehicles

Enabling automation transparency in future urban traffic

Carmen Marqués Ortega Design for Interaction · Master Thesis

Design of an external communication system for expressive autonomous vehicles

Enabling automation transparency in future urban traffic

Master thesis,
Delft, March 2022

Education
MSc. Design For Interaction
Delft University of Technology
Faculty of Industrial design Engineering

Supervisory team
Project Chair:
Dr. Ing. Marco Rozendaal
Project Mentor:
MSc. Ilse van Zeumeren

Collaboration
Company:
Swov
Mentor:
Dr. Angelique Tinga

Author:
Carmen Marqués Ortega

“Interaction design is the creation of a dialogue between a person and a product, system or service. This dialogue is both physical and emotional in nature and is manifested in the interplay between form, function and, and technology, as experienced over time.”

- Jon Kolko

ACKNOWLEDGEMENTS

This project represents the final steps of this learning experience that started in February 2020, these two years have been a period of personal, academic and profesional growth that I hope to continue in the newly started phase of life. As many other events in life, this experience would not have been the same without the people that supported me, listened to my complaints, celebrated successes, and ultimately made Delft become Home for the time spent here.

I would like to firstly thank my supervisory team for the support provided in this graduation project, Marco Rozendaal, Ilse van Zeumeren and Angelique Tinga. Thank you for your availability, your interest, and guidance during this whole process. Following, to all the enthusiastic people that have actively contributed to this thesis by participating in research activities along the project, without your input and opinions, the result of this project would have been flat and a lot less relevant.

In the personal side, friends and family have at all times been a great source of support, fun and happiness all along this time.

To my family, Papá y Mamá, gracias por confiar en mi criterio en cada decisión tomada desde que me fui de Valencia. A Nacho y Fran, por apoyarme siempre desde la distancia aunque no entendáis muy bien lo que hago, y tener la paciencia suficiente para que lo entienda yo antes de contároslo.

To my Delft family, starting with Nuria, no me imagino estos dos años sin ti, qué suerte y qué placer haberlo compartido todo contigo. Roberto, Javi, Simon y Marina, Sunday lunch will never be the same without all of you there. During these last months I had the opportunity to meet some new and very important people that I hope to keep close forever, Paula and Gabri, you came last but definitely not least, thanks for making me feel welcome since we met.

To Luca, sei stato il mio best supporter, grazie per avermi aiutato a tenere i piedi per terra e a mettere i miei pensieri in prospettiva ogni volta che dubito di me stessa.

To my little studioLab family, Sofie, Irene, Mireia, thank you for making every working day more fun and always be there for moral or actual support during these few months. We did not miss any opportunity to celebrate each other's successes, a special tradition to keep when moving forward.

Finally, to my clumsy housemates, Benni, Franci and Priya, I learnt important lessons from each one of you and I will always consider you my roommates and role models.

EXECUTIVE SUMMARY

Future introduction on automated vehicles (levels 3, 4, and 5) in urban traffic comes with several societal benefits, but also challenges. One of the biggest challenges that the research community expects from this introduction is the possible problems or critical situations caused by the lack of interpersonal communication between drivers and vulnerable road users in the form of eye contact or hand gestures. To solve this problem, external Human-Machine Interfaces seem to be a suitable solutions to enable AV-VRU communication. This project reviews relevant literature on eHMI design and Human-Robot interaction to identify current knowledge gaps. Moreover, generative user research was used to identify needs and wants from vulnerable road users when interacting with motorized vehicles in traffic. Predictability, perception of vehicle's awareness, and knowing how to act around automated vehicles were found to be key elements for smooth interactions in scenarios that were considered critical by research participants, namely crossings without traffic lights and being passed by vehicles that share the road with cyclists.

In order to approach the problem, an iterative design process was followed to identify the best communication modalities and modes to be included in a final flexible and multimodal eHMI design, showing the potential of abstract light patterns and dynamic projections to enable AV transparency. The final design was evaluated through a video-based experiment in which participants were exposed to a baseline condition and the same scenario with the addition of the eHMI. This evaluation showed an improvement in the experience qualities evaluated in the presence of the eHMI designed, showing overall desirability and pointing out simplicity and flexibility as crucial qualities to design external communication systems.

GLOSSARY AND ABBREVIATIONS

AUTOMATED (VEHICLE):
Vehicle which driving activities are carried out by computers without needing human control.

VULNERABLE ROAD USER:
Those road users who are unprotected by an outside shield, as they sustain a greater risk of injury in any collision with a vehicle and are therefore highly in need of protection against such collisions.

HUMAN-MACHINE INTERFACE:
The set of all interfaces that allow for communication between the vehicle and the exterior agents.

COOPERATION:
The actions of someone who is being helpful by doing what is wanted or asked for: Common effort.

AV.
Automated Vehicle

VRU.
Vulnerable road user

eHMI.
external Human-Machine Interface

HRI.
Human-Robot Interaction

TABLE OF CONENTS

CONTENTS

Introduction to the project

01

This chapter presents the project's background, stakeholders, and specific information about the assignment and the problem approach.

BACKGROUND KNOWLEDGE

Partially and highly automated vehicles are an upcoming reality that could revolutionize mobility worldwide. The shift to automation in our vehicles could improve many aspects of sustainability and the safety of personal mobility (Tepe, 2020). However, one of the aspects recognized as crucial for the implementation and normalization of automated vehicles worldwide is the correct cooperation among all road users and the infrastructure.

In this project, two main agents are the protagonists. The automated vehicle (AV), on the one hand, has a central role as we focus on how it could communicate with others. In the other, vulnerable road users (VRU). This term is used to describe non-motorized road users, such as cyclists or pedestrians, and individuals with disabilities or reduced mobility and orientation (e.g., Visually impaired or wheelchair users). This group represents the people who can suffer the most in a traffic accident and, therefore, an influential group to consider when designing road elements. In this project, we pay special attention to them. Concretely, pedestrians and cyclists in the context of urban traffic are targeted as the receivers of this communication.

PROJECT CONNECTIONS

This graduation project collaborates with SWOV (Dutch Institute for Road Safety) to generate knowledge about and inspire future research on the interaction between autonomous vehicles and human agents who share the road.

The second essential collaboration of this project is the Expressive Intelligence Lab, from the Delft design labs. The research and design practice of the lab focuses on the communication and relationship between intelligent agents and the people interacting with them. The use of design tools and techniques supported by the lab will help frame the autonomous vehicle as an intelligent and expressive object.

ASSIGNMENT

The project will focus on designing an external Human-Machine Interface (eHMI), defined as the set of all interfaces that allow for communication between the vehicle and the exterior agents. The role of the eHMI is to support the relationship between the AV and other road users, reducing ambiguities and enhancing the experience of vulnerable road users sharing the space with AVs.

The eHMI should consider several requirements that will need evaluation to achieve a balanced outcome. These are the VRU information needs, available technology, and the car industry's scalability demands. This means it should be possible for different car manufacturers to adapt the design to their brands' specific aesthetics and personality since the outcome solution should be desirable and scalable to worldwide use.

Due to the time available for the project, several decisions have been made to define the scope better and make it possible to meet the goals in the timespan. The context chosen for the development of the eHMI is urban traffic. This means that all use cases studied arise from everyday situations that participants of the user research encounter in their everyday lives. Regarding the user scope, we focus on pedestrians and cyclists without a sense of depriving disability since requirements linked to visual or hearing impairment deserve full attention and require a whole new project approach.

The contribution of this graduation project lies, for road safety research, in the seamless collaboration between humans and vehicles in urban traffic, reducing ambiguities and improving the experience of vulnerable road users sharing the space with highly automated vehicles. In the field of industrial design, this project contributes to generating knowledge about the communication of intelligent products and its implications in the field of mobility and vehicle automation.

The main research question addressed in this project is:

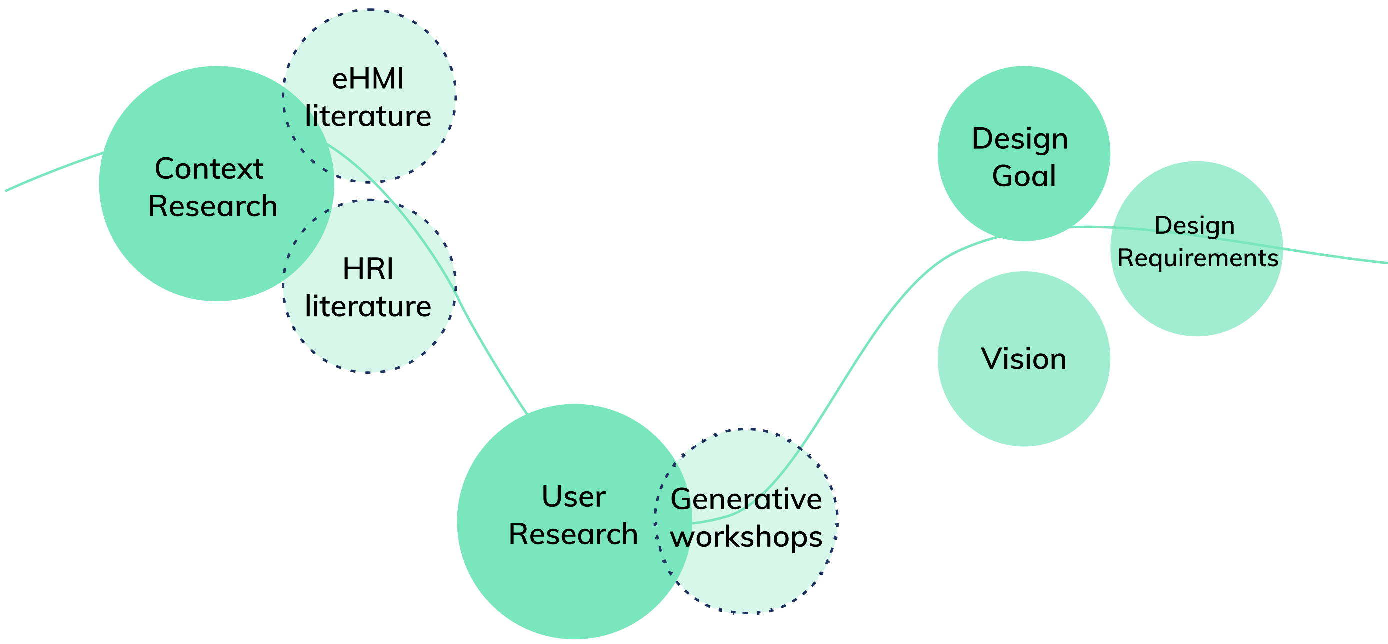
How can we design an eHMI that helps ease the interaction between AVs and VRUs in future urban traffic?

Related subquestions that will guide this design are:
- In what situations does a pedestrian or bike rider need the vehicle to communicate?
- What information does the AV need to express to pedestrians or cyclists?
- How should this information be communicated?

PROJECT OVERVIEW

This section presents the main blocks of research conducted along with the project. This table shows the activities conducted, the purpose of the phases mentioned above, and the primary outcomes of each one of them.

RESEARCH PHASE 1: SETTING THE GROUND



PURPOSE

· To familiarize with current knowledge in the project context.
· To identify knowledge from HRI that can be applied in the context

· To understand the needs and wants of people when navigating future urban traffic.
· To find relevant scenarios to be addressed by the eHMI.

MAIN TAKEAWAYS

· There is a considerable lack of consensus regarding what messages vehicles should communicate and through what channels.

· Predictability and vehicle awareness should be enhanced for good Av-VRU cooperation.

· Need to look into different scenarios to address one communication system.

· People want to feel safe when interacting with automated vehicles. This means knowing what the vehicle will do and being reassured in its own decisions.

· Some relevant scenarios that the eHMI should address are intersections and shared roads where cars and cyclists move along.

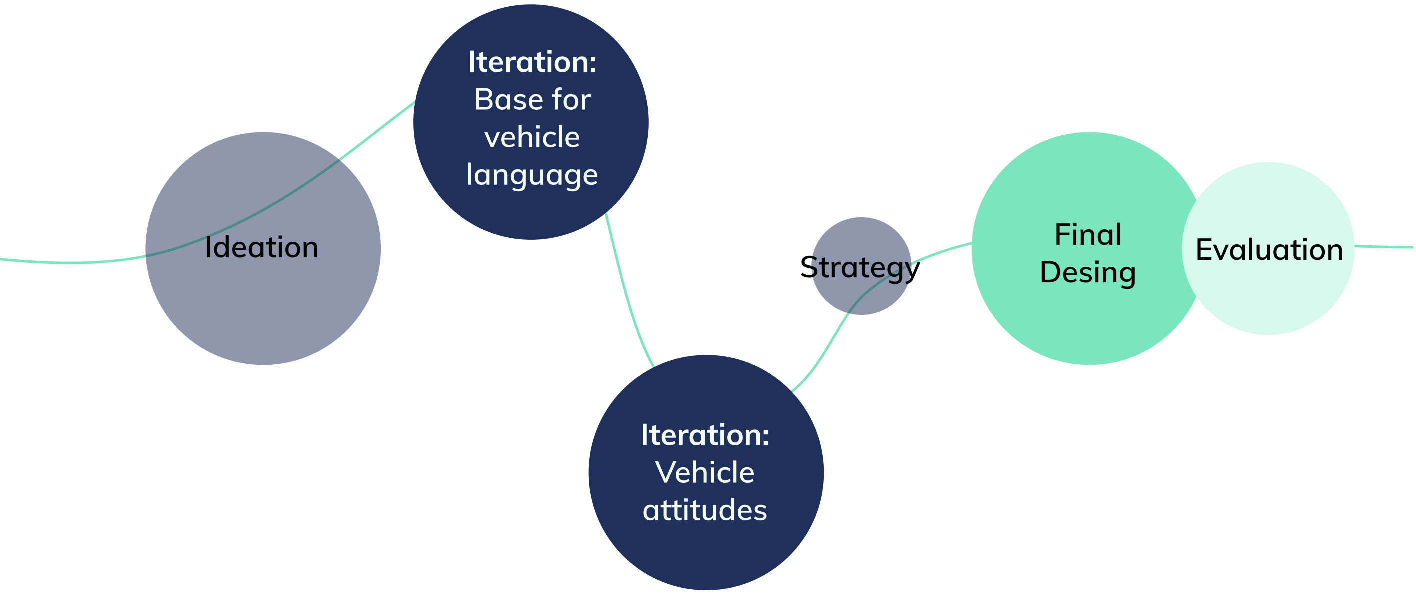
· The eHMI should adapt depending on the vehicle attitude needed and level of intrusiveness.

· The vehicle should communicate action, intention, and perception in the following scenarios.

- Intersection where VRU has the right of way.
- Intersection where the vehicle has the right of way.
- Vehicle passing by cyclists in a shared road.

PHASE 2: EXPLORING SOLUTIONS IN CONTEXT

PHASE 3: EVALUATING RESULTS



· To evaluate possible design solutions in context.
· To decide what should be the vehicle language.
· To decide how to portray the different vehicle attitudes.
· To further understand the scenarios studied.

· Abstract light that uses dynamic patterns can successfully communicate different messages.

· Change in colors helps in identifying the vehicle’s attitude.

· Projections give the feeling of dominance without increasing intrusiveness.

· SImplicity is preferred.

· The same system should adapt to the circumstances. The number of elements should be minimized.

· To evaluate the effect of the design on the interaction qualities.
· To find how it could be better by identifying weaknesses.

· Multimodal design is presented using abstract lighting and projections, color coding, and light patterns.

· The design proposed succeeded in improving the experience in terms of predictability, perception of vehicle’s awareness, and feeling of safety.

· Dynamic patterns showed to be a solid communicative tool.

· Color coding needs further research.

CONTENTS

CONTEXT RESEARCH

02

This chapter covers several aspects of the study context. First, an introduction to AVs is given. Further in the chapter, we go into how communication happens among road users in urban traffic and how this problem has been approached by the research community regarding the introduction of autonomous vehicles. Conflicts and opportunities are identified at the end of this chapter.

VEHICLE AUTOMATION: THE FUTURE OF URBAN TRAFFIC

New technologies highly influence our daily lives, from the first thing we do when waking up to the way we move. The idea of a driverless vehicle has been around for some decades. New technological developments in this area attempt to reduce traffic crashes, optimize energy consumption, reduce pollution, and improve transport accessibility. It is expected that Autonomous Vehicles (AVs) will constitute 40% of vehicle travel by 2040 and 50% of vehicle sales, and 30% of vehicles in general (Bagloee, S.A. et al., 2016).

The NHTSA (2015) explains the many benefits that Autonomous Vehicles will bring, starting with reducing accidents, since these are currently mainly caused by human errors. Moreover, AVs have the potential to help in optimizing costs of road infrastructure, having a positive effect on the management of traffic congestion due to connectivity capabilities (see appendix B) that will not only connect vehicles between each other but also with the infrastructure, allowing for more flexibility and optimization. Lastly, it is expected that AVs will enable a more inclusive approach to mobility where, for instance, people with a visual impairment might make use of personal cars.

The Society of Automotive Engineers (SAE, 2019) classifies and defines six-vehicle automation levels going 4from zero to level five (see figure 1). Level 0 implies inexistent automation, where the driver takes all the responsibility and control of the vehicle. Level 1 and 2, Include one or at least two automated control functions, respectively. We find lane-keeping systems or adaptive cruise control functionalities. Level 3 automation vehicles are capable of taking full control of the vehicle in certain driving conditions, but take over from the driver might be needed as the conditions change. Level 4 automation is the first level of full self-driving automation, where the vehicle is designed to monitor the conditions of the road and act independently of the driver. Level 5 automation is the furthest from being implemented, as it is expected that it will take at least 60 years to be developed (Tepe, 2020). It implies fully driverless vehicles that require no input from the passenger other than the destination.

Currently, levels 0 to 3 of automation have reached the market. In this level 2 and 3, the driver may activate some driving support functionalities but still has full or some responsibility and should pay attention to the road at all times. Communication with other road users also relies on the driver, who uses vehicle elements or interpersonal messages to communicate with vulnerable road users (Stanciu et al. 2018). There is an arising interest in the forms of interpersonal communication that happen between drivers and other road users. In recent years, research in academia and the automotive industry have started addressing the possible difficulties

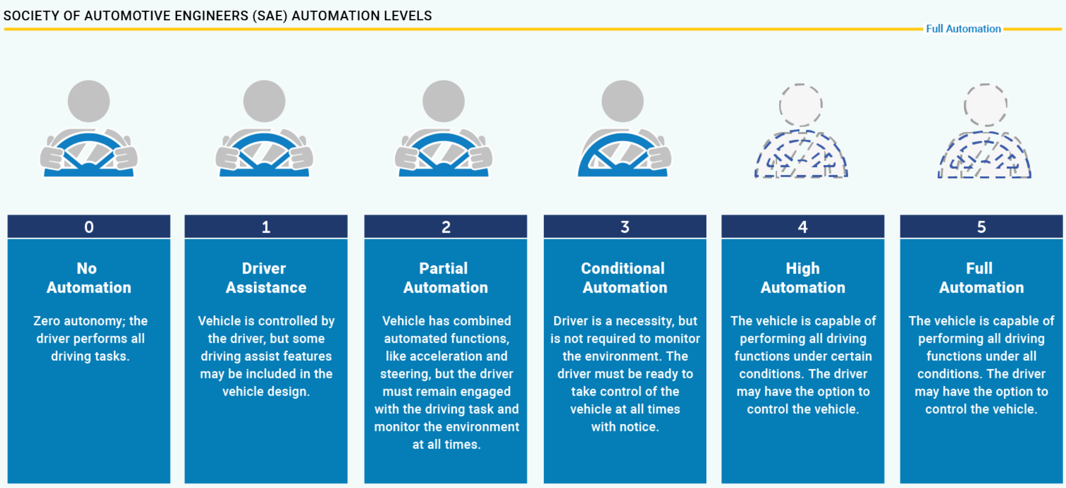


Figure 1: SAE levels of automation

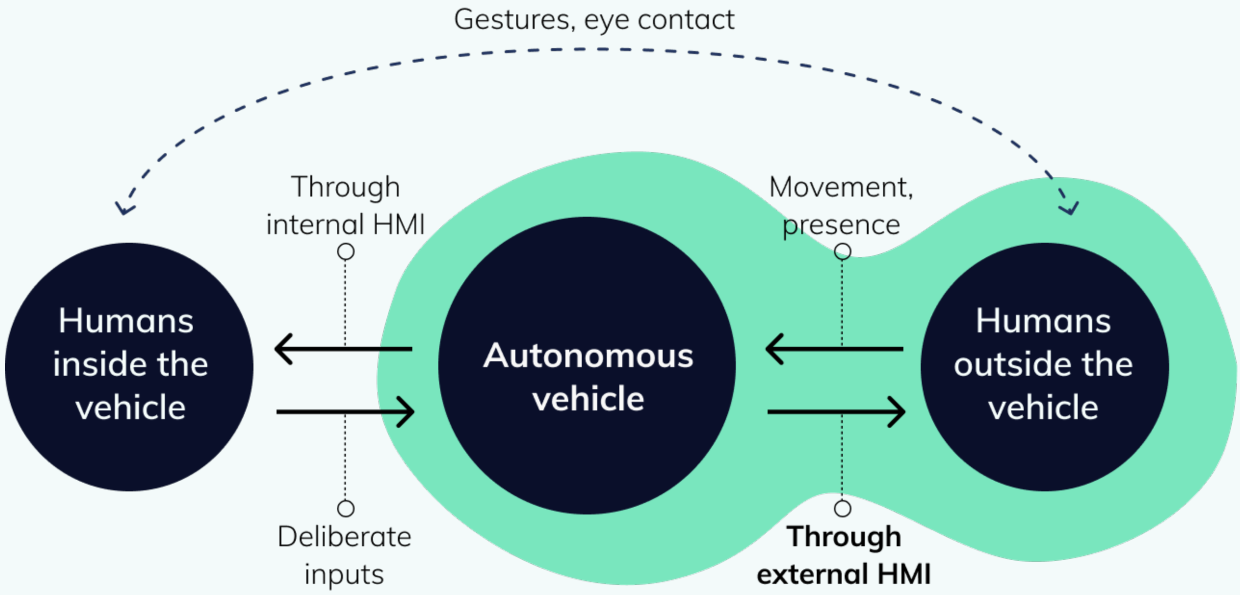


Figure 2: Schematic of the context of the project.

that eliminating the human driver could have regarding the interaction with vulnerable road users. Consequently, a number of solutions in the form of external Human-Machine interfaces (eHMI) have been proposed and tested under different grounds. This concept (eHMI) refers to the external communication system of the vehicle. In current cars, these are the position, braking, warning lights, and a set of sounds such as the horn or de artificial engine sound that is currently present in some electric vehicles. The rapid proliferation of concepts got the name of “eHMI jungle” (Dey et al., 2020), and it demonstrates the increasing interest in addressing interpersonal communication in a traffic environment dominated by driverless vehicles.

The relationship between automated vehicles and human users has been popular for a while, and there is a lot of research being made regarding driver experience of shared control. For instance, the Mediator project attempts to solve experience issues in the control transfer between a vehicle and a human driver (Grondelle et al. 2020). Yuen et al. (2021) defend that the benefits of vehicle automation can only be realized if people are willing to use them and that for people to trust the autonomous systems, thus, vehicles should exhibit system transparency to their drivers. On the other hand, Faas et al. (2020) state that “as much as human-centered in-car HMIs are key for safe driver-vehicle collaboration, human-centered eHMIs will promote better pedestrian-AV cooperation.” This statement raises awareness about the need to address all the interactions with humans that vehicles will come across in the future, both inside and outside the vehicle.

As discussed in this section, the introduction of automated vehicles in general traffic comes with the promise of benefits in terms of safety, sustainability, and accessibility. Level 4 and 5 automation are still far from being integrated, but the issues arising from their introduction should be addressed now in preparation for this event. One of the issues pointed out by the research community is the communication among road users. In this project, special attention is paid to the relationship between automated vehicles (levels 3 to 5) and vulnerable road users. A set of human factors should be addressed in order to make the sharing of the road not only efficient and safe but also pleasant.

The choice of focusing on the higher levels of automation lies in the already high cognitive load that driving activities require. Including the new responsibility of operating extra eHMI elements would probably cause more problems than benefits. Thus, this project focuses on allowing partially and highly automated vehicles (Levels 3 to 5) to communicate to VRUs present in their surroundings in the moments when the vehicle is driving in automation mode.

COMMUNICATION IN MIXED TRAFFIC

Future urban traffic will be shared by several stakeholders that need to communicate with each other in order to ensure the proper functioning of the system. In this section, communication channels between the different road users involved in current urban mixed traffic are explored. The main interest for the project lies in the relationship between human agents and autonomous vehicles and vice-versa; therefore, the communication channels used by vehicles are the main focus. We pay attention to how communication happens now and what are the challenges and opportunities in these areas when introducing connected and automated vehicles in urban traffic.

IMPLICIT AND EXPLICIT COMMUNICATION

Implicit and explicit communication is used in people's everyday lives, and so it is also used in traffic. In this section, we focus on describing these two concepts and exploring them in the context of vehicle to VRU communication and driver-to-driver communication.

Implicit communication refers to information that the receiver understands a message that is not necessarily delivered intentionally by the sender. In social sciences, this refers to the facial expressions or body language of a person. Regarding traffic situations, implicit communication would be, for instance, the acceleration or deceleration of a vehicle, its speed, driving behavior, or the distance to a VRU, who receives this message and acts according to it.

According to Rasouli et al. (2017), pedestrians look mainly at speed and distance to make crossing decisions when a vehicle approaches them, which agrees with the observation study conducted in the Netherlands (Dey et al. 2017) concluding that the body language of the vehicle is a lot more important than explicit communication in pedestrian decision making. The influence of driving behavior on the pedestrian's trust in the vehicle was also studied (Dey et al. 2021), finding considerable differences in pedestrian decision making when a vehicle yields gently or aggressively. Taking these into account, we can conclude that implicit cues are a great source of information for VRUs when navigating urban traffic.

Current research in the field of communication between vehicles and VRUs understands the road as a social environment filled with interpersonal interaction. Stanciu et al. (2018) defend that interpersonal communication is used to regulate the use of the road, communicate intent and encourage certain behaviors in other road users. These messages are usually sent through more explicit cues, using either vehicle elements, such as hazard lightings or horns, or using the driver's body or facial expressions through eye contact or hand gestures. On the other hand, there are also cues used by VRUs in response to drivers. Forms of attention such as gazing or looking are used by pedestrians in decision making, and to communicate acknowledgment, whereas hand gestures are used as gratitude signs (Rasouli et al., 2017). Since VRUs need a safe and effective way of interacting with vehicles, Jayaraman et al. (2019) defend that explicit interpersonal communication should be addressed in the introduction of Autonomous Vehicles in urban traffic.

Vehicles participating in traffic are already equipped with communication enabling technologies such as position and hazard lighting, turn signals, and horns. While these are mostly designed to formally communicate intent to other drivers, most road users understand and are capable of acting upon these signs of intent or danger. Moreover, these are also used in informal ways that are subjected to social norms, eg. A driver might horn softly when the traffic light turns green and the driver in front of seems distracted. Nevertheless, this informal use of vehicle's communicative tools, as well as the interpersonal relation between drivers and VRUs, is highly subjected to cultural differences.

In the absence of a human driver, there are a number of communicative cues that are not possible. These are all that require direct human-to-human interaction. Therefore, the introduction of AVs should come with new ways to communicate for proper collaboration and understanding among traffic participants. A number of experts in Tabone et al. (2021) point out that the social interaction among traffic participants is one of the main challenges in the introduction of AVs, concerning both VRU behavior as well as AV capabilities. These concerns have raised interest in the design of AV communication channels, which we will go into in the next section.

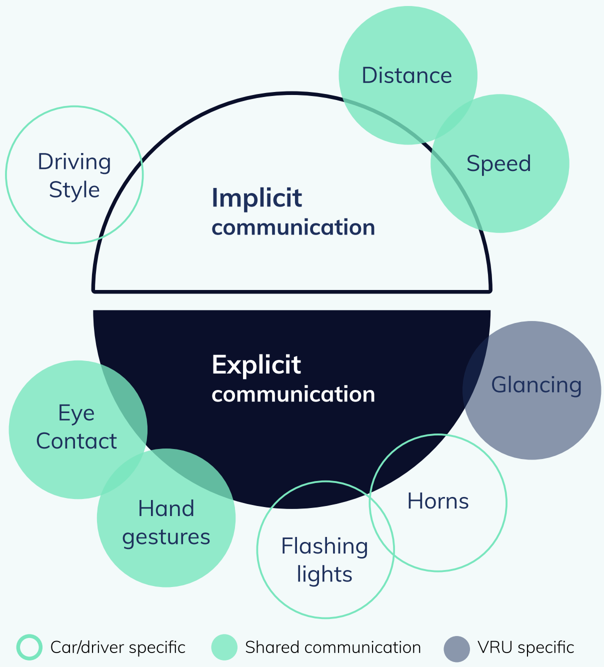


Figure 3: Summary of explicit and implicit communication channels

THE PARADIGNM OF AV COMMUNICATION

In recent years, the design and implementation of eHMIs in AVs have caught the research community's attention, both in academia and industry. In this section, we go through existing literature regarding the proposed designs. Dey et al. (2020) reviewed over 70 eHMI concepts and described AV's landscape to VRU communication design as a "jungle." Their eHMI taxonomy serves as a guideline for this section.

There are three main blocks in which the literature on existing concepts can be divided—being who is/are the target of the communication, what is communicated by the vehicle, and how this communication happens.

WHO IS THE TARGET OF THE COMMUNICATION?

It is generally believed that eHMIs are necessary to improve AV-VRU collaboration in future traffic. Moreover, the addition of communication channels between the AV and the humans outside the vehicle will increase trust in the automation, improve the feeling of safety, and reduce ambiguities in VRUs.

Two main aspects are taken into account by existing designs of AV communication: the type of vulnerable user is being targeted and how many road users are addressed by the design. Dey et al. (2020) review concepts in which the communication of the AV is directed to either pedestrians, cyclists, or vulnerable road users with special needs, such as the visually impaired. There are currently a lot more concepts directed to (or tested with) pedestrians than any other user group. No concepts have been tested with the different user groups, making it hard to draw the differences between their behaviors and preferences.

There are two different aspects of VRU-AV interaction that need to be explored for both pedestrians and cyclists. These are their behavior and the communication preferences, which may be different among these groups.
One of the main differences between the two groups is the speed at which they move in urban environments and their different positions in relation to vehicles (Hou et al. 2020). Bicycles allow for more flexibility in the infrastructure, which also plays a role in the interaction with vehicles (eg. Cyclists may share the road with vehicles and move to more segregated spaces within seconds). While pedestrians usually move in devoted spaces and encounter motorized vehicles mostly in crosses, cyclists usually merge in traffic, sharing the space closely with cars and motorbikes and having to adhere to the rules applied in these environments.

Due to the speed at which cyclists ride, the decision-making time is very short when encountering vehicles. Riding in shared spaces supposes for cyclists a big mental load since it is hard to predict other vehicles' intentions (Berge et al. 2021). Cyclists use a number of strategies to communicate using mainly hand gestures and motion cues (eg. Raising the arm and reducing speed to communicate the intention to turn), which supposes a reason for concern in the introduction of AVs in urban traffic regarding the capabilities of AVs to understand these cues. For this reason, cyclists would prefer AVs to communicate intent and perception explicitly.

As mentioned before, pedestrians usually walk-in spaces apart from motorized traffic. This makes the situations in which they encounter vehicles more limited. Most studies represent a scenario in which there is a cross without a traffic light, as traffic signaling highly affects trust in Autonomous Vehicles (Jayaraman et al, 2019) and the lack of traffic signaling subjects the encounter to ambiguities. Regarding communication preferences, pedestrians would like to know whether the vehicle is driving in automation (status) and its intent (Faas et al. 2020). Moreover, the qualities of the information that pedestrians value, were found to be the visibility of the system and the ease of understanding the messages transmitted (Métayer et al. 2021).

Regarding the number of people being addressed by the vehicle communication, we find concepts that use broadcasting as their communication strategy and others that send a specific message to a specific person (unicasting). In terms of scalability, broadcasting seems to be the best strategy for AV-VRU communication (Dey et al. 2020), but the message sent, should then be focused on vehicle state and action.

NOTE

In this project, we pay attention to a target audience without disabilities, and while we are fully aware of the importance of addressing these groups, they would deserve a whole new project, potentially including connectivity capabilities of AVs and personal devices. As mentioned in the introduction, we focus on pedestrians and cyclists without sensory impairments.

WHAT DOES THE VEHICLE COMMUNICATE?

There are a number of messages that research in eHMI design attempts to explicitly send to vulnerable road users around the vehicle, these can be divided into two big categories, the allocentric and the egocentric messages. Figure 4 summarizes and illustrates the different message typologies.

Allocentric messages:

Allocentric messages directly attempt to communicate data from the environment. Within this messaging category, there are two main messages attempted through eHMI design for Autonomous vehicles that Dey et al. (2020) review.

Communicating advice: Advice messaging focuses on clearly telling the vulnerable road user how to act in a specific situation, this is usually attempted by displaying written messages. The communication of advice proved to be effective in terms of message understanding and feeling of safety in ambiguous situations (Faas et al. 2020), nevertheless, it is pointed out that communicating advice could lead to ethical and liability issues since an AV can not really know if the vehicle coming after it will act the same way (Dey et al. 2020), this becomes even less predictable when sharing the space with human-driven vehicles.

Communicating situational awareness/ perception: Communicating perception was found to be most desirable by cyclists (Hou et al. 2020, Berge et al. 2021), but it seems to be less effective in the case of AV to pedestrian communication since it would potentially impact traffic flow (Faas et al. 2020). Moreover, this kind of message supposes a big challenge in terms of how to make clear who is the receiver of the message, due to the vehicle not being able to clearly unicast information to a single or a specific group of VRUs. The existence of a perception message would be beneficial to reduce ambiguities in giving information about the why behind a specific behavior.

Egocentric message:

Egocentric messages focus on communicating data about the vehicle itself. The most popular messages attempted through current eHMI designs are the status of the vehicle, as being driven manually or in automation mode, the vehicle intentions, or the current functional state.

Communicating vehicle state: Informing about the state of the automation was found to improve the trust of pedestrians on autonomous vehicles (Faas et al. 2021). Agreeing with this statement, it is expected that AVs exhibiting system transparency will play an important role in the adoption and trust-building of vehicle automation (Yuen et al. 2021). On the other hand, the communication of the state could cause misuse of the system, leading to VRUs taking risky actions.

Communicating current functional action: This kind of messaging attempts to communicate explicitly the actions being carried by the vehicle, the actions communicated in the reviewed eHMIs are usually yielding-not yielding, slowing down, resting, and starting to drive. Among these, yielding-not yielding signs seem to be the most popular among the research community and the most valued in terms of VRU user experience (Faas et al. 2020). It is worth mentioning, though, that no research has been found on overall situation awareness, this means, all research focuses on the experience of one person looking at the interacting vehicle and don’t consider, for instance, a VRU that approaches the cross when the car has stopped.

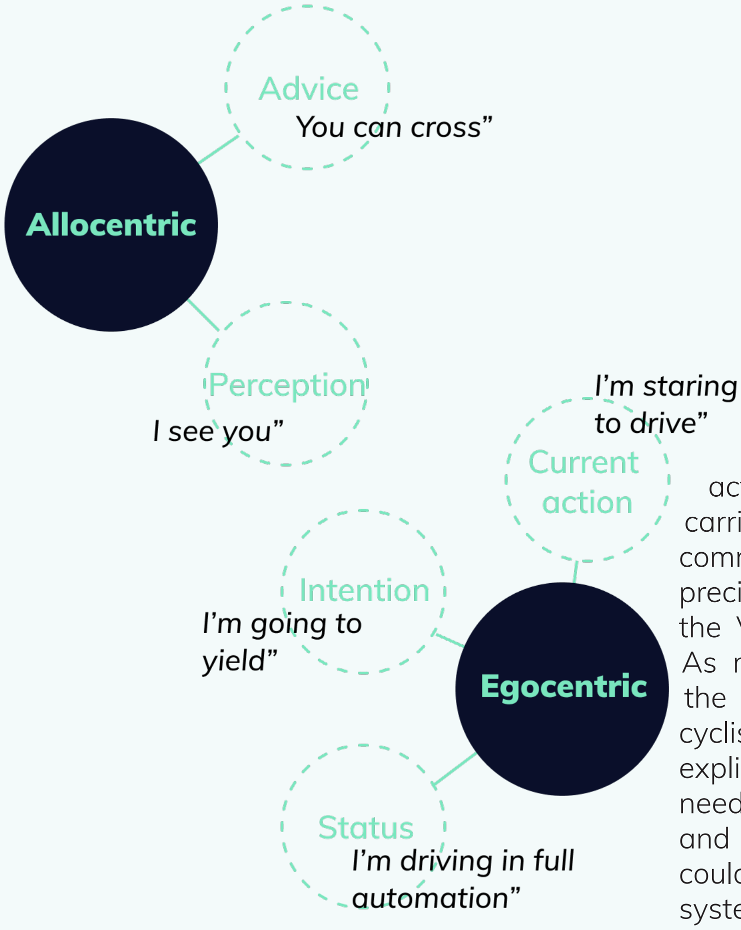


Figure 4: Schematic of different allocentric and egocentric messages

Communicating intention: communicating intention is highly related to communicating o the current action. The difference is that the communication of the next action starts moments before the action is carried out. In some concepts, the intention is communicated along with a timer that indicates precisely when the action will start to allow the VRU to act accordingly in the time given. As mentioned before, intentions are generally the desired message by both pedestrians and cyclists, but it is important to highlight that the explicit communication of state and intention needs to work together with the body language and implicit cues of the vehicles. Otherwise, it could cause further confusion and mistrust in the system (Dey et al. 2021).

Discussion:

As seen in this section, autonomous vehicles' perception, state, and intention are the most desirable messages to VRUs. One of the limitations in current research is the lack of consensus about the overall communication strategy. While some strongly advise the use of an egocentric approach (Bazilinskyy et al. 2021) others prefer allocentric approaches (Tabone et al. 2021).

NOTE

There is little consensus in the world of eHMI design due to being a considerably new field of research, that is why, in this project, no communication strategy is chosen over the other. The decisions about vehicle messages will be strongly influenced by the use cases derived from the user research (see chapter 4). By looking into specific communication needs in differen scenarios, we could then find other situations with similar needs. That way we can create an eHMI that works across many situations.

HOW DOES THE VEHICLE COMMUNICATE?

There are different sensorial approaches that are taken in eHMI design research, in general, vision is considered the predominant sense involved in the decision-making of vulnerable road users for people without vision-related disabilities (Verma et al. 2019) and therefore is the most used in the different eHMI concepts. Other communication modalities that vehicles use now and have also been considered in the design of automated vehicles, these are the sound and movement capabilities of AVs. Following, a review on the state of the art of communication modalities.

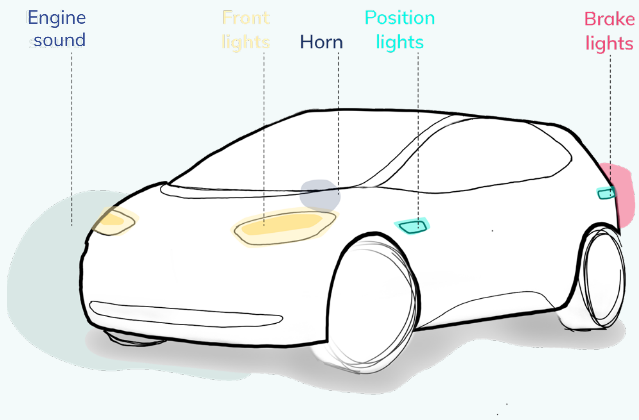


Figure 5: Current car eHMI

Visual signals

The most popularly used visual signals are **abstract signs, in the form of led strips or projections.** Projections are envisioned to be useful in situations in which the vehicle and the VRU are moving in the same direction, for instance, a led projection on the ground could give a sign to a cyclist that is going to be overtaken, reducing the need for the cyclist to look over the shoulder (Hou et al. 2020). Nevertheless, in a busy traffic situation or a very bright day, this signal on the ground could easily get lost, and therefore counting on projections only is discouraged. Led strips, on the other hand, are the most popular in current research (Dey et al. 2020), this could be due to the already light-predominant aspect of human-driven vehicles communication system used in current traffic, moreover, light is recognizable from a distance and has been proven to require a small amount of practice for VRUs to get used to it (Bazilinskyy et al. 2021).

Another popular eHMI design is based on **written messages**, text-based eHMIs are usually used in the communication of advice, and they have proved to be very effective in ambiguous situations. Nevertheless, experts advise against them due to language issues among countries and that children should also understand AV signals (Tabone et al. 2021). Furthermore, Bazilinskyy et al. (2021) point out that text is not legible from afar.

The use of **anthropomorphism** as a communication modality has also been explored in the design of vehicle interfaces (Verma et al. 2019), primarily used in the form of smiles or eye-like elements. While experts point out that anthropomorphism is worth exploring, they disagree with the current forms of implementation (Tabone et al. 2021).

In other Human-Computer Interaction (HCI) research fields, anthropomorphism is used to mimic movements or real actions from humans, but when acknowledging the fact that these can be impractical depending on the context, designers reach for different ways of expressing an agent's intelligence. For instance, Song et al, (2019) conclude that the use of dynamic lighting can help in making the interaction with smart objects more harmonious. This supposes a more subtle way of giving human-like expressiveness to AVs.

Regarding the colors used in the different visual interfaces, most designs reviewed in Dey et al, (2020) do not follow the current regulation, which implies that colors already present in traffic infrastructure should be avoided in the design of vehicle external eHMIs, unless research finds enough proof that the use of these is necessary to improve interaction. Figure 6 shows the list of colors which should potentially be avoided. On the other hand, other researchers recommend the use of mind-modeled colors such as green and red in order to improve the interoperability

Figure 6: Colors "to be avoided" due to being present in current traffic system

of the designs (Carmona et al. 2021), which contradicts with the current regulation. Moreover, it was found that tones of blue, such as cyan and turquoise, seem to be preferred in eHMI research. These tones of blue are not yet associated by the general public with anything in particular, having little effect on the feeling of safety of VRUs compared to the use of green (Bazilinskyy et al. 2021).

In current human-driven vehicles, explicit visual communication happens through lighting and body language. Figure 5 indicates the different elements of the light eHMI. We can see, that the purpose of the different elements are allowing the vehicle to be noticed by others (position lighting and front lamps) in situations of low visibility, indicate intent (in the case of turning signals), or information about a current functional action, like breaking. Hazard lighting lets other road users see that there's a problem related to either the vehicle itself or the road conditions, communicating the need for extra awareness.

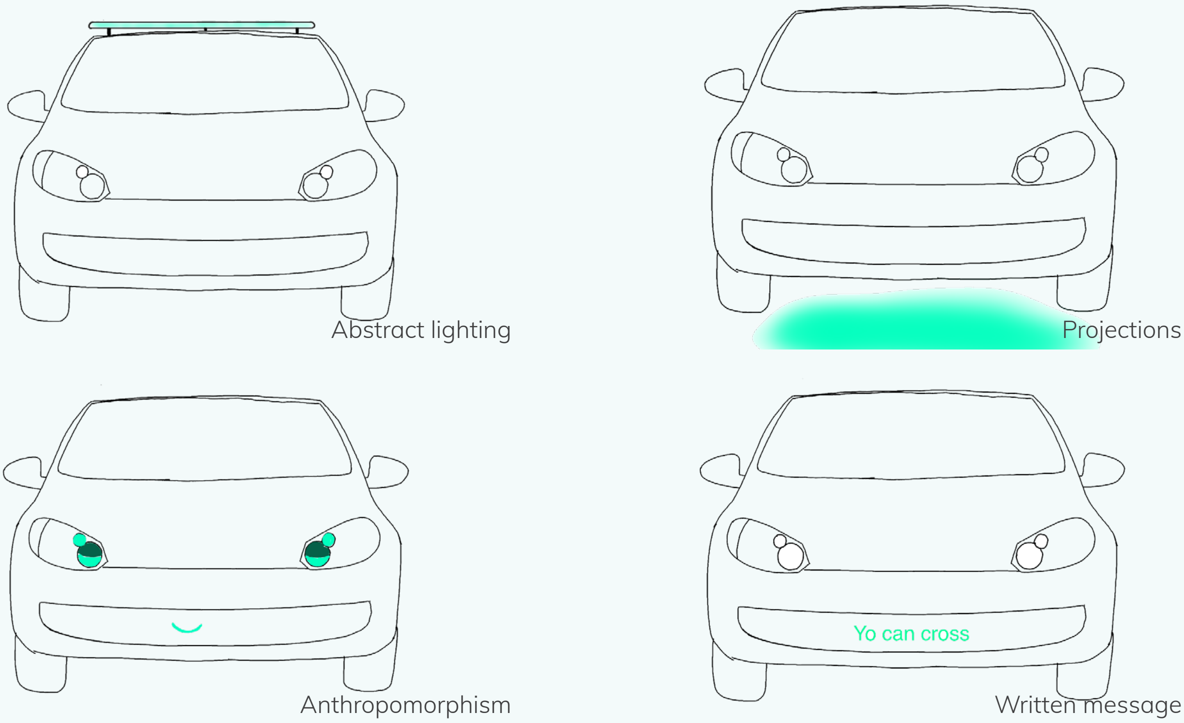


Figure 7: Visualization of different visual communication interventions found in eHMI research.

Auditory signals

Audio signaling appears in different forms in the various concepts. These are speech-based audio signaling and abstract signs. Speech-based audio interfaces are commonly used to communicate current action or intent, using words such as “stopping” or “starting to drive” We could argue that speech-based signaling comes across the same issues as text-based signaling since they are subjected to language barriers among countries.

The auditory signals present in current electric vehicles (EVs) are mainly the synthetic sound of the engine and horns, the latter to be used only in cases of danger and urgency. Auditory signals have proven to be a good way to **trigger attention** and can enhance the effectiveness of visual communication (Heydra et al. 2014). Moore et al. (2020) Explored the potential of designing **context-aware engine sounds** to enhance AV-VRU interactions. Through the implicit sound, pedestrians were better able to identify the yielding intent of the vehicle in crossing situations. Nevertheless, it was acknowledged that sound behavior should change according to the communication needs of specific situations since **every application context will be different.** For instance, they conclude that in busy streets, shifting the pitch and volume would allow for the sound to be identified more clearly, but it should not draw attention to the vehicle when this is not necessary, since noise pollution should be minimized.

Body language

According to Dey et al. (2020), the use of body language as a form of explicit communication has not yet been researched enough, and therefore it should be further explored. As mentioned previously, implicit communication is one of the main things VRUs look at when making traffic-related decisions, nevertheless, the use of motion and body language, which are usually considered implicit communication modalities, have also the potential to be used to deliver explicit messages.

Sripada et al. (2021) explored the communication potential of the lateral positioning of autonomous vehicles when approaching a cross. In their experiments, the vehicle would deviate towards the pedestrian and show the turn signal when it had the intention to yield, likewise, in non-yielding situations, the vehicle would deviate towards the other side of the road. Early deviation towards the pedestrian made participants think it is safe to cross earlier in time. Participants also regarded the tuning indicator as an intuitive signal for vehicle yielding, this could be linked to the general use of the turning signal when a driver is looking for parking on the side of the road. Some participants assumed that the deviation (moving away from pedestrian) for non-yielding, meant that the vehicle was trying to avoid collision with them. In general, the “towards pedestrian” yielding sign was more intuitive than the “away” sign.

Nevertheless, this study has certain limitations worth mentioning, such as the presence of only one car in a very wide street, or the absence of pedestrians on the other side of the cross, to which the “towards pedestrian” sign would be the opposite, communicating therefore that the vehicle would not yield. Even though this solution might not be definitive, it opens the door to consider vehicle movement not only a message in itself but as a way of expressing something else.

Multimodal

Very few concepts found by Dey et al. (2020) address multimodal communication strategies. This supposes an opportunity for new designs since as mentioned in the previous section, visual signals such as **lighting and body language** cannot be segregated when being part of the vehicle’s body. Moreover, using **auditory signals** to increase awareness would enhance further visual communication. This unveils an opportunity for designing a more holistic vehicle communication system (eHMI) that enhances the human experience in the interaction with autonomous vehicles.

		+ strengths	— weaknesess
Visual communication	Abstract: light strips.	· Easy to learn. · Very visible.	
	Abstract: Projections	· Good for cyclists riding along with cars	· Hard to see in bright spaces
	Text based	· Very clear	· Language barriers. · Interaction with kids.
	Anthropomorphism	· Familiar. · Attribution of agency	· Not naturally present in car design. · Ambiguous
Auditory communication	Sound caused by movement.	· Brings attention to the car	
	Speech based	· Very clear	· Language barriers.
	Abstract	· Good for urgency situations	· Annoying
Use of body language		· Attribution of agency	· Could compromise safety if not well implemented

CURRENT SITUATIONS STUDIED IN EHMI RESEARCH

Due to the great diversity in concepts and studied interactions, it is important to pay attention to the situations studied and how these may affect results and recommendations given by different researchers. Among the literature studied in these projects, there is one context of interaction that stands out for being the most widely used in eHMI research, this is a pedestrian crossing a street in the absence of strict traffic signaling (Rasouli et al. 2017, Moore et al. 2019, Chen et al. 2020, Bazilinskyy et al. 2021, Faas et al. 2021). None of these consider also cyclists as possible participants in crossing situations and focus solely on pedestrians.

Cyclist-focused research is rare among the papers referenced in this study, one paper was found that studied interactions with cyclists in situations where cyclists incorporate to main traffic in highways (Hou et al. 2020). This scapes to the current scope of research, which focuses on urban traffic, since this situation happens in roadways outside cities.

A different scenario includes the consideration of shared spaces, these are a new way of traffic organization not yet extended in which pedestrians, cyclists, and motorized vehicles drive, ride and walk freely (Li et al. 2021). These spaces are subjected to specific characteristics such as the low speed of vehicles and high amount of interpersonal interactions due to the self-regulatory characteristics of the spaces.

A big part of the research on eHMIs follows a pattern based on choosing a target and a situation (mostly pedestrians in a crossing), followed by applying some new features to cars and test that through the designed experiments. There is a generalized lack of depth in the situations considered and the different ways that interaction could develop. Studies portray “ideal situations” where there is a single car and a single pedestrian on one side of the road, which is not the most natural environment in urban traffic.

DISCUSSION

As well as any other new field of research, there is a generalized lack of consensus regarding user preferences, best communication modalities, messages needed by VRUs, etc. The first conflict that comes across in the literature is the messages that should be communicated by the vehicle. While the communication of state and intention seems to improve trust and the user experience of VRUs, some argue that communicating state would cause misuse. Perception messaging is also a popular and desired solution, especially by cyclists, nevertheless, it is hard to design eHMIs that target only one road user and semi-targeted communication should be explored. In terms of efficiency, advice messaging seems to be the best, but the use of text or audio speech is discouraged since there are language barriers that would affect its implementation in different countries, and limit the understanding of the signals for kids. Moreover, communicating advice without knowing the intentions of other vehicles such as human-driven personal cars could potentially lead to liability issues.

The need for explicit forms of communication for AVs is also argued in the literature, while some defend that the implementation of such channels would improve trust and acceptance of the technology by helping to clarify ambiguous situations, some argue that people rely mostly on implicit cues of the vehicle and explicit communication channels would cause information overload in VRUs (Moore et al. 2019). Moreover, Moore defends that implicit cues should always remain the main source of information to ensure VRU safety, that is why eHMI designs should never be alienated from the movement of the vehicle.

Apart from disagreements in the field of AV-VRU interaction, there are also some knowledge gaps that need to be addressed. Most concepts are evaluated with one user and one vehicle communicating in an empty street, which fails to portray real urban traffic scenarios (Colley et al. 2020). Moreover, we have not found research in which the scenarios are further studied since most studies focus only on pedestrian decision-making. Discovering critical scenarios in which AV communication would be valuable is therefore one of the main focuses of this project, which will be addressed during the user research.

So far, automated vehicles have not been considered expressive themselves, instead, research has focused on adding communication elements that are sometimes alienated from the vehicle (eg. The Addition of eyes or smiles, which are not natural elements used in car design). This brings up the opportunity of framing the expressiveness of automated vehicles more holistically, using their already existing expressive capabilities.

Regarding the situations to study, figure 8 presents the project strategy that will be followed in this project, a participatory approach is taken to find scenarios (A, B, C) that people encounter in their everyday lives and that are critical in terms of communication. These will be used as a base to get to communication needs that the design will need to address. Once the messages and communication is designed, the result will be evaluated in representative scenarios.

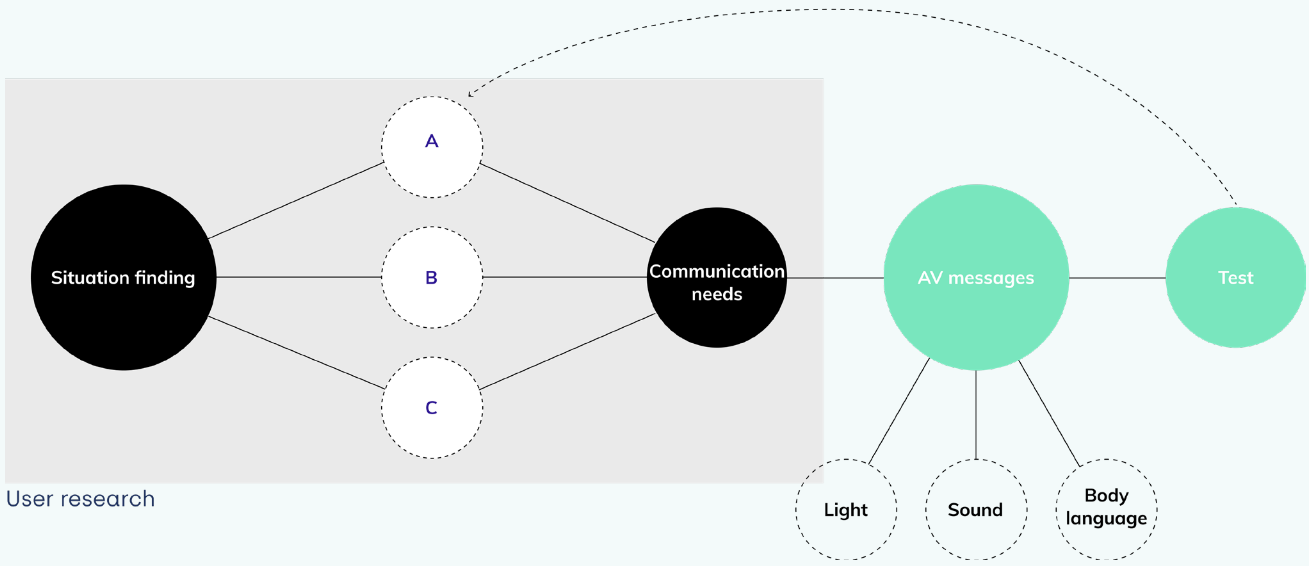
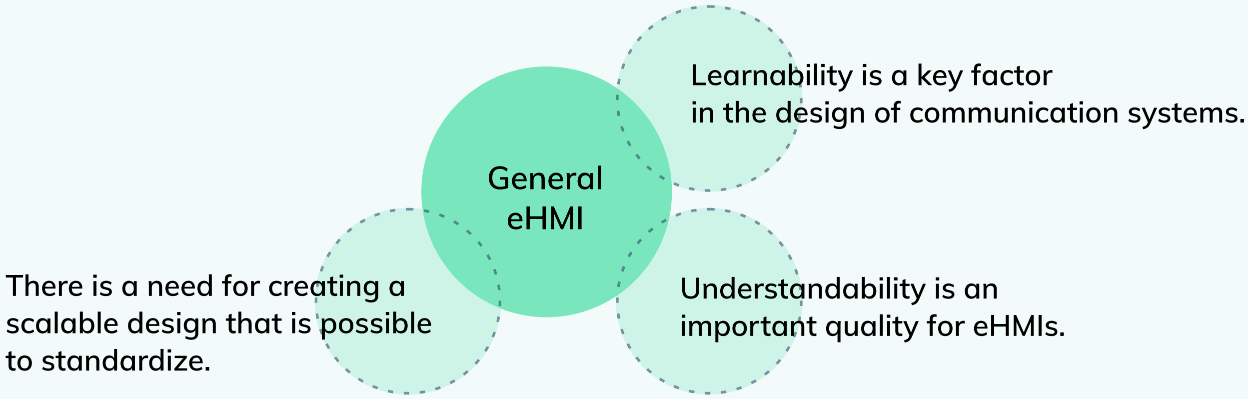


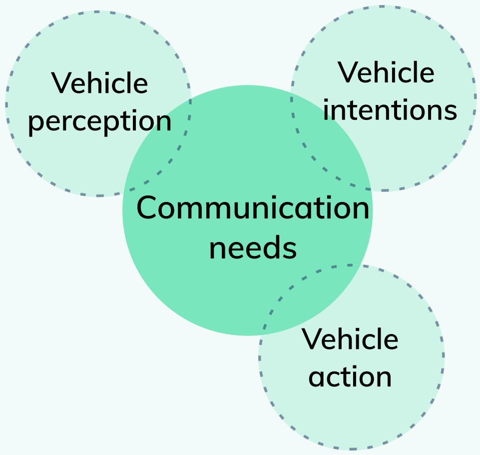
Figure 8: Project strategy derived from Literature review on current eHMI design research..

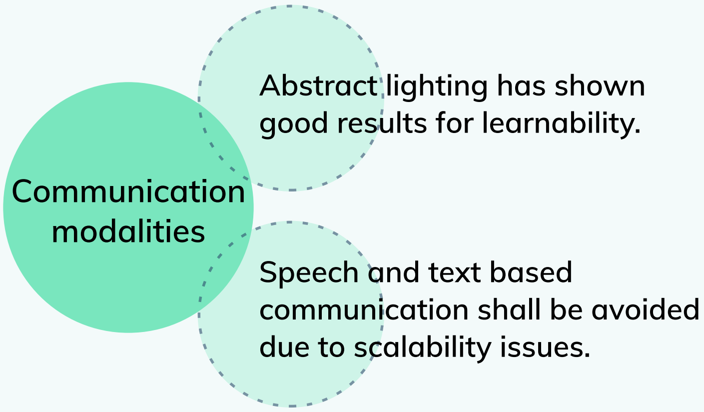
NOTE

We argue that by implementing explicit appropriate communication channels, the introduction of eHMIs would be beneficial for the human experience of sharing the space with AVs without impacting the traffic flow negatively. These communication channels need to support the movement and body language of AVs, work according to human intuition, and target the right human communication needs in the different scenarios.

LEARNINGS







REMAINING QUESTIONS

- How could we prevent VRUs from taking risky actions?

- What scenarios should the communication system address?

- What are the communication needs linked to these scenarios?

- Given the lack of consensus, what can we learn from HRI research?.

CONTENTS

Human-Agent interaction

03

This chapter focuses on defining the AV as an intelligent autonomous agent. First, an introduction to what intelligent agents are is presented, followed by the current challenges in the design of intelligent agents for cooperation with humans.
A link is made to knowledge related to eHMI design.

As mentioned in the discussion of chapter 2, current research on AV-VRU interaction focuses on adding or using single elements for vehicle expression and focuses on evaluating how these affect the decision-making of pedestrians or cyclists.

This project attempts to explore the expressive potential of vehicles taking inspiration and knowledge from a much more studied field of research in human-computer interaction (HCI), this being human cooperation and collaboration with intelligent agents. How to set the ground for correct human-intelligent agent collaboration will serve in guiding the design of the vehicle's communication system.

AUTONOMOUS VEHICLES AS INTELLIGENT AGENTS

The role of automation is historically reducing user's workload, cost, and errors, while increasing precision in the task accomplishment, therefore research in the automation field focuses on efficiency, productivity, and reliability, and it is usually studied within controlled environments. Parallel to research on automation, the field of robotics emphasizes intelligence and adaptability to cope with unstructured environments (Goldberg 2012). Autonomous vehicles operate in a widely unstructured environment subjected to many variables and interactions, which makes taking inspiration from robotics much more suitable for the design of the interactions a vehicle will come across on a daily basis.

A robot, also known as an Intelligent Agent is defined as an automated agent that can relocate the functioning of human beings. This implies the perception of the dynamic conditions of the environment, the interpretation of the perceived information, the solution of problems, and the decision of actions (Chakraborty et al. 2013).

There are a number of characteristics that are used to define intelligent agents, these are divided into two levels:

The **primary characteristics** are the ones that allow for an object to be categorized as intelligent, they include autonomy to operate on its own, being able to exchange high-level information with other agents (cooperation), The ability to learn and improve performance over time, and the possibility to move on their own (Chakraborty et al. 2013).

Chakraborty et al. (2013) also present the **secondary characteristics** by which intelligent agents can be defined. These are, for example, their pro-active versatility, which is the degree to which they can pursue a single goal or engage in a variety of tasks, their social abilities, such as truthfulness, benevolence, or their emotions; and finally their mental attitudes: such as beliefs, desires, and intentions. When introducing social abilities and mental attitudes in agents' actions, better collaboration can be achieved, since humans are therefore more prone to empathize with the object and attribute agency to it. Thus, correctly shaping AVs' intentions and attitudes will help to add value to VRUs experiences when AVs are introduced in urban traffic.

Both groups of characteristics affect the actions that an AV takes in specific situations. The other important factor affecting these actions is the environment and the evolution of the same. As any other intelligent agent, AVs operate in a three-phase design known as "see-plan-act" used in robotic systems (Bagloee et al. 2016). An explanation of how AVs see and plan their actions can be found in appendix C.

The main focus of this project is on AV communication with VRUs, this is subjected to both the primary and secondary characteristics of autonomous vehicles, but what kind of relationship is there between them? The next section focuses on describing this relationship and the main design challenges subjected to it.

VRU-AV RELATIONSHIP

There are different types of relationships that can exist between intelligent agents and their users depending on the level of dependency among them and what role an agent plays in its user's goal. Intelligent agents can be categorized as things, tools, agents or partners, (Rozendaal et al. 2020):

Thing: Object that is not experienced as having an intention of its own.
Tool: The intention of the object is perceived as conducive to the intention of its user.
Agent: Perceived as having an intention of its own
Partner: Perceived as both a tool and an agent.

Autonomous vehicles have relationships with a number of traffic participants. For instance, a driver of an autonomous vehicle can consider the car as a partner or a tool, depending on whether they are sharing driving responsibilities or the car is driving in full automation mode. Instead, the relationship between a person outside the vehicle and the automated car can be seen as an agent-agent relationship, in which each one of them has their own goals and intentions and have to cooperate to avoid traffic accidents and ensure everyone's safety.

Rozendaal et al. Also point out that for future integration of autonomous agents in society, it is important to consider mixing human and technology agencies to respect human functioning across individual and societal levels. To accomplish that, there is a number of interaction issues that should be avoided and addressed in the design of intelligent agents.

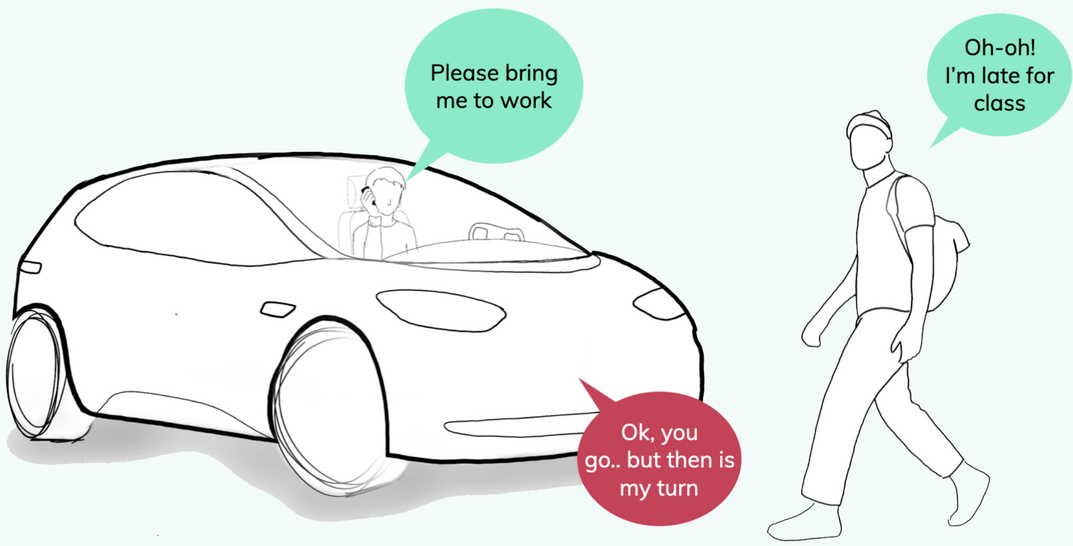


Figure 9: Illustration on AV relationship with humans

WHAT ARE THE EXISTING CHALLENGES IN HUMAN-AGENT COLLABORATION?

Awareness:

Firstly, interaction issues that arise from technology acting just beneath or just above the user's awareness should be avoided. This means that predictability is a key factor in human-intelligent agent collaboration settings. This phenomenon was also observed by Berberian et al. (2019), who state that displaying intention before action is conducted increases the feeling of control and acceptability of the automated system by the human user. This goes in line with research made on eHMI design for Autonomous vehicles, where one of the most valued messages from the vehicle is indeed the **communication of the immediate intention** (Faas et al. 2020).

Sense of agency:

Another challenge that should be addressed is the calibration of the sense of agency. This refers o the extent to which one participant of the collaboration feels in control of himself, the environment, and the other participants (Wooldridge et al. 1995). The sense of agency is usually affected by the perception of a specific action causing the expected result in the intelligent system, for instance, "clicking" on the browser icon on your computer is what causes a new window to open (Limerick et al. 2014). Nevertheless, the input that an AV will receive from a VRU is not that explicit, instead, the vehicle perceives the presence of the human, its movement, and tries to predict behavior to act accordingly. Therefore, our focus lies more on the **system feedback** and how this can affect the vulnerable road user's sense of agency.

The **attribution of agency** can be misled by a number of factors regarding the expectations of the user. While it is possible that the expected outcome realizes without the system perceiving his input, the user would still feel in control (be the cause) of this outcome even if the cause might be another one (Limerick et al. 2014). Or opposite to that, if the outcome does not match expectations, people would attribute something else as being the cause for the outcome. As an example related to AV-VRU interaction, a car could fail to detect a specific pedestrian about to cross, but perceive something else such as a stop sign. Since the outcome is the same as if the car had detected the pedestrian, he could start crossing at the same time as the vehicle starts driving and possibly cause an accident. Instead, if the car would communicate the cause for its actions, this could be avoided.

Another possible problem that could derive from VRUs sense of agency is the basic notion that the car will always prevent hitting a VRU because it is what "is designed to do", this could potentially cause **misuse** and people to take advantage of AVs and cause problems in traffic flow and safety. In these situations, the vehicle should be able to communicate its own intent and agency over the situation, the vehicle should become assertive in a way. This issue was also addressed by Faas et al. (2020) in relation to autonomous vehicles explicitly communicating their nature of being AVs, but without the consideration of this **calibration of agency through the attribution of assertiveness** on the vehicle.

Intentions and attitudes:

It is generally said that humans are very liberal in attributing agency and life-like characteristics to objects. As a consequence, people interact with media in a very similar way to which they interact with other people (Song et al. 2019). Thus, the way people perceive an object can affect their attitude towards it. Between people, an arm movement can be interpreted both as welcoming or aggressive depending on the character the recipient of the message perceives the sender's behavior (Rozendaal et al. 2018). This also applies to relationships with objects and supposes the third challenge in AV-VRU cooperation, which lies in the evoked attitude that VRUs attribute to vehicles. This arises the question of what attitudes and intentions should be displayed by AVs in the future, and will be further explored in the user research phase. Autonomous vehicles are already designed with a set of goals that shape the way they behave in traffic. They are designed to reach their destinations in ways that are **optimally safe, fuel-efficient, and travel-time efficient**. These goals have an impact on the driving style of AVs. To pursue fuel-efficiency cars will not accelerate vigorously and will naturally break gently. Safety-enhancement characteristics make AVs avoid the safety-critical situation (eg. Staying longer behind a cyclist before overtaking). Lastly, they are designed to follow traffic rules more strictly than human drivers do (Nyholm and Smids, 2020). These kinds of behaviors already shape AVs as normative and respectful, but the **social aspect of their relationships** with humans is not yet determined. Therefore the social capabilities of Autonomous vehicles remain an open question. Being this a human-centered design project, we will attempt to fit these secondary characteristics to the desired attitudes and feelings that people have today, therefore this will be further explored in the user research.

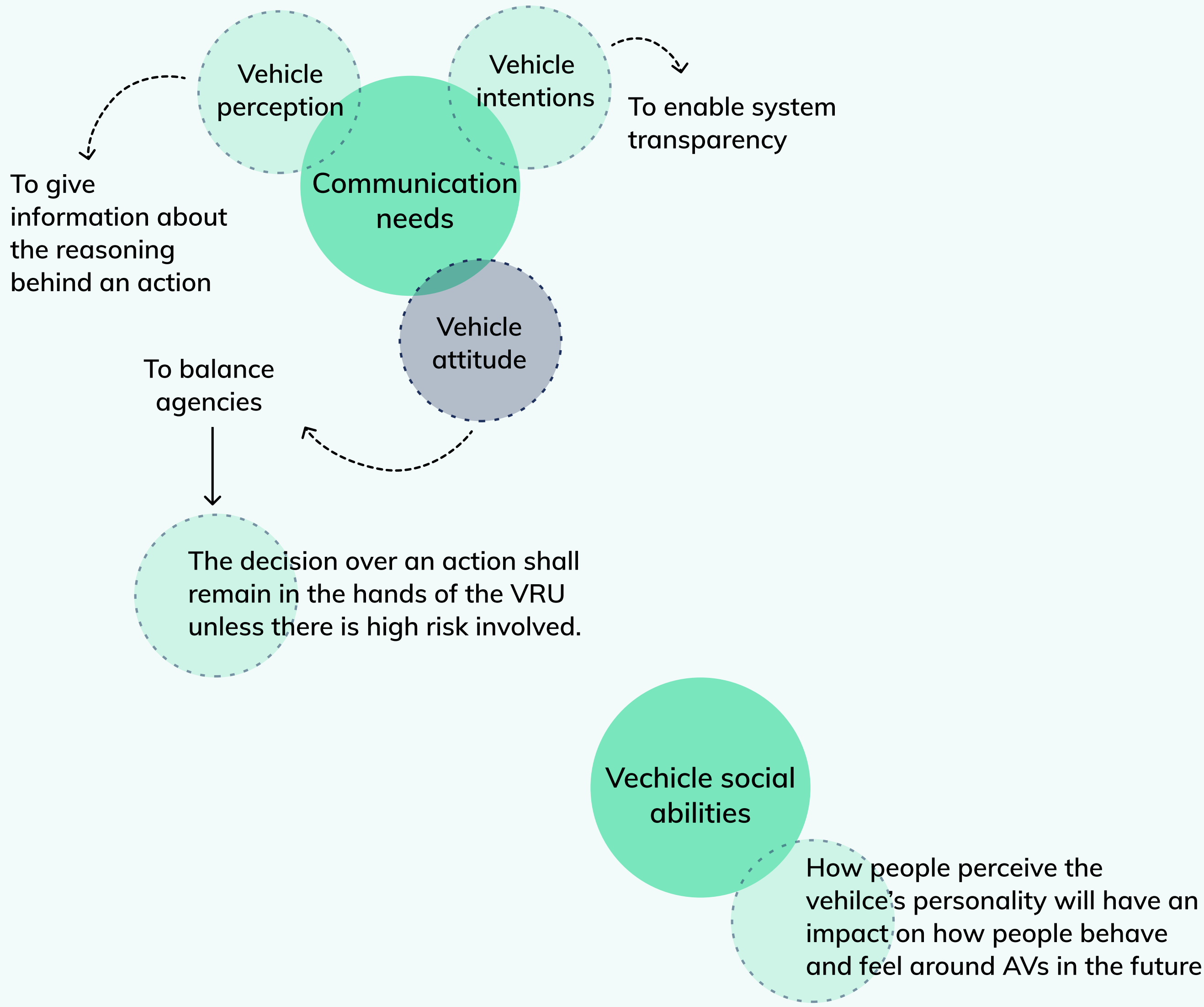
DISCUSSION

Being Human-Robot Interaction (HRI) a more developed field of research, a set of relevant learnings can be borrowed to be applied in the current challenge of AV-VRU communication faced in the eHMI design research and this project. Firstly, the predictability aspect of AVs actions is critical to ensure proper collaboration with human agents, this is something that relates closely to research done in the eHMI field, where the explicit display of vehicle's intentions is considered crucial for a good AV-VRU interaction.

One of the main challenges in HRI is the balance of agencies, a concept that has not been found to be included in the current AVs communication research. Including this kind of knowledge in new research, gives the opportunity of deepening into the studied interactions, considering that for different specific scenarios or situations the car might need to express the reason behind its actions, be compliant with VRUs actions, or oppositely take control and act upon its own decision power and agency.

While the basic driving style of AVs is determined by their three main goals, there is still room to look into how VRUs would like the relationship with vehicles to be in the future. This challenge will be looked into in the user research phase and will help guide the project in a human-centered direction.

LEARNINGS



REMAINING QUESTIONS

- What are the needed and desired vehicle attitudes to be portrayed by the communication system?

CONTENTS

User Research

04

This explorative research phase gives insights on how people feel when encountering a vehicle in the context of urban traffic and how these interactions could be improved in the future, with the introduction of autonomous vehicles. The insights gained during this research phase were used to informing the early design stage of the project and serve as a base for further research in Human-AV interaction. For this purpose, generative research tools and techniques were used.

GENERATIVE RESEARCH

Generative Design Research takes a design-for-research approach and adopts a participatory mindset using generative tools to enable and encourage users to express their experiences in a playful way. Through a set of tools, users become more aware of their experiences (Convivial Toolbox, 2012). In Generative Research sessions, participants express their goals, the motivation behind their actions, what these mean to them, what are their latent needs, and practical matters of the context of the study. After doing a set of activities, participants are asked to generate alternatives to the current analyzed situation.

GOALS OF THIS RESEARCH PHASE

There are two main things that lead this research, firstly, during the context research about eHMI research, a knowledge gap was found regarding the possible situations in which the lack of communication causes people to feel uncomfortable around vehicles. This explorative research attempts to shed light on situations that people find in their everyday lives to be addressed in AV's communication system design. Secondly, there is a need to understand how people want to interact with vehicles in the future, to shape the vehicle's mental attitudes and social capabilities.

For this purpose, the following **research questions** were formulated:

General human needs
- What are the needs and wants of people when encountering vehicles in urban traffic?

Case scenarios
- What specific situations do people encounter en their everyday lives?
- What are the feelings linked to these encounters? What are these feelings dependent on?
- What do people really look at en these situations in order to make their decisions?
- What social interactions occur in these situations?

Dreams for the future
- How would people like vehicles to behave and interact with them in the future?

METHOD

A young group of participants was targeted due to the technological literacy of this group (since data collection was conducted using a number of Digital tools such as Miro or Video calls). Moreover, this project is looking very far into the future, and younger people are more familiar with technology and have a greater potential to imagine possible future scenarios that include intelligent objects. Additionally, participants recruited had to live in Randstad, since in bigger cities, finding critical situations than in smaller ones. The recruitment was done through word of mouth from the researcher's social group; therefore, the sample of participants might not be representative of a wider population.

Figure 10: Method followed in Generative User Research

The study was conducted with 6 participants between 23 and 28 years old (Mean=25.33, std. Deviation)=2.16) living in the Netherlands, more concretely living in some of the main cities, namely The Hague (n=4, 66.7%), and Amsterdam (n=2, 33.3%).

For this study, participants were asked to perform a number of activities in the previous days to the generative session. To these, we give the name of the sensitizing package (see Appendix E). The sensitizing intended to help participants immerse in their everyday interactions with vehicles and reflect on these. The completion of these activities was used as a data collection method in itself since they already give insights into what people do in relation to vehicle-to-VRU interaction as a form of self-observation.

After collecting the filled sensitizing activities from participants and doing the first Analysis, two generative sessions (Convivial Toolbox, 2012) were planned in small groups of three. In the sessions, a number of activities were conducted to generate discussion among participants. They were semi-structured so that the conversation could take different directions. While facilitating the session, the researcher was able to ask extra questions to go deeper into topics found relevant or interesting. The activities performed were the creation of a college through a given material, brainstorming on situations that feel uncomfortable in traffic today, a deep dive into the scenarios looking for key interactions, and the brainstorming of future solutions. The sessions were recorded to be rewatched or listened to again in the analysis phase. The Miro results can be found in appendix G, and figure 11 presents the link between data collection methods and the results presented in the coming pages.

DATA ANALYSIS

For the Analysis of the generative sessions, the Analysis on the Wall method (Convivial Toolbox, 2012) was chosen to get deeper insights. All the video footage from the sessions was reviewed, and statement cards were created to allow the researcher to interpret the results and better understand the portrayed situations.

The statement cards highlight reflections and interpretations by participants, allowing the researcher to translate the communication needs from participants into vehicle messages and communication modes. It is important to highlight one limitation in the data analysis, and it is the presence of a single researcher. A group of them usually conducts these studies.

Once the statement cards were completed, they were divided into thematic clusters and reviewed again.

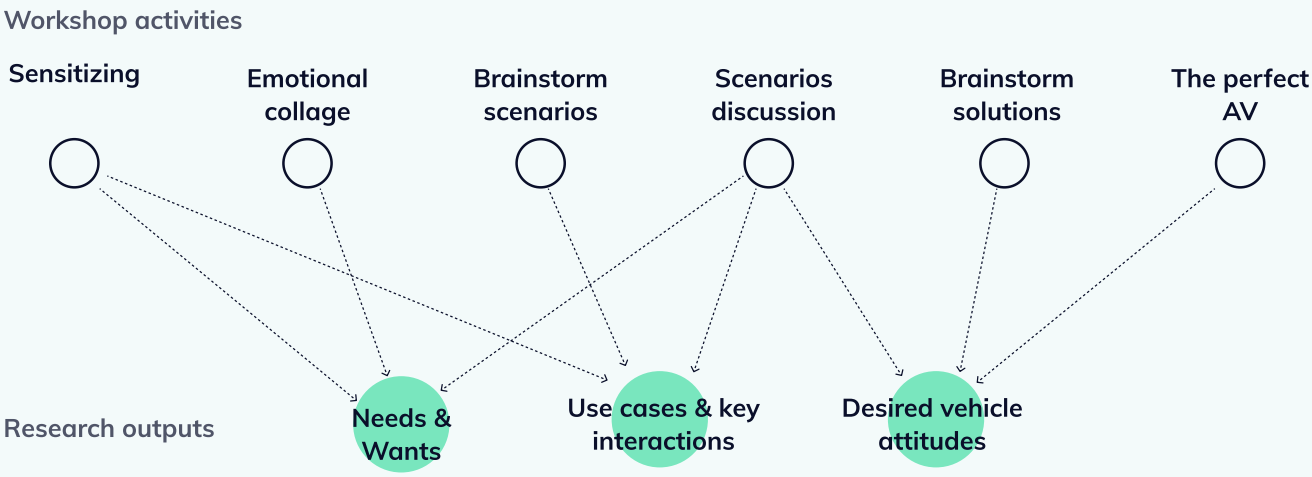


Figure 11: Method followed in Generative User Research

GENERAL NEEDS & WANTS

After conducting the thematic clustering, the main topics that arose were the need for feeling safe in urban traffic and the willingness to cooperate with AVs.

WHAT DOES THE FEELING OF SAFETY MEAN FOR VRUS?

Three main sub-topics appeared in the research, disclosing important insights to take into consideration in the design phase. These were:

Participants expressed a generally negative experience in busy environments as opposed to a more **enjoyable experience in quieter ones**, one participant mentioned that *"If I know what is happening around me, I can enjoy the scenery and have a peaceful and safe walk"* or *"I put the loud word aggressive and noisy. So these are the things that I don't like when I walk or cycle in the street because give me a feeling of uncertainty."*

Situation awareness:

In order to achieve situation awareness, participants mentioned the use of **different senses** and while some rely mostly on the **sight** to manage their decision-making, others pointed out the importance of **hearing** to gain awareness of the surrounding environment, mainly in situations where the car could be behind the VRU. *"I think I rely a lot on hearing what surrounds me because you cannot see backward. So sometimes you can get an extra input on the situation." "You look around a lot, to the left, to the right, to make sure."* Regarding the sound inputs, participants mentioned a great concern about the silent electric cars present in the street nowadays, *"the car was so silent that we didn't really even realize until he was very, very close behind us."* In this regard, Dey et al. (2020) defend a multimodal approach to eHMI design that seems to be desirable for participants.

Another important topic within situation awareness was the **management of expectations** when encountering vehicles in traffic. While participants mentioned in several moments that they look at the vehicle movement to try to predict its behavior in the encounter, it was mentioned that is not always easy, because a vehicle might be decelerating with not intended to stop in the end. *"I would look at whether the car is slowing down. It is difficult, cause sometimes cars are slowing down but you can not assume they will completely stop."* Therefore it can be seen that predictability is an important factor in these interactions. These opinions by participants go in line with previous research made on the literature on both eHMI design research (Faas et al. 2020) and further in intelligent agent-human collaboration design (Berberian, 2019).

Reassurance in decision making:

In order to be more clear about what the vehicle will do, participants talked about the interpersonal interactions that may happen with drivers in different encounters. While these did not come across as crucial for their feeling of safety, it was a general opinion that it is nice to feel reassured in the decisions you make as a vulnerable road user. *"An exchange with the driver happens also, where they kind of look at you, they offer you to pass because they're breaking. So I feel really reassured when they do that. And it feels like a really easy interaction with the vehicle and also the driver in the vehicle."* When talking about future traffic and the introduction of autonomous vehicles, participants expressed a generally positive attitude towards self-driving vehicles being able to provide this kind of reassuring feedback. *"Will be nice for the car to actually can give feedback to the pedestrian, kind of like the driver does this (doing a hand gesture)."*

This confirms the general premise that

interpersonal communication should be addressed in the introduction of autonomous vehicles in traffic (Faas et al. 2020). And while there is research in favor of avoiding explicit communication systems (Dey et al. 2017, Rasouli et al. 2017), it seemed to be desirable to all participants of the generative study due to two main reasons. First, the reassurance that explicit communication could provide, and secondly, the simplification in the expectation management.

Presence of traffic rules:

The presence of traffic rules in the moments of interaction was mentioned as positive since they reduce uncertainties. *"There are rules for example, the zebra crossing or the bike lane or the sign that help you feel like you are protected."* Nevertheless, it was acknowledged by the participants that rules do not always solve the tensions that can arise from small failures in the system. *"There are rules, but the tension moments are there. Because you or the driver can always be distracted, and then is when it becomes dangerous".* Not only strict traffic rules were mentioned, but also the social traffic norms *"Strict and social rules are very important for me, like knowing that the person coming from the right has the preference, that helps a lot."* The effect of traffic signaling on VRU's trust in vehicle automation was already addressed in research of eHMI design (Jayaraman et al. 2019)

Regarding future traffic, it was also mentioned that these tensions that we find today, will still exist, because *"machines also fail"* and therefore the mechanisms used to solve these today, should be addressed in the future. This also constitues a need to improve trust between road participants. Being autonomous vehicles the novel agents, they will have to gain trust over time by communicating with human road users.

ATTITUDES TOWARDS THE INTRODUCTION OF AVS IN THE FUTURE

Another topic that arose was the willingness to cooperate with AVs in future traffic. *"We need to learn how to interact with these vehicles and learn how to predict their behavior so that we can keep ourselves safe in the presence of the cars".* Participants also mentioned that even if the cars would be designed to always avoid collisions with VRUs, they should have their own mechanisms to prevent being taken advantage of *"If you're tending to cross the roads, it slows down and then you cross it and it stops. Then no one is going to go to the zebra paths anymore". "There are situations where I also don't respect the rules. So I feel a bit sorry for maybe making others act inappropriate."*

NOTE

All of the needs of people when interacting with vehices lead to situation awareness, neverhtless, there is an aspect of temporality to the interactions. While creating a calmer environment will affect an early stage of an interaction, expectation management comes into play when VRU and AV are close. Reassurance in decision making, instead, is cherished when VRU has already "made" a decision on how to act.

FINDING SCENARIOS

One of the main goals of the user research was to find situations in which the interaction is important for VRUs feeling of safety and real safety when misunderstandings or unexpected events happen. Once analyzed, these situations can be seen as dialogues that can go many different ways. This is something that, as mentioned in chapter 2, current research in AV-VRU interaction does not explore, which generally leads to overlooking the role of the eHMI.

In order to find these scenarios and look into them, participants were asked to brainstorm traffic situations in which they feel uncomfortable today.

Group 1 came up with the following:
- Crossing without strong traffic signaling.
- Cycling in mixed traffic, where other vehicles also move.
- Rainy nights.
- Intersections where vehicles incorporate to street where you're cycling.

Group 2 mentioned the following scenarios:
- Crossing without strong traffic signaling.
- Residential streets, mainly with silent cars.
- Not allowed crosses.

To summarize the results of the mentioned important interactions and possible problems that the introduction of AVs could cause, table 2 was created.

The "Dark and rainy" scenario was not included since the cause of the lack of comfort is not precisely the interaction with cars but simply the environmental conditions.

The "key interactions" column was filled with the interactions mentioned by participants. The "considering AVs" column was completed by interpreting and speculating about what problems could derive from AV preset in the same scenario.

Looking at the presented table, it can be seen that scenarios 3 and 5 presented (silent vehicles in residential areas and vehicle incorporating) seem redundant, In the case of scenario 3, because the other three interactions could occur in residential areas. The second presented already considers the need for noticeability of the AV. Scenario 5, on the other hand, shows needs also present in scenarios 1 and 2. When choosing which scenarios are appropriate for further analysis, the aim is to

	Situation as presented	Key interactions as mentioned	Consideration of AV presence
1	Crossing scenario with no strong traffic signaling (both groups)	· Looking for eye contact. · Following the signaling. · Stopping until car fully stops. · Waiting for driver's hand gesture.	· Not possible to find eye contact. · Not possible to receive hand gesture. · Hesitation until vehicle fully stops.
2	Cycling in mixed traffic (Group 1)	· Signaling own intentions with arm gesture. · Being very attentive. · Looking over the shoulder when hearing something. · Not moving far from the road border.	· Just as EVs, most likely AVs are silent.
3	Silent vehicles moving in residential areas (Group 2)	· Being very attentive. · Looking to both sides when about to cross.	· Just as EVs, most likely AVs are silent.
4	Cross where vehicles have the right of way or perestrians are not allowed (Group 1)	· Looking for eye contact. · Stopping until there is a gap in vehicle traffic.	· Easy to take advantage and just cross when VRU is not allowed to.
5	Intersection where a vehicle incorporates to main street (Group 1)	· Look carefully if the vehicle is going to stop · Looking for eye contact to see wether the driver saw you. · While cycling, reducing speed until sure.	· Not possible to find eye contact. · Hesitation until vehicle fully stops.

Table 2: Outcome scenarios overview

see as many different communication needs as possible. Therefore, scenarios 1, 2, and 4, were chosen for further interpretation since they present different needs.
After analyzing the situations from the perspective of the vulnerable road user, it was necessary to change the lens through which the situations were examined—taking the perspective of the vehicle allowed for simplifying the possible scenarios and translating those communication needs into vehicle messages.

The following journeys describe the “conversation” between AV and VRU in the three chosen scenarios. These helped in concluding the communication needs that the design should address (Figure 12).

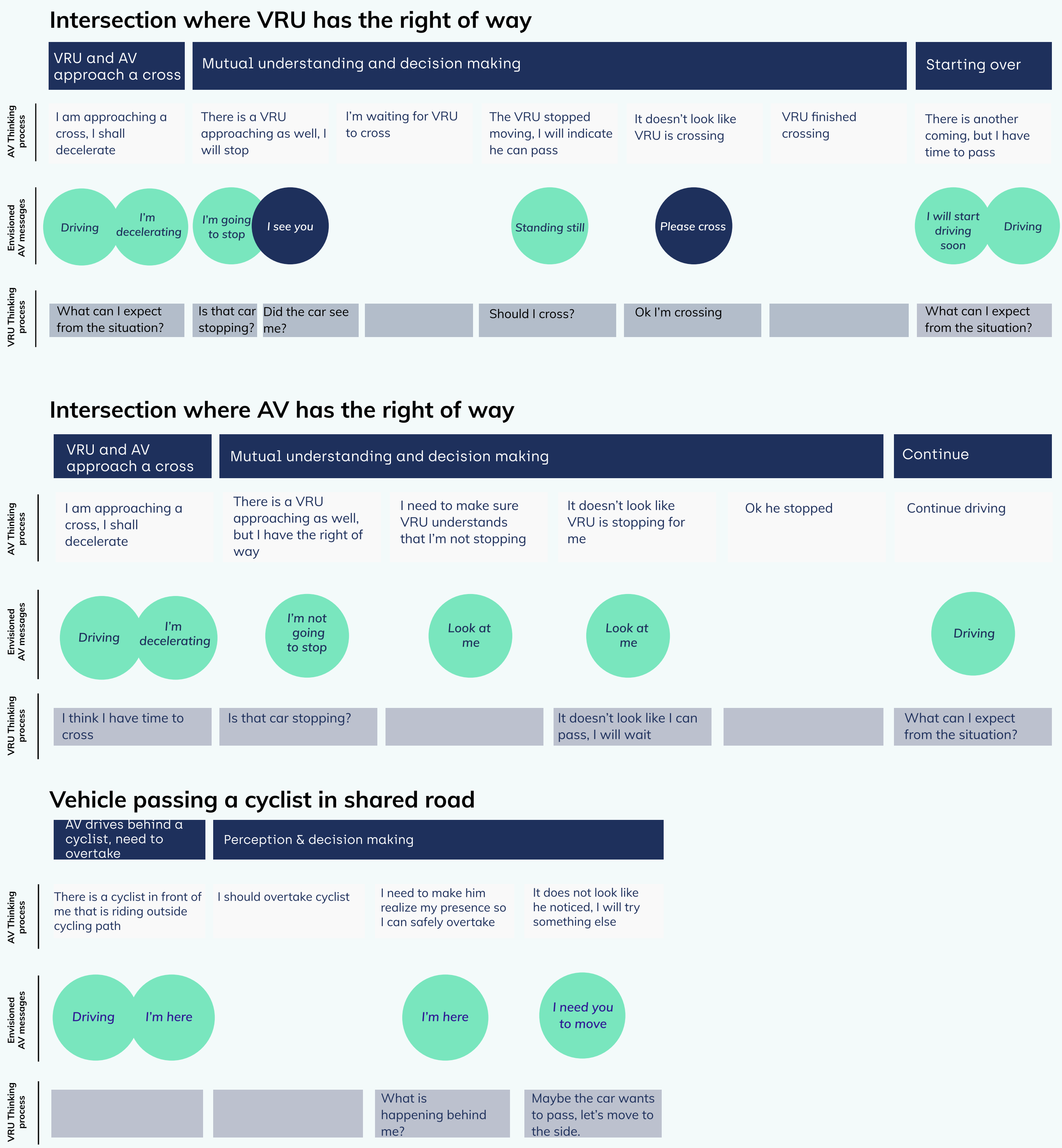


Figure 12: Interaction journeys in the chosen scenarios.

COMMUNICATION NEEDS

The communication needs to be derived from the situations presented in the previous page lead to a number of vehicle messages (figure 13).

These messages were then categorized in layers by the researcher, according to temporality and level of intrusiveness or attention needed from the vehicle. The first communication layer is that which anticipates and eliminates ambiguities in the intentions of the vehicle, when it comes to its movement, as it has been previously explained, in situations where the movement of the vehicle is hard to read, some kind of explicit cue is needed to set the proper expectations on the VRU and reduce ambiguities.

Expressing perception can give extra information in relation to the reason why an action or another is taken, eg. The vehicle could be stopping for a VRU to cross or because it has detected a possible different obstacle. In the latter scene, a conflict could arise when the vehicle and VRU start moving at the same time. Therefore the expression of the why could potentially reduce further ambiguities.

As seen in the analyzed situations, there are moments in which the vehicle needs to bring attention to itself for different reasons. We see that in the overtaking situation, where early acknowledgment of the vehicle presence from the cyclist can prevent conflicts. Moreover, we need to consider that in intersection situations, VRUs can also be distracted, which could cause accidents as well. Furthermore, in situations in which the car has the right of way and VRUs might not be respecting it, the car will need to be assertive and stand for its right to prevent being taken advantage of.

Figure 13 maps the vehicle messages in different levels of intrusiveness. Moreover, the distinction between messages related to vehicle movement and intention are distinguished from messages related to the VRU, such as perception messages, advice, and vehicle needs. On top of that, messages are presented in a chronological sequence, reflecting the "conversational" aspect of the communication system.

The **first arrow** represents a baseline communication that contributes to situation awareness while keeping a calm environment by being subtle but providing enough information to VRUs around the vehicle to make sense out of its action.

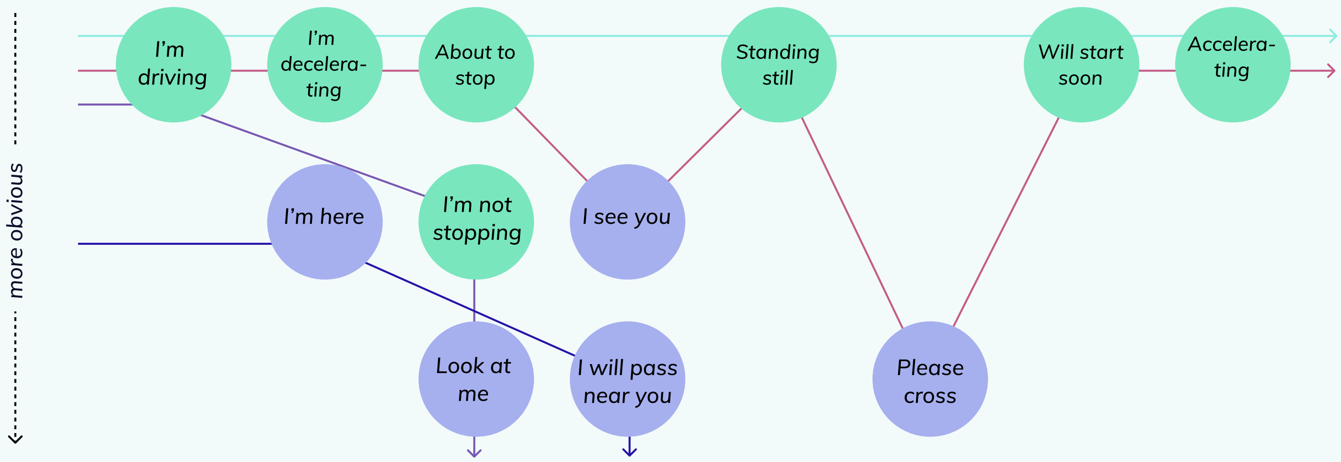


Figure 13: Vehicle messages covering all communication needs.

The **second** represents a possible sequence of messages which fit intersection situations, with the addition of the perception communication and the clarification in case no reaction is detected from the VRU. Regarding the needs identified during the user research, it contributes to reducing the ambiguities and reassuring in the intention of letting the VRU pass (or cross) first. This line of communication is envisioned to be the most used one since intersections are the main interaction moments between VRUs and cars in current traffic. The complete concept design will be based on this communication layer.

Following, the **third arrow** represents a sequence in which the vehicle becomes assertive and imposes its own right of way when that is the case determined by traffic rules. The attitude attributed to the vehicle should change from more friendly and submissive to assertive and dominant.

Finally, the **fourth arrow** reflects the different communication needs present in the overtaking situation, where the car needs to make itself noticeable by the VRU riding ahead to notify its presence and prevent unpleasant surprises.

It is important to mention that while all these messages are the result of the situations analyzed during the user research and will set the base for the concept development, we still need to learn whether all these are necessary or not. The balance between giving enough information and avoiding an information overload needs to be achieved and will be looked into in the conceptualization phase.

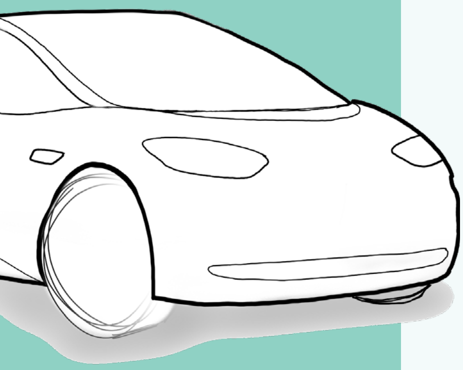
DESIRED VEHICLE ATTITUDES

The desired vehicle attitudes arised from the User Research are portrayed in this section and take the form of an object persona.

CAR PERSONA

In design, Personas are the description of fictional users. Is a technique widely used to make it easier for designers to relate to users Pruitt et al. (2003). Personas include character and individual stories, thoughts, and experiences. Nevertheless, recent developments in the design field, in order for products to express their designed intentions, affordances, expertise, etc. Designers need to decide on the behaviors and personalities of these objects. Cila et al. (2015) introduced Object personas with two main goals. Firstly, analyzing the use of objects, and secondly, to stimulate creativity in the design of products based on those objects' lives, movements, and transformations.

In this case, we are interested in the attitudes, and feelings of the vehicle that affect their communication and behavior, the data used to create this vehicle persona comes partly from literature, such as the main goals affecting vehicle's behavior (Nyholm and Smids, 2020) and partly from the generative sessions conducted during the user research, where participants were asked about desired future interactions and brainstormed together (Appendix X).



GOALS, BEHAVIORS AND FRUSTRATIONS

" I want to arrive from A to B optimizing my energy consumption, this makes me drive in a ***gentle*** *way, never accelerating or braking abruptly, I'm more an endurance runner than a sprinter to this matter. Also, I want to arrive in the shortest time possible, which makes me choose the routes accordingly, sometimes this implies trying to not get stuck in traffic. My third duty as an autonomous vehicle is* ***to ensure the safety of my passengers and everyone else on the road****, which highly affects the way I behave when I'm surrounded by people.*

To ensure the safety of people walking or cycling close to me, I am ***transparent*** *about my actions and intentions, I am sincere. Still, I don't like to be the center of attention, there are far more pretty things to look around, but sometimes, when people come too close and are distracted, I need to call their attention.*

I always respect other's rights and would like to be treated the same way *in return, sometimes I feel that people take advantage of me because they know that I will always stop if they stand in front of me, but I'm learning to impose myself and let them know that I'm not stopping when I'm not supposed to"*

WISHES FOR THE FUTURE

"I WANT TO BECOME A NICE CITIZEN BY LEARNING FROM MY MISTAKES."

"ME AND MY MATES WANT TO BE UNDERSTOOD BY EVERYONE IN THE WORLD."

SOCIAL RELATIONSHPS:

Traffic rules

Ruling, I have to obey cause they have my best interest at heart.

Human-driven cars

Acquiantances, it is hard to predict their moves, so I don't enjoy hanging out with them.

Autonomous vehicles

Friends, we get each other and it is easy to be open and share all of our experiences

Passengers

I have a duty towards them, they rely on me and I can't fail.

VRUs

It is hard to predict their actions. I would like to communicate with them, but we should understand each other to ensure everyone's safety.

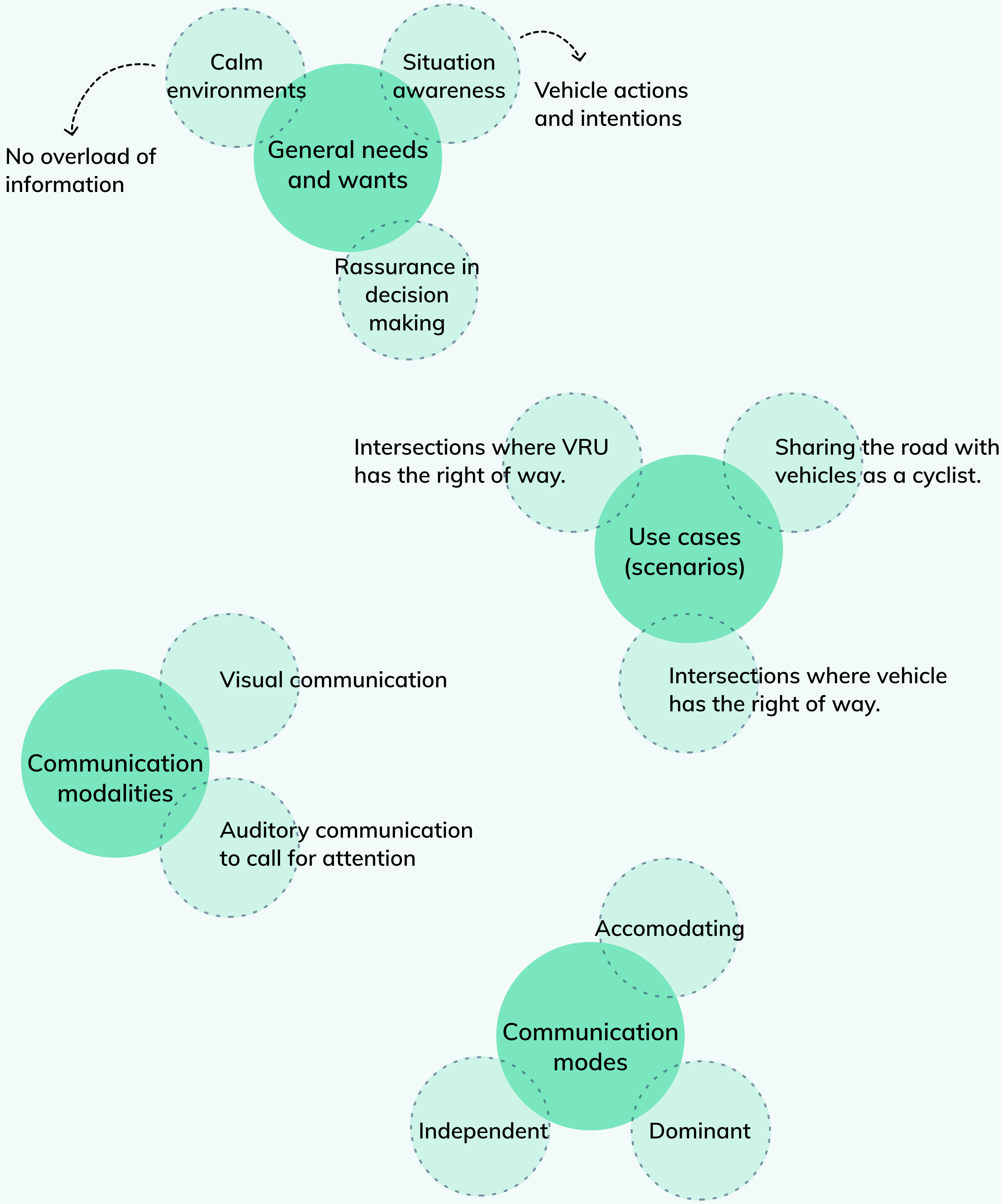
THE JOURNEY

In order to put together all the insights gained in previous research phases, a journey map was created. It is mainly divided into three phases relating to the temporal development of VRU-AV interaction (Y-axes). The X-axes present the human needs and vehicle's communication responsibilities at every stage of the interaction. Finally, design requirements particularly linked to the specific scenarios explained in chapter 4 are presented.

	Description	Situation Awareness	Communication needs	Vehicle messages
	Based on the different journeys studied, the goals of each one of the phases are:	In order to accomplish VRU situation awareness in each one of the interaction phases, the eHMI design should aim for:	The things that people need to know in order to feel in control and secure are:	To fulfill the communication needs the vehicle should display the messages:
Pre-Interaction	VRU and vehicle approach an interaction scenario: VRU attempts to make sense of the situation around.	**Calm environment:** People would like to make sense of what is happening around them without paying too much attention. **Multisensory involvement** to pay attention to what is necessary. **Expectation management:** Making sense of what VRU will encounter.	Detecting the presence of a vehicle. Vehicle actions and inmediate intentions.	*About to stop* *Standing still* About to start *I'm here*
Interaction	*VRU has the right of way* VRU and interacting vehicle are close to each other and need to achieve mutual understanding in order to ensure safety. This interaction phase includes the VRUs decision making. *Car has the right of way*	**Expectation management:** When VRU has the right of way, he/she tries to predict what the vehicle will do. In order to make the appropriate & safe decision to cross. **Balance of agencies:** VRU feels in control over the situation when the car acts according to his right of way. **Expectation management:** When VRU does not have the right of way he/she tries to predict wether has time to pass before the vehicle reaches the cross. **Balance of agencies:** Car takes control over the situation and provides behavioral cues to VRUs.	VRU needs to know wether the vehicle action is related to him/her or not (perception) Vehicle intentions.	About to stop For VRU(s) I'm not stopping Watch out! I'm here
Post-interaction	VRU and interacting vehicle are close to each other and have achieved a mutual understanding. VRU has made a decision on what to do and acts accordingly.	**Expectation management:** Once an action is taken by VRU, he will try to keep an eye on the interacting vehicle in case changes on the state appear. **Reassurance in decision making:** People value reassurance when they act in traffic situations.	Changes in the actions and intentions of the vehicle. Continuous perception of VRU.	*Waiting for you to pass* *Standing still* About to start *I see you*

Vehicle attitudes	**Specific per scenario**	
The vehicle attitude associated with the messages sent should be:	**CROSSING**	**OVERTAKING**
Accommodating Discreet Subtle	In intersection scenarios, the predominant sense used is sight, therefore visual communication better fits the scenario. The design should be discreet but clear in the communication of intent. The VRU should be able to easily identify what is happening and will happen with the vehicle next.	In overtaking scenarios there is no direct visual contact with the vehicle, therefore auditory communication better fits the scenario. The design should be discreet but clear in the communication of presence, to be detected by VRU with enough reaction time.
Accommodating Discreet Subtle	The design should be discreet but clear in the communication of intent and perception. The VRU should be able to easily identify what is happening with the car and why.	
Assertive Dominant	Audio signaling should be used to bring attention to a more dominant visual communication. The design should be clear in the communication of intent. The VRU should be able to easily identify the assertive attitude of the vehicle.	In overtaking scenarios where the cyclist should give way to the car, and has not done it after the car attempts to communicate presence, the design should be clear in the request for the cyclist to move. This could be done through more obvious audio signaling or a visual intervention.
Independent Discreet Subtle	The design should be discreet but clear in the communication of intent and perception.The VRU should be able to easily identify what is happening with the car.	

LEARNINGS


Calm environments
Situation awareness
Vehicle actions and intentions
No overload of information
General needs and wants
Rassurance in decision making
Intersections where VRU has the right of way.
Sharing the road with vehicles as a cyclist.
Use cases (scenarios)
Intersections where vehicle has the right of way.
Visual communication
Communication modalities
Auditory communication to call for attention
Accomodating
Communication modes
Independent
Dominant

CONTENTS

From research to design

05

This chapter holds all the insights gained from the previous research phases important for the design process. First, list of requirements for the design. A design goal is presented together with the interaction qualities that the design will aim for.

DESIGN REQUIREMENTS

The research outcomes presented, helped in formulating design requirements for the coming phases. All insights from the three research phases conducted previous to this point give an idea of what is needed in the further development of the design.

GENERAL REQUIREMENTS:

- Information about state and intention should be displayed by the communication system in a way that is understandable.

- Information about state and intention should be displayed by the communication system in a way that is easy to learn.

These two requirements take protagonism in both, literature related to eHMI design research and intelligent agents research. On one hand, Dey et al (2020) point out the importance of creating a system that is easy to learn and can be standardized, on the other, Barberian et al (2019) values predictability as a key factor in increasing trust and acceptability of automated systems. This project should therefore attempt to create a system that allows understandability with a minimal learning curve.

- Information about intent should be accompanied by information about perception to avoid ambiguities and identify possible system errors.

While action and intent of the vehicle are possible to understand and predict by looking at vehicles' implicit cues, such as movement, speed, and relative positioning (Dey et al, 2017), knowing the why behind how an automated car intends to act can further reduce ambiguities and improve acceptability and cooperation (Rozendaal et al. 2020).

- The communication system should be adaptable to the situation, generally discreet, but with the possibility to claim attention and make the vehicle stand out when needed.

During the user research, it was found that generally, people prefer discreet systems that do not claim a lot of attention, since the environment in which they walk and the cycle is more pleasant when is not loud or overstimulating. Nevertheless, it was also pointed out that vehicles should be able to prevent risky actions by VRUs by claiming their attention, when they are distracted or attempt to take advantage of the automated vehicle.

- The eHMI should provide behavior hints without taking away VRUs sense of agency.

Rasouli et al (2020) point out the importance of vehicle communication being informative rather than advisory since a vehicle will never be able to control the actions of another automated vehicle or a human-driven one. So the ultimate decision on how to act for the VRUs should always remain on themselves.

- The communication system needs to work across the different scenarios found during user research.

One of the gaps present in the literature is the focus on trying one or different eHMI systems in a specific situation, opposite to that, this project attempts to create one system that can tackle different situations using the same communication elements.

- The communication system should be possible to standardize and be applied by multiple car brands.

One of the main challenges now faced in eHMI design research is to find agreement into what is necessary to be implemented across different countries and by different car manufacturers (Dey et al. 2020), for this reason, abstract communication modalities seem to be more appropriate.

- The communication system should be visible from all the relevant directions in all weather and light conditions.

Chen et al. (2020) defined a number of design requirements to take into account when designing eHMIs for automated vehicles, most of them relate to the visibility and intuitiveness of the system.

DESIGN GOAL

A design goal and interaction qualities were formulated in order to guide the design and the evaluation of the final concept.

"To clearly communicate the perception, intention, and action of Autonomous Vehicles in situations where understanding from Vulnerable Road Users is important to ensure safe interactions."

AV-VRU RELATIONSHIP

Following the learnings from the communication needs from VRUs and the desired vehicle attitudes that have been seen previously, the agent-to-agent relationship between AVs and VRUs should be based on mutual understanding and willingness to cooperate.

ACKNOWLEDGED:
VRUs should perceive that the vehicle they are interacting with is aware of them. Not only their presence in the sight field of the car but also their intended actions.

RESPECTED:
VRUs should feel their intentions, rights and safety are respected by autonomous vehicles at all times.

CARED ABOUT:
VRUs should feel autonomous vehicles are intentional about keeping them safe during all interactions.

SAVVY:
VRUs should feel confident interacting with autonomous vehicles due to the mutual understanding perceived between them, they should know what to expect and therefore how to act around them.

To accomplish this, a number of **interaction qualities** were defined, it is important to mention that while this are not the final design in itself, they will help in taking different directions along the conceptualization process

INTERACTION QUALITIES

Transparent
eHMI exhibits system transparency on its actions and intentions.

Clear & understandable
eHMI should give clear information that is understandable by all VRUs who can see the vehicle. Confusion and ambiguities must be avoided.

Intuitive
eHMI behavior is easy to learn and follows intuition.

Directive
eHMI directs the attention to where VRUs need to be looking at to get clear information about the action, intention, and perception of AV.

CONTENTS

Concept development

06

This chapter contains all the activities conducted in order to get to a final design concept. An initial ideation phase was conducted and a number of user tests are presented. The process was divided into two phases in order to ease the prototyping activities.

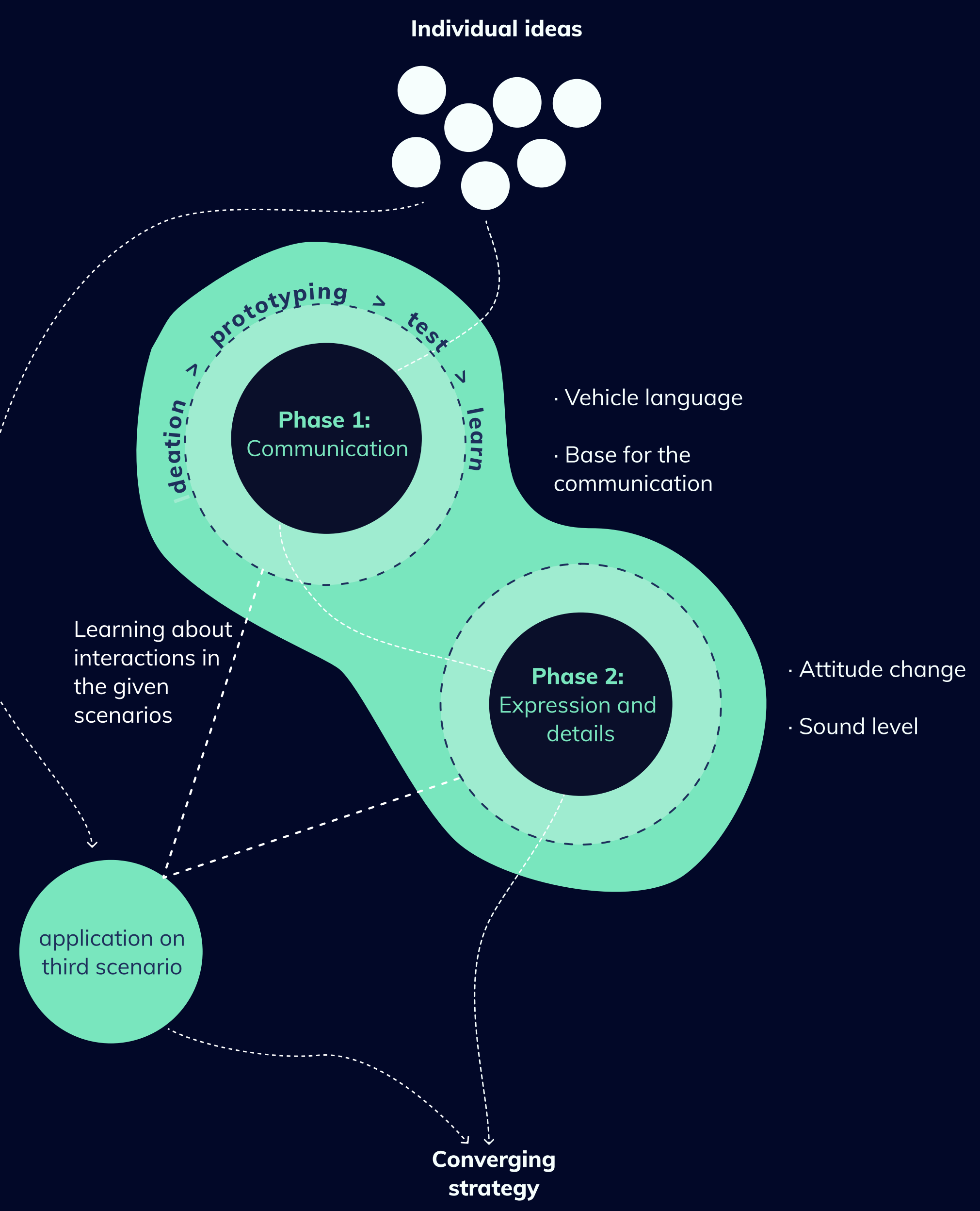


Figure 14: Iteration process visualization

ITERATION PROCESS

As seen in page 50, there is a need for different communication layers. Not only do the messages need to be communicated clearly, but the elements of the eHMI need to be orchestrated so the overall experience is consistent and the communication clear.

During the ideation session (see appendix I), a number of ideas arose tackling the different communication lines presented. While the intersection scenarios inspired a lot of different solutions, the overtaking scenario was more limited in the possibilities that could help in the situation. That, together with time limitations related to prototyping activities, led to conducting two main phases of iteration were conducted targeting the two first communication lines. For each one of these phases, similar evaluation techniques were used. Some concepts derived from the ideation activities were prototyped and tested with users to unveil the individual and joint potential of the different elements and concepts to guide the final holistic design, moreover, these evaluation sessions were also used to gain more insights about the interactions portrayed, continuing the research conducted in the first phases of the project. Figure 14 graphically represents this iteration process. The method used in these conceptualization phases is inspired by Interaction Prototyping & Evaluation (Delft Design Guide, 2017), where low fidelity prototyping is used to check the designer's assumptions. In this way, concepts are quickly tried to come up with a final design that fits the users' opinion.

Phase 1 focuses on the communication of action and immediate intention of the vehicle regarding its movement, and perception of VRUs in a situation where they have the right of way. This first phase gave an idea of what the language of the vehicle could consist of to communicate expressively. Phase 2 focused on the attitude change of the vehicle from accommodating and discreet to assertive and dominant. In this phase, new details started to get shaped and sound interventions were also evaluated and portrayed to inform the sound interventions of the final design. In each one of the iteration phases, participants also got to give their own input in the final design, and a lot was learnt about the interactions studied.

After evaluating three different low fidelity prototypes in each phase, a converging strategy was created taking into account, not only elements of high potential but also the evolution of the "conversation" and learnings from the studied scenarios. The learnings gained in this phase also helped in shaping the design of the eHMI intervention in the overtaking scenario, together with the ideas arised in the ideation session.

PHASE 1: EXPLORING THE VEHICLE LANGUAGE.

The first phase of conceptualization focused on the pre, during, and post interaction parts of the VRU journey, where the communication is highly visual and the vehilce attitude is gentle. Therefore, the goal was to clearly communicate action, immediate intention, and perception of the VRU in a discreet way. The crossing situation was chosen for prototyping in this phase due to the highly visual character of the scenario.

Different ideas from the ideation session were integrated in three concepts exploring differnt ways in which the car could communicate. The engine sound was added to the prototypes to create a more realistic experience, but this element was not evaluated.

There is a common element to all concepts, being this the light behavior during "waiting for yo to cross" and "will stard driving soon" communication. These follow a breathing pattern for the standby state moving into a blinking state when the car is about to start driving. This pattern was integrated into all concepts due to having been already examined by Lui et al. (2017) who studied the expressiveness of different point light patterns. These proved to be intuitive enough for people to understand what they would mean even when decontextualized from products. This would help to confirm or disprove wether it would be a good idea to be integrated in the eHMI, since one of the goals is to create an intuitive design that will be easy to learn. Moreover, communicating that the car is "waiting" can be a good way of showing pedestrians that they are being perceived by the car (Dey et al. 2020) without targetting a specific VRU, but everyone around.

Prototypes used can be found in **this link.**

CONCEPT 1: ABSTRACT LIGHTING

This concept focuses on using abstract light communication. It has two main elements to the design, firstly, a light strip on the side of the vehicle, its behavior follows the movement of the vehicle. Secondly, there is a point light that appears on the front of the car when a VRU is detected, while approaching the cross, this point light will move to the side where the VRU is detected.
Figure 15 represents this concept.

CONCEPT 2: CLOSING EYES

This concept focuses on subtle anthropomorphism, using the front lights of the vehicle as "eyes". The behavior mimics a pair of eyes looking in front to looking down. This was achieved through light shape change from completely on to a reduction in size towards the lower end of the front lights. Figure 16 respresents this concept.

CONCEPT 3: REVERENCE

This third concept focuses on body language as the sign of perception and "respect", the car mimics a reverence when a VRU is about to cross. The side light strip was also added, but the behavior is a bit different, this will help to identify further strengths and flaws of the element. Due to the prototyping techniqu used, the "reverence" was attempted by enacting a backward movement of the car. Figure 17 represents this concept. This supposes a limitaion, sincethe prototype

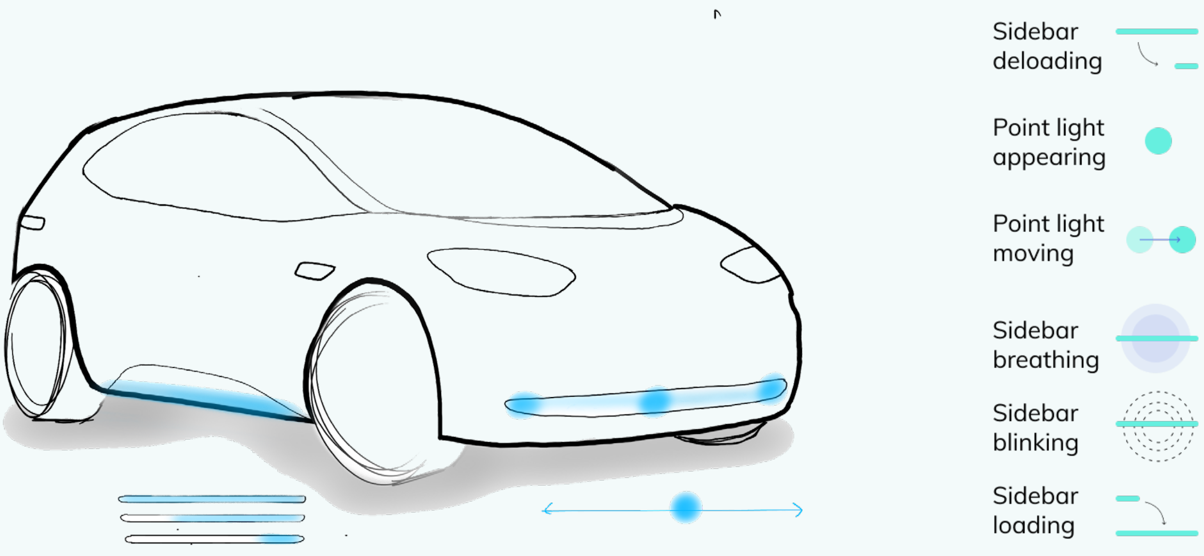


Figure 15: Illustration and communication storyboard concept "Abstract lighting"

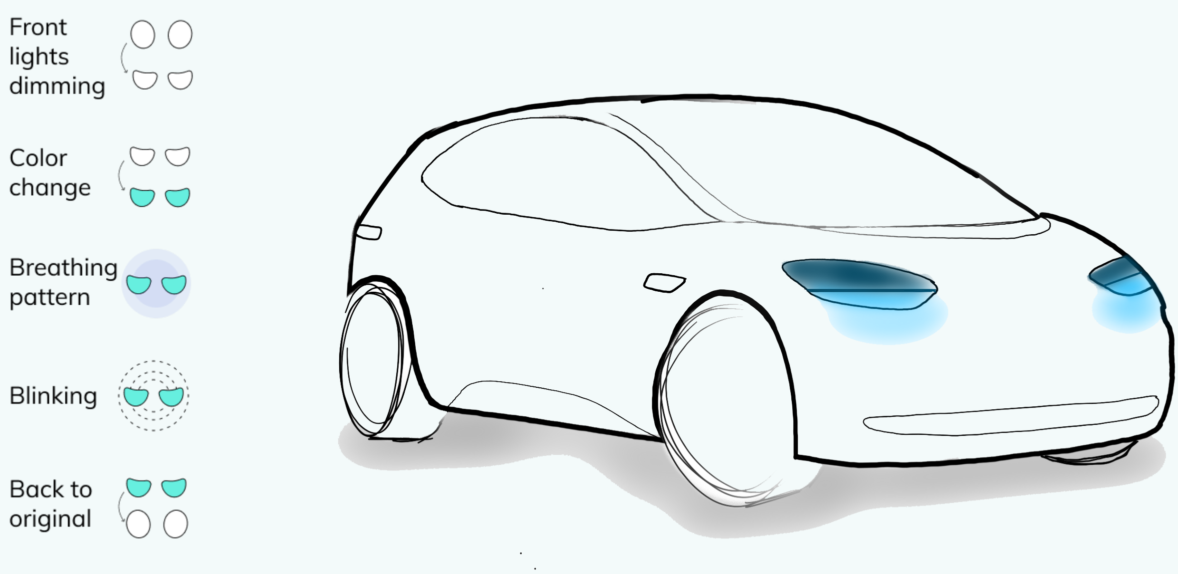


Figure 16: Illustration and communication storyboard concept "Closing eyes"

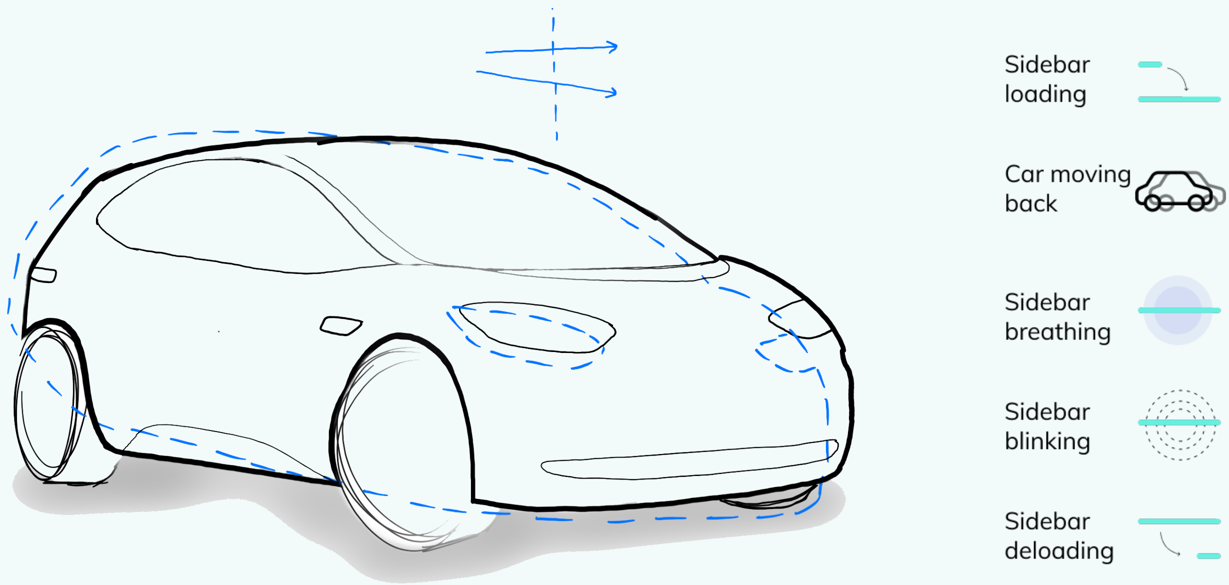


Figure 17: Illustration and communication storyboard concept "Reverence"

EVALUATION METHOD

The goal of this evaluation is to test the different concepts on an experience level. We want to understand what elements work in giving the information and contribute to a calm environment.

The research questions are:

- Which communication modality works better to understand the vehicle's actions and intentions?
- What elements of the designs help VRUs to understand the automation actions?
- What character/attitudes do participants attribute to the vehicle? What elements evoke these attitudes?

8 participants took part in this concept evaluation test (Average age=25.37, std. Deviation =2.66). A good balance between female and male participants was achieved (50% Female 50% Male). Previous to showing the videos, participants were explained the situation to create a more realistic ambiance. The three video prototypes were played to the participants, after each video, participants were asked to fill in a questionnaire consisting of some open questions, from which the answers were also audio-recorded, Likert scales, and PreMo "pick a mood". Appendix K contains the questionnaire used and the overall resuts.

After the three videos were shown, a spatial presence and immersiveness questionnaire was done (Vorderer et al. 2004). This will serve as the comparison between the concept test phases and the final user test, in which we intend to create a realistic experience through video.

Figure 18: One of the Low fidelity prototype used in this phase.

In order to gain some more qualitative information and ideate together, after the test, participants were asked informally a set of questions to elaborate on how the designs could be improved and how a change of attitude in the vehicle could be achieved. These insights and ideas were used for the third conceptualization phase and informed the final design of the communication system.

RESULTS & DISCUSSION

Figure 19 presents the average scores given to the different items of the questionnaire and the std. Deviation of them, following, we go into the details of the results.

The **Abstract Lighting** concept was rated the highest in terms of experience as being pleasant, and safe. Moreover, it also got the highest ratings in the understanding of the intentions of the vehicle, this could be caused by all the messages being sent in an explicit way despite having an abstract form. *"I like that just looking at the car you always know what's happening with it. The information is non-intrusive and doesn't disturb my "walk" through the city, but I still have all the information I need"* and another participant mentioned *"I like the "language" of the car to be through lights, is something people are very used to already since is used a lot, especially in traffic, I would get used to this easily"*. Therefore, this concept shows the potential of the use of abstract lighting as the base for vehicle's communication, even when not really understood, all participants agreed that once they would know what the different things mean, the interaction would be very easy and pleasant.

While the front point light was understood by a number of participants, and it affected the score of awareness, they still interpreted the message of "*waiting for you to cross*" without that explicit sign of perception, in the other concepts. Moreover, some mentioned *"Since I know it is going to stop, I wouldn't even wonder if the car saw me, I already have enough information"* This gives the understanding that as long as the intentions of the vehicle are clear, perception might be understood implicitly.

For the participants who understood the point light as "I see you" this concept was also perceived as overstimulating *"Altogether is a bit overstimulating. In 15 seconds there are 4 messages to understand happening suddenly. That's a bit overwhelming"*.

The **Closing Eyes** concept was the clearesr according to participants, some understood the anthropomorphic reference: *"This concept seems more human-natural interaction since the front lights feel like the eyes of the car"*. The fact that the whole interaction was concentrated in one place, had both positive and negative reactions from participants, for instance, one said *"I actually like that I just need to focus my attention on the front lights, which is normally the most attention-drawing part of the vehicle, and all the information would be communicated through there"*. On the other hand, another person mentioned *"I think maybe looking directly into the front lights of a car at night might be annoying since they are so bright. Also, the dimming of the front light when being white is very hard to see, since the difference between the starting state and the final one is not that much."*

In general, this concept was less informative than the previous one, *"Not all the elements were clear or differentiable, missing some information"*. Nevertheless, the change of color of the lights is something people valued a lot as a sign of right of way, therefore it would be interesting how to integrate it in the final design.

Despite not communicating clearly the perception of the VRU, most particpants mentioned they would start crossing when the lights turned turquoise, this helps undersanding that this change of color has a lot of potential to indicate right of way.

The **Reverence** concept was mentioned to be the most confusing *"is the most confusing of all, mainly because of the sudden backward movement. I would most likely lose trust in the car if these were doing this all the time, it feels like a mistake."* Another concern about the car behavior was the lack of frontal communication present in the first two concepts, which was very well perceived *"After the other two concepts, I miss some frontal communication/*

	Abstract light	Eyes closing	Reverence
Interaction			
Easy	$3.1_{1.1}$	$4_{1.2}$	$2.8_{1.6}$
Pleasant	$4.4_{0.9}$	$3.9_{1.1}$	$3.3_{1.6}$
Safe	$4_{0.5}$	$3.4_{0.5}$	$3.1_{0.6}$
Intent			
Yield	5_{0}	$3.9_{1.4}$	$3.9_{1.4}$
Awareness	$4_{1.4}$	$2.8_{1.3}$	$2.9_{1.2}$
Take my time	3.9_{1}	$2.9_{1.4}$	$4_{0.8}$
will stop for me	$4.4_{0.5}$	$3.4_{1.3}$	3.9_{1}

Figure 19: Total scores from the Likert scales + standard deviation

interface. The side one does not feel like it is enough". Regarding the behavior of the sidebar, people mentioned that starting from behind might not be the best since this is opposite to the car movement, and should accompany it instead, but conveys the message better than the abstract lighting concept. Since its default state is off and only lights up when a message is communicated.

The backward movement was perceived as a very expressive element, one participant mentioned that *"It makes you feel like the car is alive since it's imitating how humans would act when giving way to someone else, when entering or exiting a room, for example"*. This perception of the vehicle intelligence, however, showed a **steeper learning curve** in comparison to the use of light, since people perceived it as a sign of error or confusion.

Overall all of the concepts were well received by the test participants, and everyone showed a positive attitude towards AVs being able to communicate with them in the future, one of them even mentioned *"Actually I would like this kind of system to be implemented now, even if you have the option to look at the driver, sometimes I would really like to know this information at a glance"*. Nevertheless, some elements of different concepts were preferred over others.

CONCLUSION & TAKEAWAYS

Elements of the three concepts showed great potential to be part of the final design for the vehicle's communication system. The sidebar of concepts abstract light and reverence showed to be a very good way to convey intent to stop. The front positioning of the eyes closing concept and the change of color showed good results for the visibility and the expressive element of dynamic lighting for indicating the right of way since most participants stated that they would decide to cross when the color changes from white to turquoise. Nevertheless, there should be front communication that accompanies the intent to stop, and the placement of the front eHMI should not be on the front lights due to the difficulty of looking at them at night.

Regarding the post-interaction elements of the eHMI, the breathing pattern of the lighting system followed by the blinking pattern showed to be desirable for easily identifying the state of the vehicle at a glance. Nevertheless, it is important to look into how the actions follow the communication and how fast this happens to make sure the communication is not a cause for stress, even when the intention while prototyping was to have the same pattern, participants noticed differences between the different concepts. Therefore, the final design should aim to have a very slow breathing pattern, which was qualified as "inviting" by participants.

The reverence, even when not prototyped correctly, showed good potential to be a more explicit sign of clarification when no reaction to other signs is seen in VRUs, still, it also showed a steeper learning curve which is one of the main goals of this project to reduce.

After this first iteration phase, the communication layer tackled by the different prototypes was also revisited (see figure 20). While the perception of a specific VRU was found to not be necessary, the perception of VRUs around was desirable according to participants. Moreover, at the moment when the car is standing, people identified the breathing pattern as an "invitation" to safely cross the street. The fact that the car will wait as long as the VRU takes to cross needs, therefore, to be perceived by VRUs.

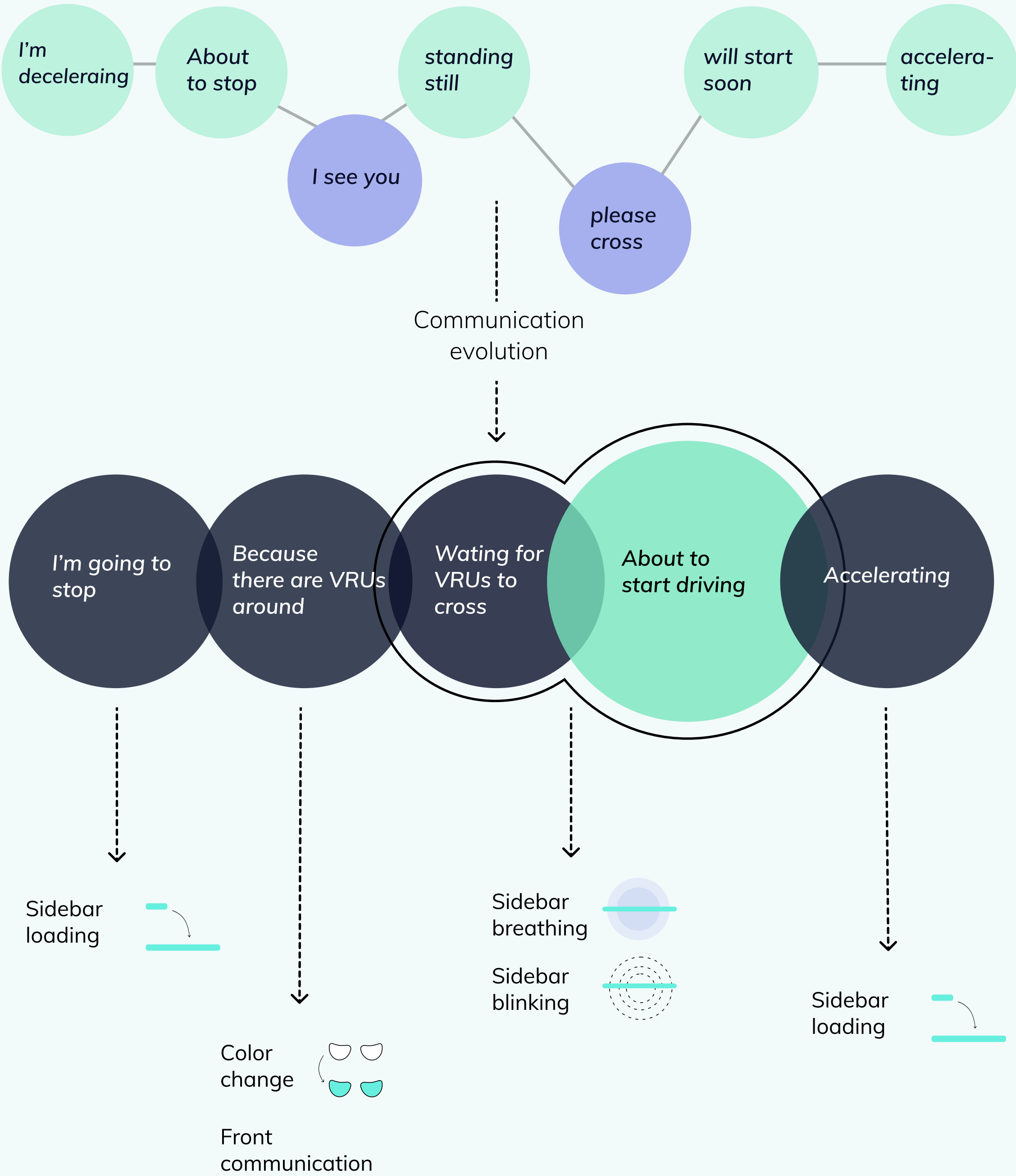


Figure 20: Iteration phase 1 outcomes.

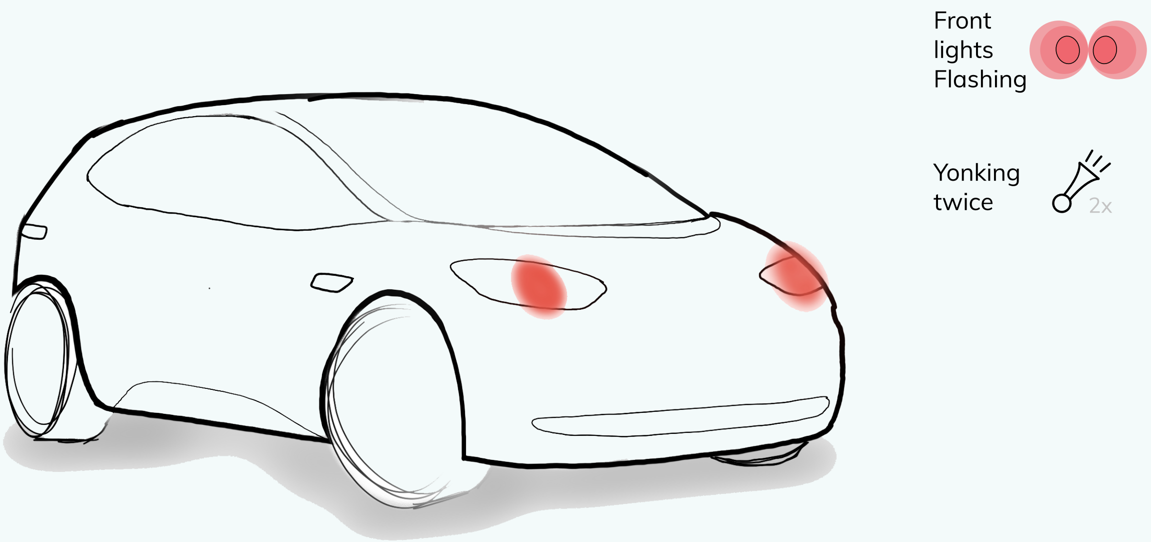


Figure 21: Illustration and communication storyboard concept "Abstract lighting"

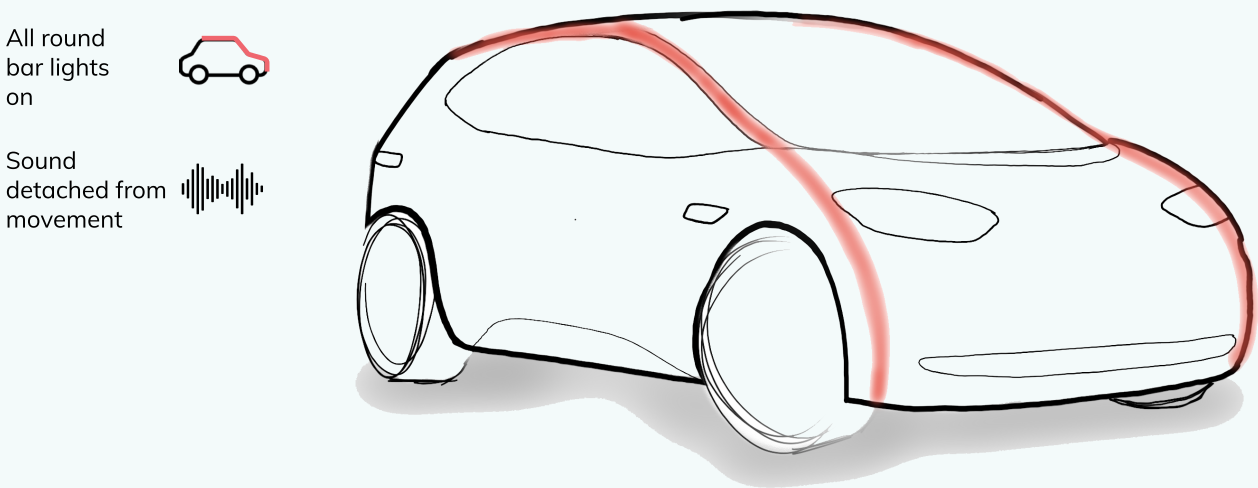


Figure 22: Illustration and communication storyboard concept "Closing eyes"

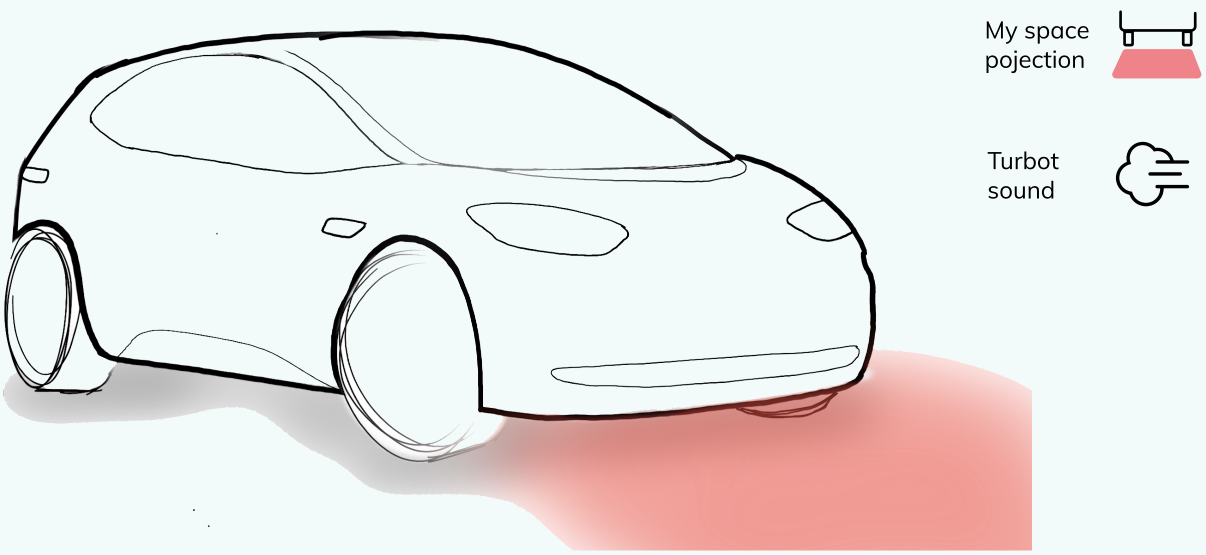


Figure 23: Illustration and communication storyboard concept "Reverence"

PHASE 2: EXPLORING THE CHANGE OF ATTITUDE.

The second concept creation and evaluation phase attempted to create a change in the perception of the vehicle's attitude, this corresponds to the third layer of communication presented in page 50. This communication layer becomes relevant when the vehicle needs to claim its own right of way and be persuasive to prevent VRUs from taking risky actions.

Due to this communication layer being (somewhat) dependent on the first exploration, a sketchy prototype of this was created to show previous to the new concepts during testing. For this exploration, three concepts were prototyped based on the ideas from the creative session and taking learnings from the previous phase into account.

On top of the visual communication, a number of sounds were also added to accompany the different designs, in this way, not only the visual communication would be assessed, but also the auditory signals, which will also help in defining the sound communication of the eHMI in the final design proposed. Özcan et al (2005) created a framework to associate product sounds with semantic categories. Their descriptions are used here to describe what kinds of sounds were proposed as solutions in the ideation session (see appendix I). The two main sound categories that were proposed were Air sounds and Alarm sounds. According to the framework, the Air sounds, relate to motor sounds as well as the aero dynamism of the product which emits them. Likewise, Alarm sounds are generally linked to beeping sounds, warnings, and the need for attention from the emitting product.

Three main sound interventions were included in the concepts, starting on the base that engine sound is necessary to prevent VRUs from not detecting the presence of it close to them.

CONCEPT 1: (UN)KNOWN SIGNS

This concept uses familiar signs used nowadays by drivers. To indicate the right of way to pedestrians from a distance, this is a double flashing of the long-reaching front lights. In this concept, this intervention was used to determine whether a change of color of the light will give the opposite feeling. To this visual information, a gentle horn "pressed" twice was added to call the attention of the viewer. represented in figure 21.

CONCEPT 2: DOMINANCE THROUGH SIZE.

The second concept follows the principle that by making itself look bigger, the car will show dominance, two light strips following the shape of the car on both sides form this design. The sound behavior supports the intention to not yield by not reducing with the deceleration. Represented in figure 22.

CONCEPT 3: PROJECTING MY ROUTE

The second concept uses projections to show the intended route of the car, in a red-ish color to indicate that that's its own space and the interacting VRU should not invade that space in order to be safe. The sound chosen to accompany the visual information was a turbot sound imitating conventional gas cars. Represented in figure 23.

Prototypes used can be found in **this link**

EVALUATION METHOD

The goal of this evaluation is to test the different concepts on an experience level. We want to understand what elements work in portraying the dominant attitude of the vehicle in situations where it claims its right of way.

The research questions are:

- Which communication modality works better to understand the vehicle's actions and intentions?
- What elements of the designs would help VRUs to understand the automation message?
- What elements of the design evoke a dominant attitude?
- What are the important aspects of these interactions to be taken into account in the final design?

6 participants took part in this concept evaluation test (Average age 24.5, std deviation 0.8. 50% Male, 50% Female) . Previous to showing the videos, participants were explained the situation to create a more realistic ambiance, in this case, participants were also told a bit of background information about the specific communication layer these concepts target to encourage a more fluid conversation.

The three video prototypes were played to the participants, after each video, participants were asked to fill in a questionnaire consisting of some open questions about the visual and auditory information individually, from which the answers were also audio-recorded, and Likert scales. In this case, the Likert scales were based on the requirements that specifically apply to this communication layer. The complete questionnaire can be found in appendix L. The spatial presence questionnaire present in the first conceptualization phase was also included in this test.

The results from the Likert scales were then visualized in the form of a Harris Profile (Harris, 1961), this is a technique used to visually compare different concepts according to the design requirements. This visual technique, together with the qualitative information gained from testing helped in drawing conclusions.

As done in the previous phase, a Spatial presence questionnaire was asked to be filled after all videos were shown and evaluated.

RESULTS & DISCUSSION

Concepts 1 & 3 were successful in communicating the intention of not stopping the car. The systems' characteristic that helped in this was mainly the red-ish color used in the visual communication present in all concepts. While concept 2 also attempted to use the red color, the materialization of the prototypes was not successful in showing this properly.

The concept **(un)known signs** was overall the best rated for all the design requirements. The combination of lighting and sound stimuli helped in conveying the message and calling attention on the possibly endangered VRU *"I think the signs complement quite well in sending the same message. The noise is a bit aggressive, meaning that it alarms you a bit. But I wouldn't leave it out because the lights by themselves might not be enough, since you can miss them when not paying attention."* Nevertheless, it was also pointed out that the horn sound might not always be needed, one participant mentioned *"while the horn sound calls a lot of attention, it is a very intrusive sign. I am used to looking to both sides of the road when I'm going to cross, the lights would be enough most of the time since the color indicates to me that I should not cross, the sound should only be used if I am in real danger."* And another one stated,

Prevents VRU from taking a risky action

The design helps VRU understand that they should not continue walking/cycling

Visible from different perspectives

Communication system makes the vehicle stand out

Design helps vehicle in conveying a dominant attitude

Easy to integrate with the design of the gentle communication

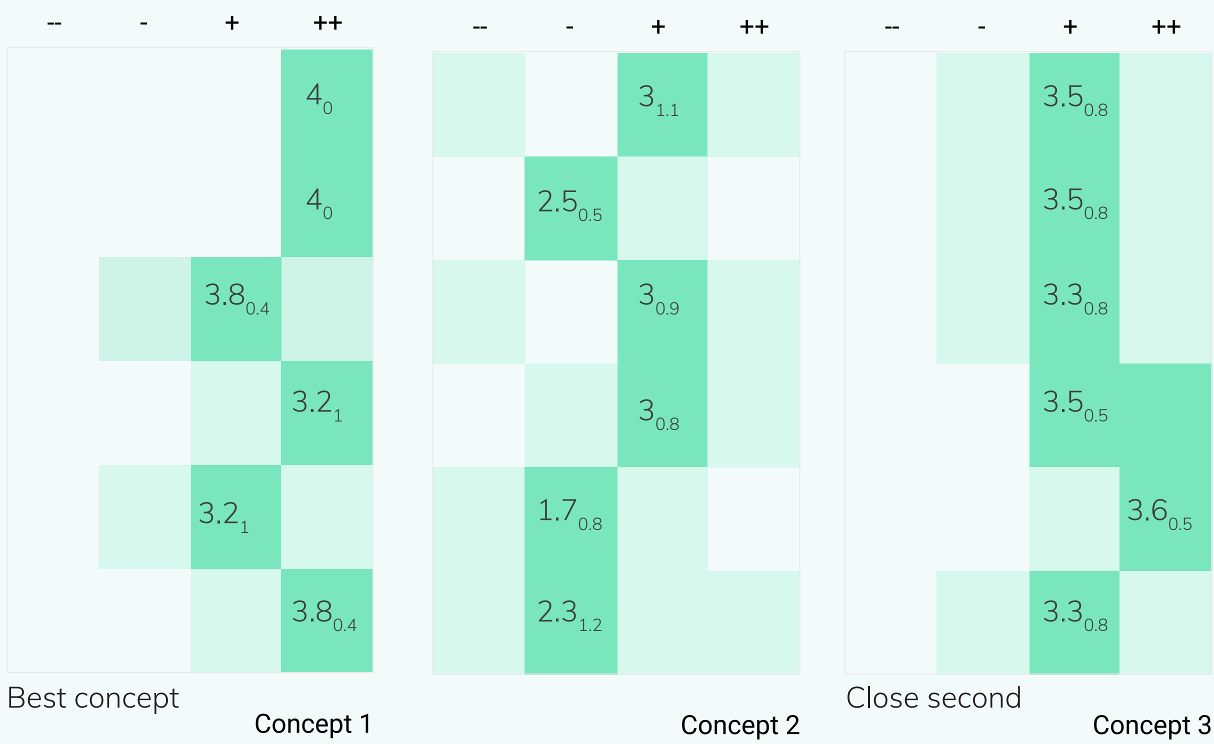
Figure 24: Harris profile visualization.
Likert scales questionnaire results.

"It is a bit redundant in regards of the message urgency, I would only use the horn if I have previously neglected the light". Regarding the dominant attitude, this concept got the lowest ratings for conveying it. Which was considered as a good thing by participants. *"I wouldn't like to be afraid of cars, is good that they want to warn me to keep me safe, but they can still do it being gentle and non-disturbing".*

The concept of dominance through light got the lowest ratings for the most qualities assessed in the user test, most participants stated that the way it communicates would not make them decide to stop walking or cycling. Moreover, most of them did not understand what the car wanted to communicate *"It is very confusing, the light bars turned on don't really tell me anything other than the car is driving".* Only one participant mentioned *"I understand from the lights being red that I cannot interact freely around the car. It reminds me to be blocked or inaccessible, so I wouldn't cross or pass in front. But from the shape of the car, I do not really understand the message."* Nevertheless, this concept was generally not well received.

Regarding the sound intervention, most participants did not notice at first, and when explained, they expressed concern about losing trust in the car *"The sound intervention is very imperceptible, and I think I would lose a bit of trust in the car if the "engine" sound does not work according to the movement of the car, that is its purpose."*

The concept of projecting my route got good ratings in the message effectiveness and preventing risky actions from VRUs, regarding the dominance aspect of the interaction one participant mentioned *"Without being the most invasive, I think is the most dominant from the three videos. I feel the car is in a dominant status, meaning that it has control or ownership of the situation."* The light projection was well-received, nevertheless, a concern was raised regarding it visibility in bright days, *"The projection itself helps me understand the intention of the vehicle, but I don't know whether I would see it when there's a lot of light."* The sound intervention used in this prototype, on the other hand, was not well received by participants *"It feels like the car is kind of angry (because of the sound). It seems like I did something really wrong and that it wants revenge".* Another mentioned, *"I really hate when drivers do that kind of sound with the cars, it is just annoying and useless."* Therefore it proved not to be a good addition to the communication system of AVs in the future.



CONCLUSION & TAKEAWAYS

Regarding the visual stimuli studied in the three concepts, the redish color used in all of them showed the intent of not stopping from the car, it was also successful in conveying the dominant expression, showing that color-coding of the visual elements of the eHMI could be used when addressing different scenarios. The light displayed from the front helped in gently communicating the intention of the vehicle, but since its visibility was limited, another way of adding this light should be sought. The dominance aspect of the interaction was especially seen in the “my route” concept, where the car claims for its own space and rights on the road. The combination of the two would have the potential to solve most situations that need to address this kind of communication, but probably not all the time.

The sound level of the designs showed that engine sound should always accompany the movement, alterations regarding volume could be done, but it should never mismatch its intrinsic purpose, which is accompanying the movement of the vehicle. Moreover, extra signs of attention like the one used in the concept (un)known signs should be used in cases where it could help prevent a dangerous action from VRUs.

Regarding the communication line addressed in this iteration round, it didn’t suffer a lot of changes. The main thing would be to have different levels of intrusiveness within the same message to be able to adapt better to the specific situations encountered by the vehicle.

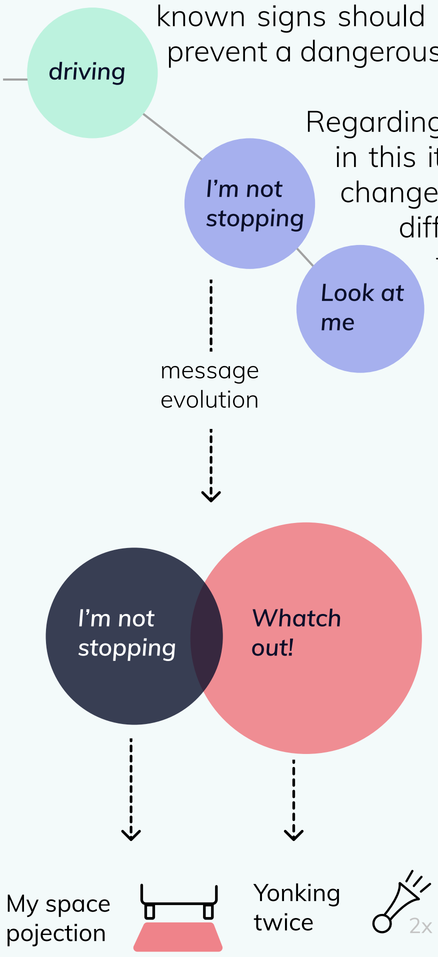


Figure 25: Iteration phase 2 outcomes.

EFFECT ON OVERTAKING SCENARIO.

As mentioned at the beginning of the chapter, the overtaking scenario triggered fewer ideas than the other two, and due to time limitations, a full exploration phase was not conducted. Instead, learnings and potential elements of the eHMI studied in the first two iteration phases, together with the ideas shared in the ideation session were analyzed and transported to this scenario. Thus, this final iteration phase focuses on defining the elements that will potentially be used in the final concept design for this scenario.

Looking at the communication needs associated with this scenario, we can see that the messages from the vehicle focus on making the vehicle more noticeable for the cyclist, in order to avoid unexpected cyclist reactions that could cause an accident. In the second iteration phase, different sound interventions were used as interventions to convey dominance and claim attention on the vehicle. nevertheless, all of these were considered too intrusive and even "scary" to participants. Contrary to that, an idea that appeared in the ideation phase, focused on using context-aware engine sound to increase noticeability without visual contact. This gives the opportunity of making the cyclist aware of the presence of the vehicle sometime before the car overtakes.

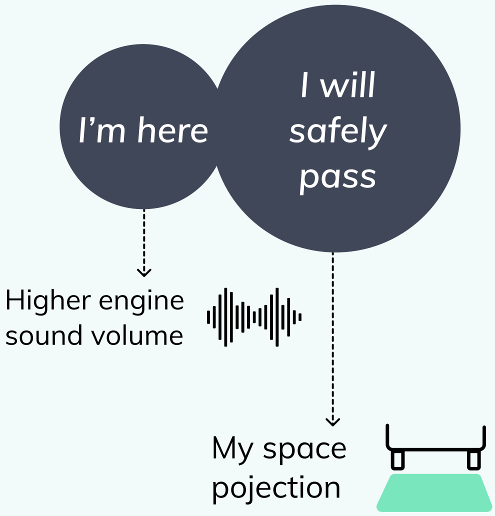


Figure 26: eHMI lements fitting for scenario.

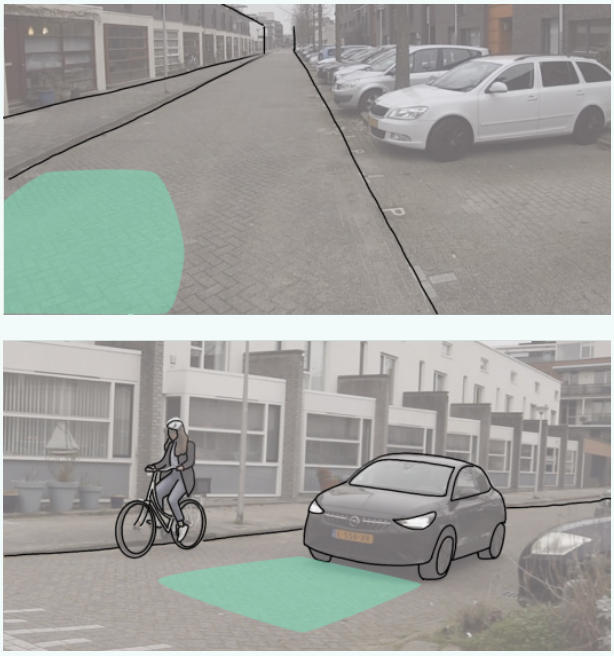


Figure 27: outcome visualization.

While an auditory intervention seems to be most fitting for the context and the point of contact between cyclist and vehicle, it would be possible that someone is cycling while listening to music or talking on the phone, which would make this intervention difficult to detect.

Iteration phase two (page 75) showed the potential of projected abstract light, which can be translated to this scenario. A "My space" projection coming from the car, could show the cyclist the space that the vehicle will make use of while passing by, easing the interaction. The color of this projection, though, should be altered from what was seen in iteration phase 2, since in this scenario the attitude from the vehicle should not be dominant but more neutral, or even accommodating.

Figure 27 shows the sketch of what the cyclist will see.

CONVERGING STRATEGY

All the qualitative information and data collected during the ideation session & discussion and the two conceptualization phases helped to define a direction for the final design. The best elements of the different concepts tested were the starting point to create the final eHMI.

During the conceptualization phase of the project, a lot has been learned about the interactions with vehicles in urban traffic and future desired interactions that add to the knowledge gained in the research phase. All of these learnings and tensions will also guide the final design and are here presented.

COMMUNICATION ADAPTABILITY

While information about the vehicle's actions and intentions needs to be visible and interpretable at a glance, the interference with people's calm should be minimized. Therefore, the communication should most often be un-intrusively informative. For this, abstract lighting showed really good results by being informative without claiming attention.

At the same time, autonomous vehicles should be able to assess whether the specific situations they're facing require a stronger sign or not in order to ensure safety. This could be done by having different levels of intrusiveness per the information shared with the interacting VRU, and adding other sensory inputs such as sounds to support the urgency of the communication.

· From literature we know that the system needs to be visible and easy to understand.

· From User research we found a preference from calmer environments.

· Iteration phase 1 showed the potetnial of abstract lighting, which agrees with the general trend in eHMI research.

· Looking into the situations to be addressed, we saw that vehicles might need to impose themselves sometimes, by calling attention from VRUs involved in unsafe actions, for instance.

MINIMAL ELEMENTS = GREATEST IMPACT

The success of the eHMI design lies in being able to communicate effectively with the minimal additions being made to vehicles' current external communication system. A balance must be achieved between clearly conveying messages through a number of sensorial stimuli and not overcrowding the vehicle with extras. In the other hand, manipulating the current eHMI could cause confusion and is therefore not a suitable solution.

· From literature we know that multimodal communication will perform best, however, we need to balance enough information with information overload.

· As we saw in iteration phase 1, people get confused when having to look to many different places.

CREATING AN EQUAL RELATIONSHIP

Achieving a balance in who has the control over the situation without letting vehicles become a ruling agent has come up along the project. The designed communication system should support this by being always accommodating to VRUs actions, unless it is crucial to take control in order to ensure the safety of all traffic participants. Color change from one with positive cognotations (green) to more negative ones (red) showed to help in making VRUs understand this.

· As seen in literature about human-robot interaction, the intentions of the differnt agents might clash.

· Iteration phase 2 showed that vehicles can impose their will when needed by portraying dominance.

CONTENTS

Final concept & evaluation

07

This chapter contains the explanation of the final design proposal, its features and functioning. It starts with an overview of the messages that are communicated through the eHMI, and how this materialize. After, a longer explanation in the form of a storyboard is presented to show de details of the design.

DESIGN ELEMENTS OVERVIEW

In this section, we focus on explaining the elements of the eHMI that form the final design. After an overall introduction to the design elements and behaviors, we will look closely at the different scenarios in which this design is based. Looking into specific behaviors and orchestration of the different eHMI elements.

The final eHMI design is formed by two main auditory elements and two visual elements. The auditory features are a **context-aware synthetic engine sound**, and an **artificial horn**. The engine sound allows the car to raise or lower its volume depending on the level of attention needed by the car in specific situations, for instance, the car could raise the volume of its engine sound when approaching a cyclist riding along the same road, maximizing its noticeability. The horn, on the other hand, will act only in high urgency situations, where a dangerous action from another traffic participant should be prevented.

The visual elements of the resulted eHMI are an **all-around light system** that is visible from all sides of the car and a **projection system** that enables what we name the **"my space"** effect. These two elements express a number of messages through their **color coding** and the **dynamic patterns** associated with different messages. The color coding choice was made to maximize intuitiveness of the design, since mind-modele colors will helpin clearly conveying the behavioral hints intended in the differnt scenarios. The colors used are green, red, and white. While green is usually associated with positive attitudes, feelings, and ideas in general, in the case of the eHMI it reflects on an *accommodating attitude* of the vehicle towards VRUs actions and intentions. Likewise, the red represents a *dominant attitude* from the car and is used in situations where it needs to take control over the situation. The white color appears when the car behavior is not dependent on any other road participant, but on its own intentions, this payes a crucial role from the perspective of the VRU, who can then detect that he or she is not the cause of the action of the vehicle. The projection system presents a "my space" effect in the cases when any communication is needed. It anticipates vehicle intentions regarding its movements signalizing the space the car is occupying or will soon occupy, it follows the same color coding as the lighting system.

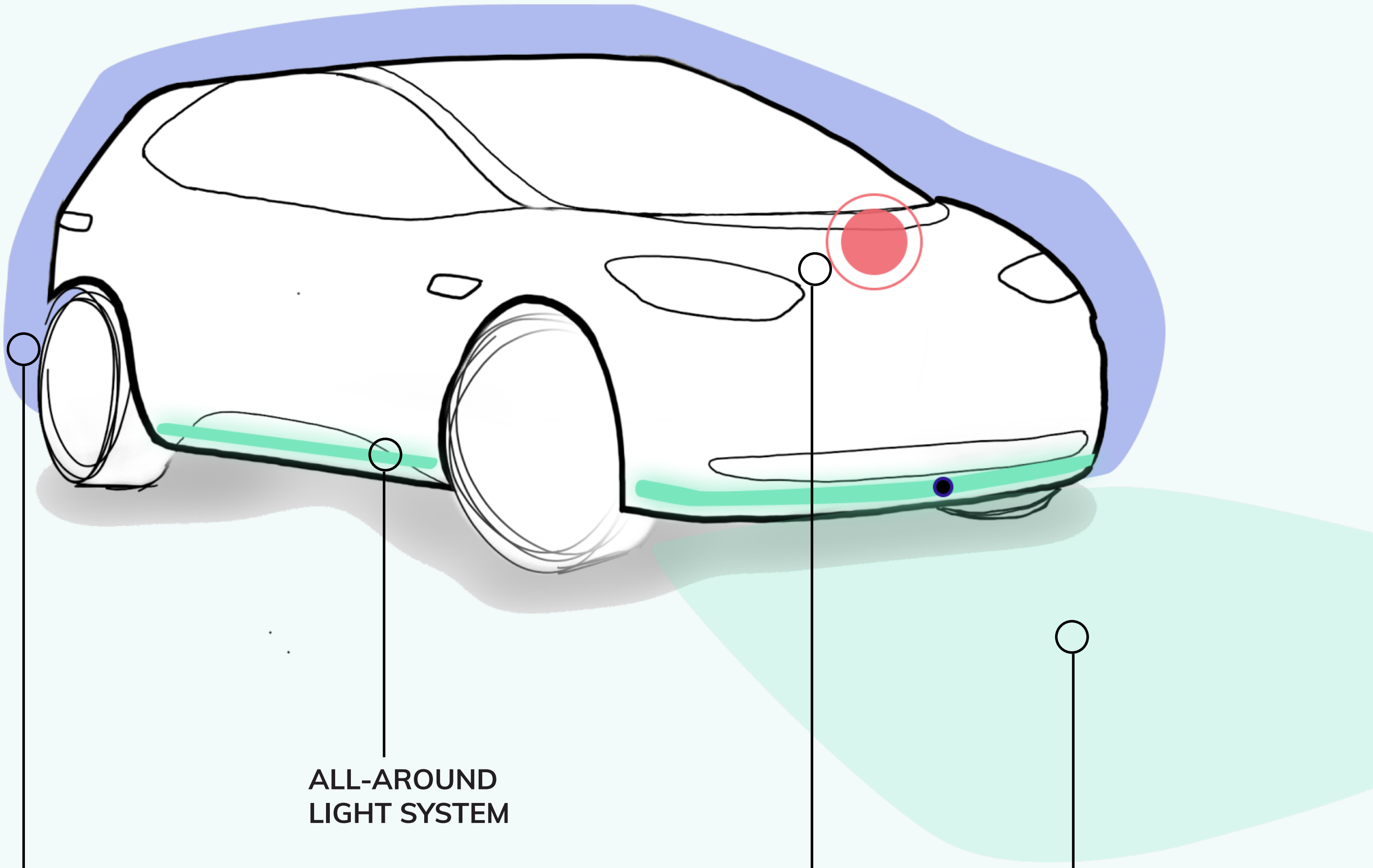
CHOICE OF COLORS

As mentioned in chapter 2, there is no agreement on what colors should be used since, on the one hand, current regulation does not allow for the use of green and red used in traffic lights. On the other hand, mind-modeled colors can help design a more intuitive system.

A choice was made to prioritize intuitiveness in the design since ease of learning is one of the main goals we want to achieve. However, the colors green and red used in the design are different shades than the ones present in today's infrastructure.

DESIGN ELEMENTS

This page contains an overview of the elements that form the designed eHMI.



SMART ENGINE SOUND

The car can choose to higher or lower the volume depending of attention needs.

ALL-AROUND LIGHT SYSTEM

Visible from all sides of the vehicle, communicates main actions and intentions through dynamic patterns.

Communicates vehicle attitude and percetion through color coding.

ARTIFICIAL HORN

Only used in hight urgency situations, it intrussively warns VRUs to prevent risky actions.

"MY SPACE" DYNAMIC GROUND PROJECTION

Supporting visual cue that anticipates vehicle movement. Uses the same color coding as the all-round light system.

CAR DECISION MAKING

This first visualization attempts to illustrate the decision making process of the the AV in the situations studied, this map helps in understanding, not only the decisions of the vehicle, but also the messages that it needs to communicate to VRUs in the given scenarios.

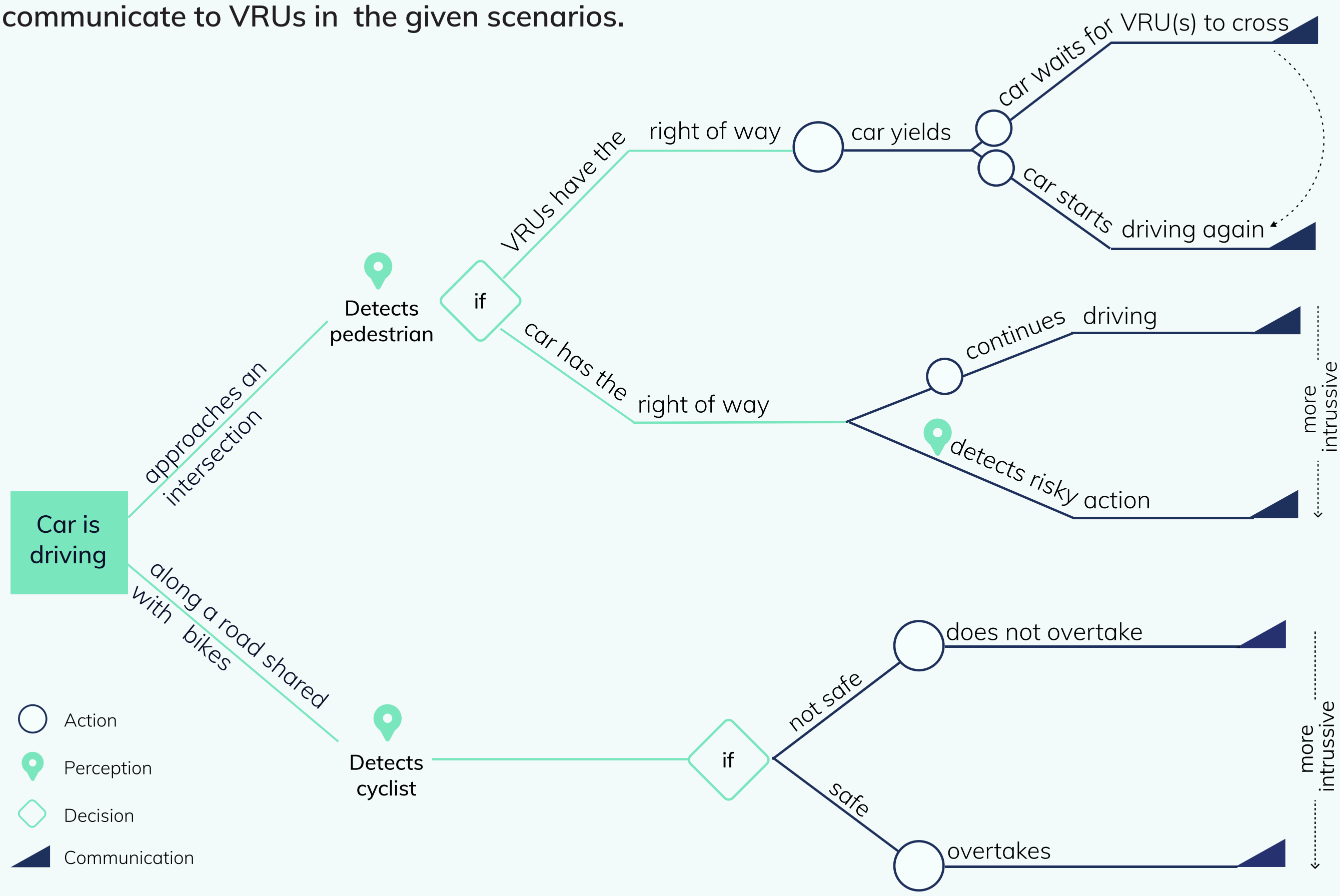


Figure 28: Car decision making process, actions resulting in communication to VRUs.

What the car communicates and how it does it highly depends on the reasoning behind the decision it makes on how to act. In figure 28, the blue lines represent the moments of the decision-making in which the vehicle needs to communicate to the VRU through the eHMI.

This figure portrays the central AV-VRU interactions that this project revolves around, where the main situations portray intersections and interactions where vehicles and VRUs share the road.

It can also be seen that not all actions have the same need for intrusiveness in communication. While in the scenario where the car gives the right of way to the VRU, all communication is discreet, in the other two, the car needs to communicate in more obvious ways at times, to ensure safety and prevent unexpected actions from VRUs.

Following the order in which the car decisions are communicated in this figure, the table on the roght shows the vehicle messages associated with them. In this table, the attitude of the vehicle when communicating the specific messages can be seen, along with the level of intrusiveness required and the materialization of the design, using the eHMI elements presented before. It gives an overview of the functioning of the whole concept.

While this table presents a functioning overview, a more detailed explanation of how the different elements work together in different situations is presented in the coming pages.

eHMI BEHAVIOR OVERVIEW

Intersection situations

VRU has the roght of way

Message	Reasoning	Attitude	Level of intrussiveness	Design guidelines
"I'm going to yield"	Car detects VRUs about to cross the intersection	Accomodating	●○○	· Lighting system turns on in turquoise.
"I'm waiting for (all of) you to cross"	VRU(s) are crossing in front of the car	Accomodating	●○○	· Lighting system displays breathing pattern. · My space projection fixed undernieth the car.
"I'm going to stard driving"	All VRU(s) finished crossing	Accomodating	●○○	· Breathing turns to blinking & turquoise turns white. · My space projection moves forward anticipating car movement.

Car has the right of way

Message	Reasoning	Attitude	Level of intrussiveness	Design guidelines
"I'm not stopping"	Car is aware of its right of way in the intersection	Dominant	●●○	· Lighting system increases brightness in red color. · Supporting My space projection in red.
"Watch out"	Car detects a possible risky action from VRU and warns them	Dominant	●●●	· Car honks twice to call attention of VRU.

Overtaking situations

Message	Reasoning	Attitude	Level of intrussiveness	Design guidelines
"I'm behind you"	Car has detected a cyclist in front.	Neutral	●●○	· Synthetic engine sound increases volume to maximize noticeability.
"I'm going to safely overtake"	Since is a safe action and will not affect traffic flow	Neutral	●●○	· "My space" projection.

DESIGN DETAILS

This section goes through the different scenarios designed for, explaining in more detail how the eHMI works in each one of them. The scenarios portrayed explain the "happy flow" associated with the communication line linked to them, in some cases, suggestions are made regarding the possible differences in the scenario that would therefore affect the functioning of the eHMI elements.

SCENARIO 1: INTERSECTIONS WHERE VRU HAS THE RIGHT OF WAY.

This first scenario shows how the eHMI would behave in an intersection scenario where the VRU, in this case, a pedestrian, has the right of way. The images shown illustrate the "happy flow" of the dialogue that takes place in this scenario. Later on, other possibilities will be further explained.

The first image shows a VRU approaching a cross at the same time a car does. When the car detects the presence of mentioned VRU, the light system turns on in green. This means that the car has detected the presence of the pedestrian and will therefore yield to let her pass. As mentioned before, the green color represents an accommodating attitude of the car towards the VRUs.

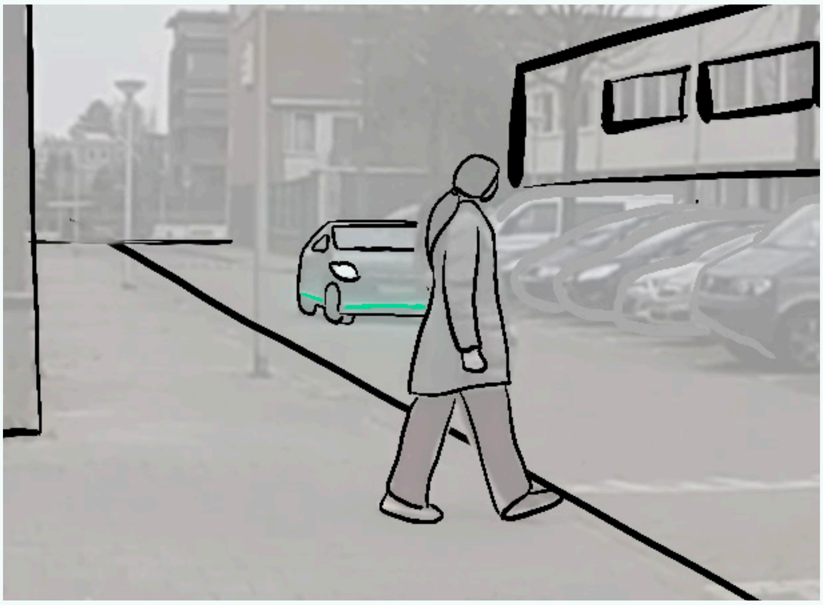
When the car has come to a full stop, the light system starts displaying a "breathing" pattern, which indicates that the car is waiting for all VRUs to cross the street. At the same time, my space projection activates underneath the car.

When no other VRU(s) are detected around, the car anticipates its moving forward by the lighting system turning white, and displaying a faster blinking pattern. At the same time, the My space projection starts moving forward, supporting the anticipation of the car's movement.

Once the car has started moving, all communication turns off beside the engine sound, which will work by default any time the car is moving.

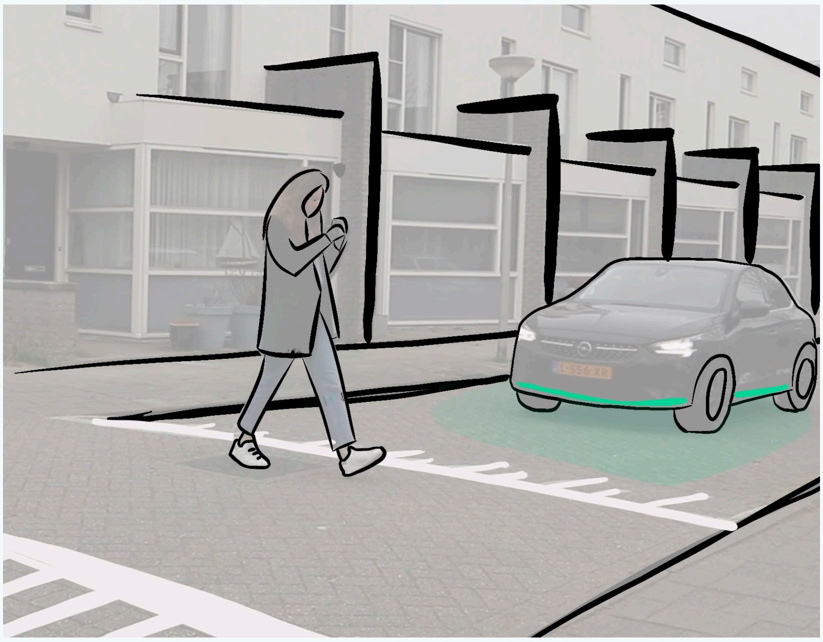
After showing what is the "happy flow" of this communication line, it is possible to think of alternative flows in case of different details of the scenario. For instance, in a situation where there would be a lot of pedestrians crossing from one side to the other and the car might be in a rush, it would be possible for the car to signalize its "I will start driving soon" message with a more dominant attitude, just by displaying the same information in red, and maybe anticipating its moving by turning on the synthetic engine sound before it starts moving. This way, the car could negotiate its way in that specific moment, using the elements of the designed eHMI.

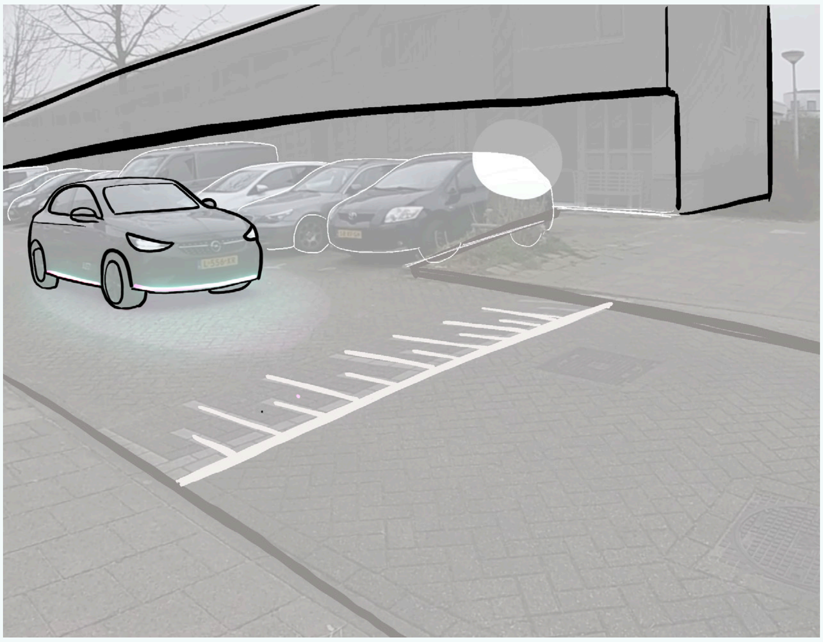
Likewise, in a situation where the car intends to stop for other reason, such a stop or yield sign, but no crossing VRU has been detected, the same light intervention could be displayed in white, thus indicating that lack of perception.



Message sent: "I'm going to stop because there are VRUs about to cross the street"
Vehicle attitude: Accommodating to VRUs actions
Expression: Acknowledging VRUs and supporting her right of way.
Level of intrusiveness: low

Message sent: "I'm waiting for (all of) you to cross"
Vehicle attitude: Accommodating to VRUs actions
Expression: Calm, the car will wait until no other VRU is detected around.
Level of intrusiveness: low





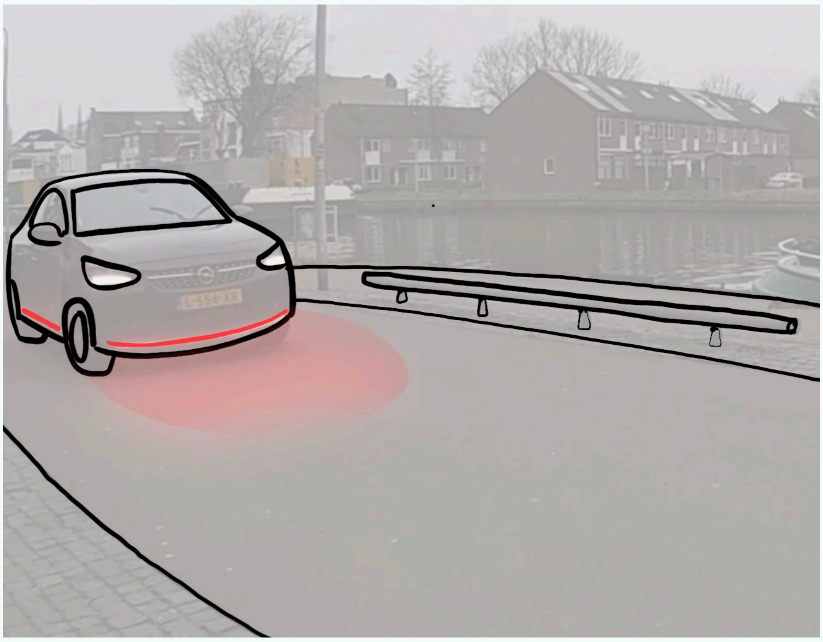
Message sent: "I will start driving soon"
Vehicle attitude: Independent, no more VRUs are detected.
Expression: Changing state, informative about its future actions, transmits a feeling of urgency.
Level of intrusiveness: low

SCENARIO 2: INTERSECTION WHERE CAR HAS THE RIGHT OF WAY.

This scenario portrays how the vehicle and its eHMI would behave in an intersection situation where the car has the right of way. In this scenario, the vehicle adopts a dominant attitude and communicates its intention of not stopping.

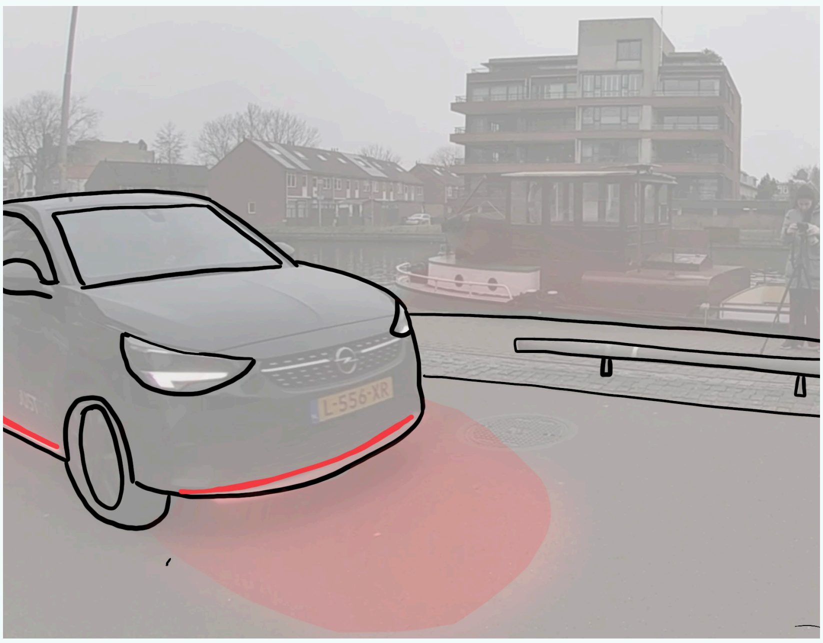
When the car detects a VRU approaching and possibly intending to cross, the engine sound volume becomes louder, moreover, the All-round lighting system turns on in red, at the same time, the My space projection in the same color projects in front of the car.

After all the previous interventions, it could happen that the detected VRU(s) has already stopped their route. In this case, the intervention from the eHMI would stop there. In the case of the car not detecting a change in the behavior of the VRU, the artificial horn would honk twice to clearly call for VRUs attention.



It is expected that in most scenarios, the first intervention from the eHMI would already affect the behavior of the interacting VRU. The horn is, therefore, an extra tool brought in from the current vehicles' communication equipment. Currently used for driver-to-driver communication in cases where it is needed to avoid collisions or accidents.

Message sent: "I will not stop driving"
Vehicle attitude: Dominant, in control of the situation.
Expression: Urgent, warning.
Level of intrusiveness: Medium.

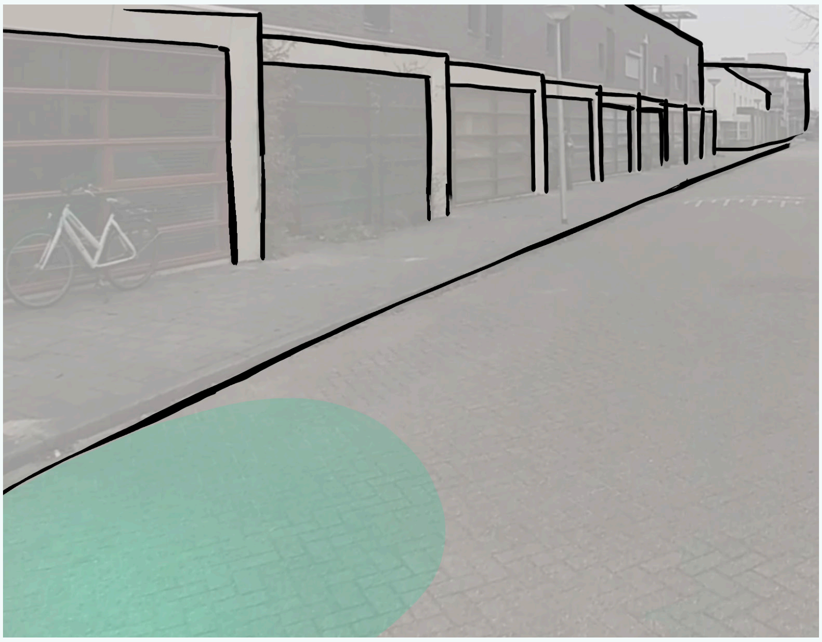


Message sent: "Watch out!"
Vehicle attitude: Dominant.
Expression: Warning.
Level of intrusiveness: High.

SCENARIO 3: CAR PASSING A CYCLIST WHEN SHARING THE ROAD.

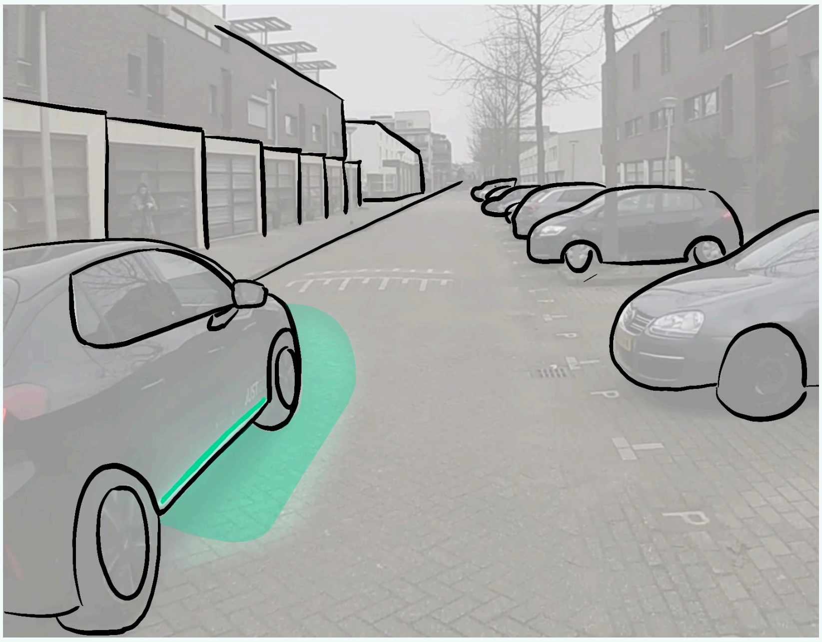
When motorized vehicles and cyclists share the road, they move along the same route. This limits direct visual contact between the cyclist and the car.

When a car approaches a cyclist from behind, its programmed behavior is to slow down and stay behind until it is sure that the overtaking action is safe. When this happens, the synthetic engine sound will rise its volume to allow the car to be noticed by the cyclist.



When the car decides that the overtaking is safe, the projection system will display the My space effect in the color green, letting the cyclist see the relative positioning of the car behind her. In this way, unexpected actions from the cyclist can be prevented.

Message sent: “I’m here behind you”
Vehicle attitude: Accommodating.
Expression: Informative.
Level of intrusiveness: Medium.



Message sent: “I will safely overtake”
Vehicle attitude: Accommodating, informative.
Expression: Calm, acknowledging.
Level of intrusiveness: Medium.

As an alternative possibility, if a cyclist were to be riding outside the cycling path, or taking up space from the road, the car could project the light in red, showing the need for a change in the behavior of the VRU.

EVALUATION PLAN

The aim of this user test is to evaluate the effect of the designed eHMI on the interactions between AVs and Vulnerable road users, to define the strengths and weaknesses of the communicated messages and the way these are displayed. There are two main hypotheses that this test wants to demonstrate, the first one, is that with the introduction of the complete eHMI, the interaction will improve significantly (increase in the feeling of safety, predictability and perception of vehicle awareness) in the three scenarios for which the interface was designed for. The second hypothesis is that the increase in the predictability of the vehicle and the perception of the vehicle awareness will affect the feeling of safety.

Since the design of the eHMI guidelines was envisioned to cover communication needs derived from specific situations found during user research, these were also used to test the eHMI goal and qualities, by comparing the interaction between a baseline situation (car without eHMI) and the presence of the eHMI in the scenarios addressed in this project.
The research questions addressed in this user test are:

RQ1: Does the eHMI affect the feeling of safety of VRUs when interacting with vehicles in urban traffic?

RQ2: Does the eHMI help VRUs in understanding how to behave around the AV?

RQ3: Does the eHMI help in the understanding of the intentions, actions, and perception of the vehicle?

RQ4: What are the strengths and weaknesses of the designed eHMI when VRUs interact with vehicles in traffic?

Figure 29 shows an overview of the data collection methods used for the test. The full questionnaire can be found in appendix M.

There was two main hypotheses linked to this experiment:

H1: All aspects of the experience (FoS: Feeling of Safety, VP: Vehicle predictability, VA: Perception of vehicle's awareness, and AA: Appropriate Action tendency) will significantly improve with the introduction of the eHMI.

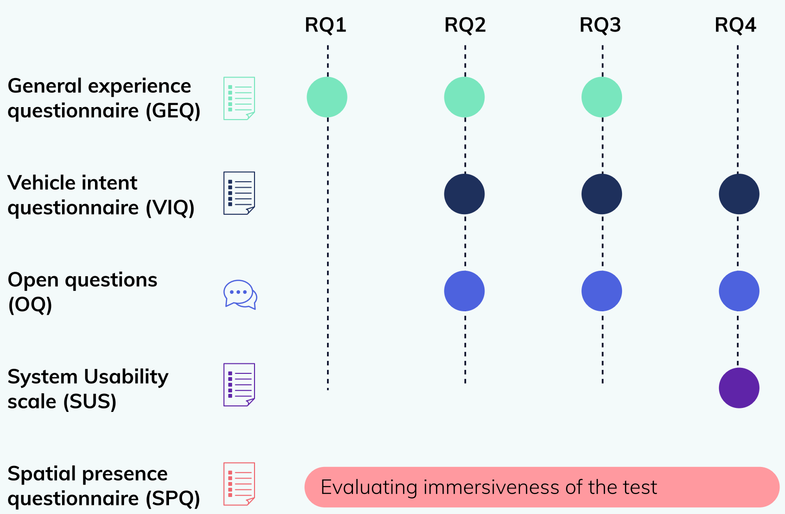


Figure 29: Research questions and data collection methods..

H2: The improvement in vehicle's predictability (VP) and appropriate action tendency (AA) scores, will affect the improvement in the scores given to the feeling of safety (FoS).

TEST SET-UP & PROCEDURE

The user test sessions took place in a room in the faculty of Industrial Design Engineering at TU Delft equipped with a table and a screen. In order to create an immersive experience for the participants of the test, a TV screen placed at the sight height of participants was used to create a more immersive experience. The sound was reproduced from a speaker strategically placed in the room of the test. See figure 32 for a visual representation.

Before the start of the test, participants were asked to return the signed consent form they were sent previously and were informed of the privacy policy and the data collection methods that would be used during the test. After that, participants were told that the vehicle they would interact with was driverless. This was done through storytelling to set the right mindset for the test.

The test procedure consisted of participants watching six videos, two for every one of the three traffic situations addressed in this project:

Scenario A: Vehicle gives right of way to pedestrian in a crossing.
Scenario B: Vehicle prevents risky action from pedestrian in an intersection.
Scenario C: Vehicle passes a cyclist in a residential area.

Three portrayed the situations with cars with no eHMI, the other three portrayed the eHMI interventions in the different situations. After each one of the videos, a number of Likert scales questions were asked (see full questionnaire in appendix M). Some regarding the general experience, and some others specific to the portrayed scenario and communication line addressed by the eHMI. The order in which the videos were shown to participants was randomized to prevent them from getting used to the scenarios and the communication of the car.

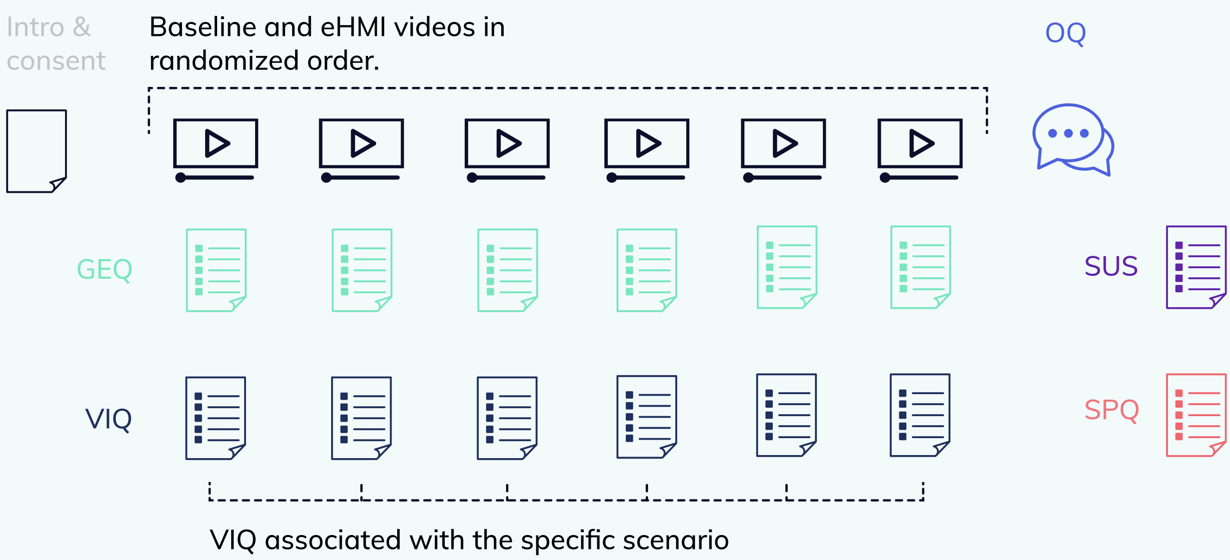


Figure 30: User test procedure.

Figure 31: Baseline and eHMI video screenshots

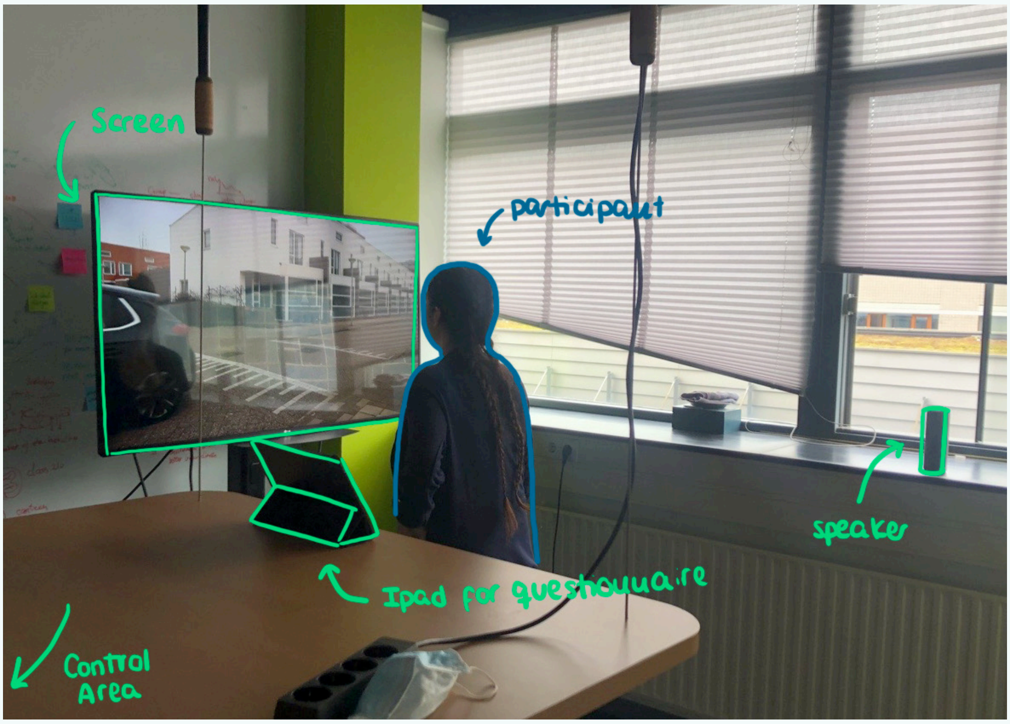


Figure 32: User test set-up

PROTOTYPING

Following the same techniques used for the previous user tests conducted in this project, video was used as the main apparatus for the participants, nevertheless, a number of interventions were made to attempt to create the most realistic experience possible. Firstly, the videos were recorded with a real human-driven car in real traffic scenarios, taking the perspective of the Vulnerable Road User. These videos were filmed with a wide-angle camera (GoPro hero 7) to better resemble the peripheral sight of humans. The eHMI was carefully added in post-production using After Effects as the main editing tool, sound effects were added in Premiere Pro.

In total there were 6 videos, two for each testing scenario, the first one of these 2, presented an unedited video, therefore, no light or sound effects were added. The second showed the eHMI design intervention envisioned for each scenario. Figure 31 presents the different apparatus used for the experiment.

PARTICIPANTS

16 participants took part in this concept evaluation. The recruitment was done through word of mouth and some recruiting posters were hung around the faculty of Industrial Design Engineering at the TU Delft. Participants' age ranged from 20 to 28 y/o with the average age being 24.4 and the std. Deviation 1.8. A good balance between female and male participants was achieved (F=56.2%, M= 43.8%). Due to convenience sampling (participants being recruited in a single context), the set of participants might not be representative of the whole population.

EVALUATION

DATA ANALYSIS METHOD(S)

In order to respond to the first hypothesis presented in the study (H1), an average score for each experience item (FoS, VP, VA, AC) across the three scenarios presented were calculated. A paired-samples T-test was then conducted to compare each item of the experience for the baseline condition and the eHMI condition. In order to examin the possible reasons, the results from the specific scenarios were also studied through the same statistical test. Since the three comparisons per experience item were done simultaneously, a Bonferroni correction (Weisstein. 2014) was applied to the alpha value for significance, resulting in $P\alpha=0.017$.

In order to respond to the second hypothesis (H2), the difference between experimental condition (eHMI) and baseline (no eHMI) , and the average of improvement per participant for each item across the different scenarios were calculated. With these data, a linear regression test was conducted considering the improvement in VP (iVP) and improvement in AA (iAA) as the independent variables. And the improvement of FoS (iFos) as the dependent variable.

The qualitative data retrieved from the "thinking aloud" exercise and the semi-structured interview questions were analyzed using thematic analysis (Braun et al. 2006). This was followed by an inductive process to define the themes, which were concluded from the data itself, and not imposing preconceived ideas or expected themes by the researcher. The analysis was mainly semantic, meaning that the data was analyzed as originally expressed by the participants, without introducing personal opinions or interpretations. Once the themes were identified, the researcher interpreted to relate them with the design elements mentioned and categorized them in strengths and weaknesses.

The usability of the system was assessed by calculating the total SUS score and the immersiveness of the test by calculating the average spatial presence score given by participants.

RESULTS

EXPERIENCE QUESTIONNAIRE

Generally, the test showed good results in favor of the presence and design of the external interface. The experience questionnaire shed light on the different aspects of the experience that improve when the automated vehicle exhibits system transparency and the open questions further helped in analyzing possible elements of the design that need improvement or that are desired by participants.

Experience questionnaire, responding to H1:

The results of the paired samples t-tests show a positive and significant difference between the means of the baseline and experimental condition in all experience items evaluated. Figures 33 to 36 present the box plots showing the increase in the feeling of safety, predictability, perception of awareness, and knowing how to act (Appropriate action tendency) corresponding to all the scenarios tested. A significant improvement in the means of all the experience qualities evaluated was found within participants in all scenarios ($P_{FoS}<0.001$, $P_{VP}<0.001$, $P_{VA}<0.001$, $P_{AA}=0.0064$).

Comparison	Mean	Std. Dev	Std. Error	Confidence interval Lower	Confidence interval Upper	t(15)	Two-sided p
FoS(eHMI-B)	1.35	1.04	0.26	0.80	1.91	5.23	<0.001
VP(eHMI-B)	1.33	1.3	0.32	0.64	2.03	4.10	<0.001
VA(eHMI-B)	1.88	1.15	0.29	1.26	2.49	6.54	<0.001
AA(eHMI-B)	1.04	1.32	0.33	0.34	1.74	3.17	0.006

Table 3: Paired samples t-test results.

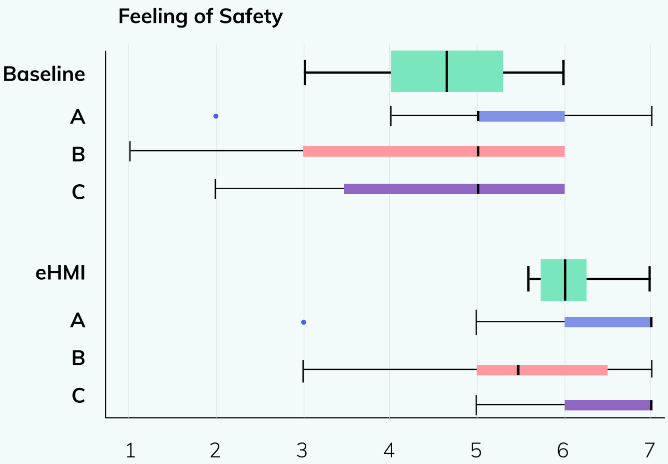


Figure 33: Boxplot FoS

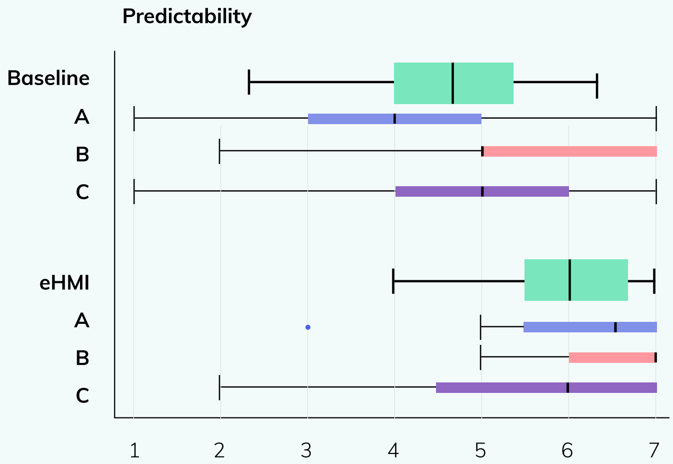


Figure 34: Boxplot VA

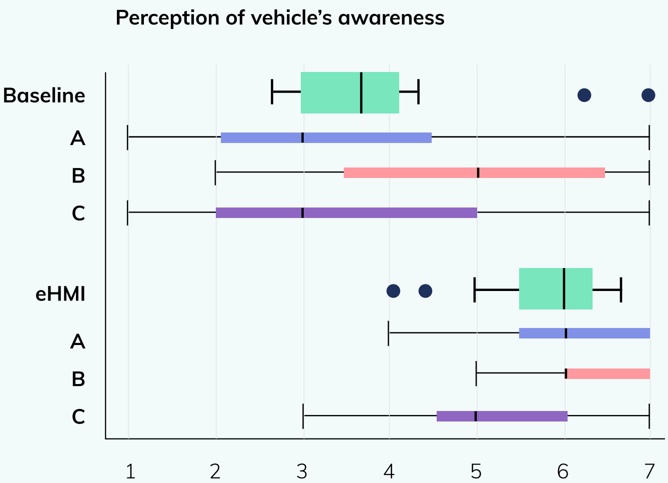


Figure 35: Boxplot VP

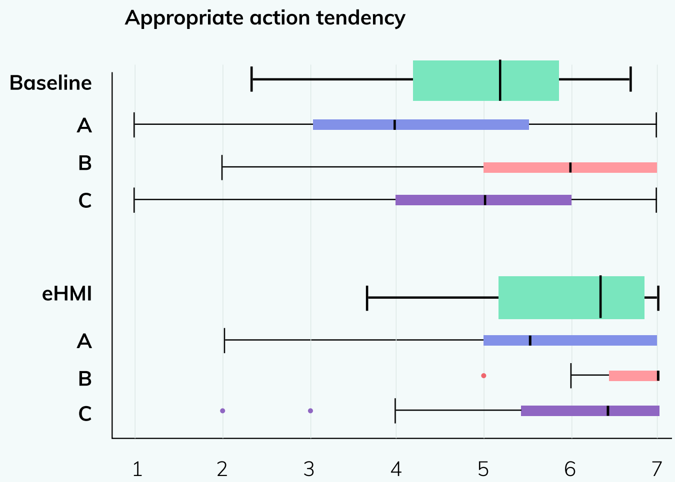


Figure 36: Boxplot AA

Overall score Scenario A Scenario B Scenario C

However, the postHoc tests helped in further understanding these results, by highlighting the differences in the performance of the design in the different scenarios (A, B, C). A general observation that can be done is that the distribution tends to be longer for all baseline items across the three scenarios, suggesting that participants perception of the baseline scenarios diferred a lot. Following we will look into the difference experience items.

Feeling of safety (figure 33):

An improvement in the means can be found in every scenario, however, only the improvement in feeling of safety was significant in scenario C. (M_A=1.06, P_A=0.021, M_B=1.19, P_B=0.02, M_c=1.81, P_C<0.001).

Aspects from the three scenarios can be considered the reason behing these results. Firstly, scenario A portrays a very ideal situation, in which the vehicle is driving very slow and stops for the pedestrian preceding the participant, therefore, it is likely to feel very safe even in the baseline condition. Someone mentioned *"I am feeling confident to cross cause the car is already stop, but I don't know if I would have crossed so confidently if I was the other girl".*

Moreover, in scenario B, people described the vehicle as and "aggressive" or "angry" due to the honking and the perceived speed of the vehicle. In this case, the light and the honk were perceived to happen simultaneously, which, while not being the intention, added to the perception of aggresiveness. *"I think only the light would be already enough, the horn feels like the car is really angry at me"*

Lastly, scenario C seems to be a very uncomfortable situation even today. Making the design intervention desirable even today *"The one I liked the most was the bike one as I because it would improve already with even non-automated cars today".*

Vehicle's predictability (figure 34):
A significant improve ment can be seen for scenarios A and B, but the improvement of predictabilty for scenario C is not significant considering Pα. (M_A=1.81, P_A=0.008, M_B=1.25 P_B=0.002, M_C=0.94, P_C=0.096)

One of the reasons why this could be explained, is that some participants perceived the projection that anticipates the appearance of the car as arbitrary rather than intentional communication. *"When I first saw the projection I was wondering whether that meant something or was simply a reflection on the ground".*

Perception of vehicle's awareness (figure 35):
The presence and behavior of the eHMI designed significantly improved the perception of awareness of the vehicle in all scenarios evaluated (M_A=2.63, P_A<0.001, M_B=1.31, P_B=0.002, M_C=1.69, P_C=0.005), the main reason appears to be the dynamic projections present in the design in all different scenarios. *"I like how it (projection) gives this spatial awareness around the car, in the sense that sometimes it was just in front and sometimes it was on the side, like changing a bit. It helps in knowing where the car is putting its attention"*

Appropriate action tendency (figure 36):
While there was an improvement in all scenarios for this item, none were statistically significant (M_A=1.31, P_A<0.038, M_B=0.81, P_B=0.032, M_C=1, P_C=0.068). This experience item is the one presenting the largest number of outliers in the evaluation of the eHMI condition, mainly in scenarios B and C. This could be due to the design being more focused on vehicle transparency rather than giving actual behavior hints. However, the colors used in the lighting were supposed to be understood as a behavioral hint, therefore the choice of colors needs to be reassesed.

Experience questionnaire, responding to H2:

The results of the linear regression showed that there is a positive correlation between the selected independent variables (iVP and iSM) and the dependent variable (iFoS) when being put together in one model, however, the prediction coeficients showed that the same independent variables separately do not have a significant impact in iFoS. Table 4.

Hypothesis	R	R²	Adjusted R²	Std. Error
H2	0.783	0.613	0.553	0.69282

Predictors: Average improvement of Apprppriate Action tendency (iAA) & Average improvement of Predictability (iVP)

Table 4: Results linear regression.

DESIGN STRENGTHS AND WEAKNESSES

Generally, participants expressed a good attitude towards the design, most found it a simple solution yet complete and informative enough in most cases. However, the following themes focus on unveiling the concrete strengths and weaknesses of the design and its features. Figure 37, shows the overview of desing elements that contributed to these. This overview will be used as reference for future recommendations.

Strengths

S1: Desirability of vehicle transparency:

As mentioned above, participants expressed an overall positive attitude towards the concept of automated vehicles being able to communicate and the design in particular. Some of them even mentioned an alike system integrated into human-driven vehicles would ease interaction already today, for instance, one participant mentioned. Moreover, the presence of the communication system allowed people to identify the vehicle as automated, someone mentioned *In this video (car not stopping with eHMI) I didn't look for the driver's face. Before (in the no eHMI video) I did try to look for this eye contact, even considering the car as automated. Now it's not necessary anymore, I know where to look.* This shows the great potential of the use of such a communication system in a transitional period when not all vehicles are automated since it would reduce possible errors.

S2: Simplicity of the design elements:

The rather simple charachter of the design proposed was one of the main qualities that participants valued. One specifically said *I see a few variables, I can count them. So three colors, fixed light or flashing light and sound. Moving, not moving. Because also, the relation between the car moving and the color is one thing, or the car moving and the flashing is another thing. So I think it's the combination of all these things together, even if there are few variables that make this* *work. So it's very good. Very simple. needed.* This statement greatly summarizes the overall perception of simplicity of the design and the overall positive attitude towards it.

S3: Positioning of the lighting system & Intrusiveness:

Participants mentioned the low positioning of the lighting system and the separation of it from the rest of the communication outputs of the vehicle. This positioning, therefore, helped in being able to know what the vehicle was communicating without these messages being intrusive or disturbing, and moreover, to identify the communication to be targeted to a specific group. One participant mentioned *I think how the lights are located makes them not so aggressive. You know, they're in the right place where they are noticeable, but not disturbing.* And another said *That's actually also nicer (lighting system being separated from current eHMI) I feel because then I know that it's something that is really for me as a pedestrian. And knowing that I think also would kind of increase my confidence.* Moreover, they valued the possibility to read the vehicle's communication from different perspectives, thanks to the lighting system surrounding the vehicle. *The fact that the lights surround the car is also very helpful because maybe you are not directly interacting with the car but from the outside, you can also know what's happening there.*

S4: Change in lighting as crucial for understanding:

Some participants mentioned the importance of seeing a change in the communication in order to feel targeted and attribute intentionality to the vehicle. Subtle changes in dynamic patterns achieved a great communicative effect on participants, for instance, in the crossing scenario where the vehicle lets the pedestrians pass a participant mentioned *I like how obvious how simple it is at the same time. I love that it's not noisy. I love that it's not demanding attention that it's very neutral. I love how easy it is to detect minimal changes, for example, in the pulsating. Like, I think the most beautiful one was the change from slow to quick pulsating. I'm about to drive. Very short, very simple, yet I know something's happening within a very short time.* This scenario is the one that showed the most dynamism compared to the other two, and it was the most valued since participants were able to identify the different stages of the interaction: "I'm about to stop", "I'm standing here", "I'm going again".

S5: Spatial awareness through projections:

Some participants pointed out the effect that the dynamic projections of the design had on the perception of the vehicle. For some, this type of information would help in understanding what are safe actions or not, for instance, one of the participants mentioned *The projected light tells me that all these areas are safe so it extends a bit like the range that I have to act or to move (when the car passes the cyclist).* On the other hand, the projected light also gave the feeling to participants that the vehicle is aware of its surroundings, as already mentioned in the previous page, one participant mentioned that the direction in which the car sets the projection gave the feeling that the vehicle was paying attention to that specific direction.

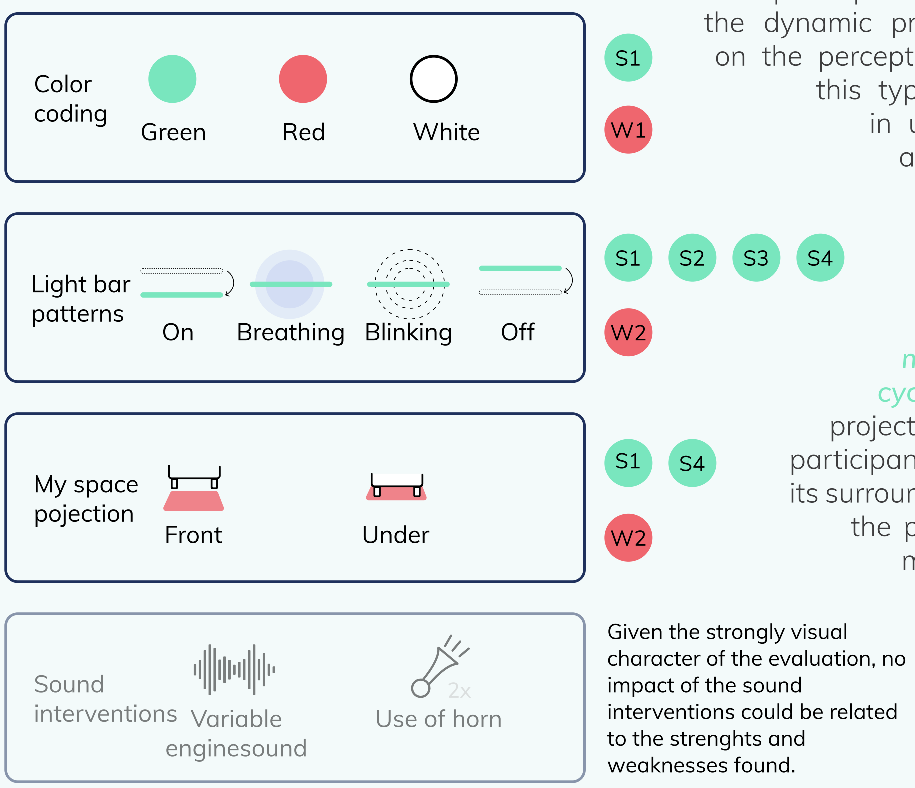


Figure 37: Design element contribution to strengths and weaknesses. Interpreted results

Weaknesses:

W1: The choice of colors in the communication:

While some participants were able to identify the color coding and link it to the right idea, there were some disagreements that should be mentioned. Firstly, while the red color used in the second scenario was clearly understood as a warning message by participants, the green was not as successful, someone mentioned *It's really just a green light where I'm like, I don't really know what it's trying to communicate to me. Because in one video it says you can go, but in the other is I'm going (talking as the car).* Moreover, comparing the same two scenarios, one participant was concerned about why the car would take a paternalistic attitude in the car passing a cyclist scenario saying *So in the crossing the green is for me to cross, but in the overtaking the car is just telling me that he's there, so why green? Why is he telling me that I can go? I know I can just continue cycling.* The number of colors used was appreciated by most participants, however, it was what they thought they would have to learn: *So I think that it would help like having a very, very simple, and short explanation of what each of the colors means. And once you get that it's very intuitive to know in which situation you're you're in or which situation you're living in that specific moment.*

W2: Feeling the target of the communication:

As mentioned in S3, participants valued change in the color, the pattern, and the presence or no presence of communication as a way to identify the intention to communicate from the vehicle. This same idea created confusion when an initial change in the mentioned features was not visible or perceived by participants. For instance, the projection anticipating the passing of the vehicle could seem accidental rather than intentional. One participant mentioned *When I first saw the projection I was wondering whether that meant something or was simply a reflection on the ground, and then when the lights turned off after the car has passed I was like, okay, the light was actually there for me.*

SUS USABILITY SCORE

The design got a total usability score of **80** (std. Deviation=9.66). This score demonstrates the concept is considered easy to learn and interact with by participants, and overall a good level of consistency and good integration across features. which were some of the main design requirements aimed for in this project. However, participants acknowledged that they would need to see the system at least once before being able to completely understand the lighting. This is normal due to the abstract nature of the design presented to participants and no explanation is given to them previous to the test.

SPATIAL PRESENCE

The spatial presence questionnaire results showed a total score of **4.43** (std. Deviation=0.36) out of 5, validating the user test set up as immersive. Thus, the results obtained are relevant fir the context examined.

LIMITATIONS

There are some limitations in the conducted study that require attention and should be addressed in future research. Firstly, due to the video-based simulation nature of the test, the evaluation focused on how the interactions are perceived by participants rather than experienced. Moreover, the video simulations used for the evaluation, portray the ideal scenarios in which eHMI interventions would be used by the autonomous vehicle, even if the presented design would be able, if implemented, to be flexible regarding which feature to use in which color at any given time depending on the "conversation" occurring between the AV and the VRU. In addition, the design presented had a multimodal typology, combining visual and auditory interventions, the evaluation mainly focused on the visual elements.

Second, as mentioned before, participants were recruited through word of mouth, resulting in a majority of participants being students or employees of the TU Delft. Future research should focus on, not only targeting a wider age range of users but also focus on evaluating the design with citizens of different countries, to validate the standardization possibilities of the designed eHMI elements.

Third, the implemented eHMI design solution is presented in a conceptual way, and attention should be paid to further detailing the functioning of the design, for instance, how long should a cyclist be able to see the front projection of the car to feel comfortable with the vehicle's actions, or what is the optimal distance from the cross for the vehicle to display intent to yield to maximize the eHMI's positive effect?

Fourth, the evaluation is limited to evaluating the effect on the interacting VRU in each given situation. It is recommended that future studies will look into how the presented eHMI affects the rest of the traffic participants.

DISCUSSION

The final evaluation shed light on the overall desirability of AVs being able to communicate, agreeing with the overall view from the research community and automotive industry (Dey et al. 2020). Alongside this, it underlined the positive and negative aspects of the multimodal concept presented. As shown in the feature overview before, most problems found were related to a lack of knowledge, this did not come as a surprise due to the first time use character of the evaluation. However, the design showed to be rather intuitive, since all participants agreed that the simplicity of it would allow them to learn and get used to the system quickly and with little practice.

Responding to the research questions presented in page 92, we can firstly focus on the change in the overall experience of navigating urban traffic as a VRU surrounded by automated vehicles. All aspects of the experience evaluated were found to improve with the presence of the eHMI across the three different scenarios designed for. Participants felt safer in the presence of the communication system, were better able to predict the intentions of the vehicle, found the vehicle to be more aware of its surroundings, and felt more at ease with their own (speculated) actions around the vehicle. It is important as well to look into what aspects of the design made these experiences improve. While the Feeling of safety and the Self management improved simply because of the presence of explicit communication, what helped in understanding the intentions of the vehicle were mainly the strip lights surrounding the car, together with the color coding and the different dynamic patterns present in the design. On the other hand, the dynamic projections helped in considering the vehicle more aware of its surroundings, since participants identified these as the vehicle showing where its attention was set.

Contrary to the the researcher's expectations, no correlation was found between the improvement of the predictability of the vehicle, improvement in self management and improvement in the feeling of safety. This could be due to different factors affecting the feeling of safety being different among scenarios, since the correlation test was run using the average improvement of the independent and dependent variables across the three scenariois tested. For instance, while in scenario A (vehicle giving right of way) the perception of awareness and predictability could have a more important role in the feeling of safety than the self management, this could be different for a different scenario. In scenario B (car claims its right of way) for instance, self management plays a more important role, since it would directly impact VRU's safety not to understand what to do in response to vehicle's communication. These small difference among interaction situations highlight the importance of investigating new and possible interactions between vulnerable road users and automated vehicles.

ON COLOR CODING

The design presented in this project used a three-color code that represented the attitude of the vehicle towards the interacting human. During the test, participants attributed personal characteristics to the vehicle depending on the scene, for instance they described the vehicle as "gentle" and "polite" in scenarios A and C, and "aggressive" or "angry" in scenario B. While these descriptions were directly related to the soft colors in scenarios A and C, the honking and the perceived speed of the vehicle in scenario B were played a role in guiding the perception of aggressiveness of the car, given that people said this also in the absence of eHMI. The color, however, was understood as a behavioral request to stop walking. The colors chosen were found by participants as very intuitive since these are present in traffic and have clear meanings, however, and considering that as much as the design is intuitive people will need some kind of training, it would be possible to investigate wether a different color coding would work just as well.

Another important aspect to consider would be the amount of colors needed in the coding. In the design presented there were three colors used, red, green and white. While the change from green to white was very well valued by participants as being a very visible cue that the car was going to start again, it would be possible to argue wether it is needed, since the green light gives the understanding that the car is detecting people crossing, the absence of light could already give that idea.

Another aspect to consider when choosing a color coding for this type of communication is inclusivity, for instance, it was brought up by one participant that this color coding didn't consider color-blindness, since the most common type of this visual defect is not being able to differentiate between green and red (Wong 2011). In todays traffic, color blind people read the traffic lights through positioning, something that the presented design does not consider, therefore, some type of intervention should be considered, for instance, adding a second light line with an accompanying color (figure 38), or changing the color coding all together.

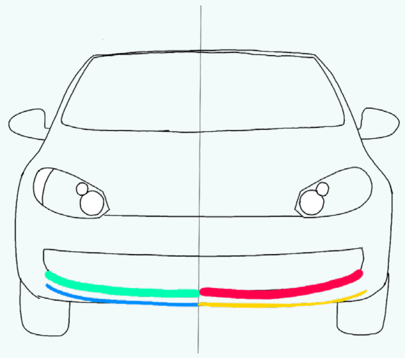


Table 38: Possible interventions for color blindness

ON DYNAMIC LIGHT PATTERNS

The design presented uses dynamic light patterns to communicate, these were different for the light bars and projections. Starting with the light bars, there were 4 possible states, Off, On, Breathing and Blinking. Participants mostly valued the four states when the change between them was visible in the videos shown, moreover, being able to see changes in the communication contributed to participants being the target of the communication, with a detrimental effect when not visible. This is why one of the possible improvements could be making the changes between off and on more obvious, given that the change from on to breathing and from breathing to blinking, was already very visible. An intervention such as a double blink before the lights turn on, for instance, would already help the message coming across. This could also apply to the my space projection present in scenario C, where the bar lights are not visible to the cyclist. Instead of the projection appearing in the vision field of the cyclist and taking more and more space, the same double blink would help cyclists in understanding the light as an intentional message.

The projections succeeded in conveying the spatial awareness of the vehicle, the design presented a simple abstract light projection that changed its positioning depending on the scenario. The use of projections is not new and industry representatives investigate its use in their automated vehicle design trials (Shane McGlaun, 2019). This interest could be due to the little impact this kind of hardware has on vehicle design, and the flexibility it provides since projections allow for flexible design, being able to project from simple lines to text or symbols (Nguyen et al, 2019). However, one of the possible issues that the use of projection-only communication systems would have is visibility issues in different lighting conditions, and this is why the combination with a more visible system is encouraged.

ON VEHICLE-VRU RELATIONSHIP

An important topic that this project investigated was the relationship between automated vehicles and vulnerable road users in future urban traffic. The design helped in creating a more equal relationship and making people feel more in control of the situation. However, it was pointed out by a participant, that while the communication system would be very necessary in a transitional period, it might become redundant over time, in which case less elements might be necessary when automated vehicles are stablished and the trust levels are high. In that case, it is possible that more minimal solutions should be investigated and created.

Another observation that came up during the development of the project was the possibility of replying to the communication of the vehicle, which would allow for actual conversation and negotiation. It has been already pointed out that automated vehicles should be able to understand the signs that cyclists do to anticipate a change of direction (Berge et al. 2021), but the possibility of creating a shared language for pedestrians to communicate with vehicles has not yet been studied. This approach would help in encouraging an even more equal relationship.

EVALUATION CONCLUSION

This user test aimed to evaluate the performance of the eHMI resulting from the previous research and design conceptualization phases conducted in the project. The evaluation criteria focused on the change in the experience of feeling of safety, vehicle predictability and VRU's self management from a VRU point of view.

The test results showed improvement in all the evaluated areas across the three different scenarios presented, responding to research questions 1, 2, and 3. However, and contrary to the researcher's beliefs, the improvement in the predictability and self management were not found to be correlated with the improvement of feeling of safety. While there could be many reasons affecting this outcome, the main possible factor could be the different communication needs present in each scenario evaluated.

To respond research question 4 (strengths and weaknesses of the design), a thematic analysis was conducted on the qualitative data retrieved from the interviews and thinking aloud exercised by participants. The main conclusions were:

S1: eHMI enabled system transparency, a desirable quality when AVs are introduced in urban traffic.

S2: Simplicity of the designed elements was valued as very positive.

S3: The positioning of the system helped in informing in a non-intrusive way.

S4: Subtle changes in the communication were important for people to understand the vehicle intentions and states.

S5: Projections triggered perception of vehicle's awareness of its environment.

W1: Color choices appeared unclear (mainly the green) in some cases and could have inclusivity issues.

W2: Sometimes, participant did not feel the target of the communication, since the changes in the patterns were not visible in all scenarios.

RECOMMENDATIONS FOR FUTURE WORK

Based on the results obtained in the concept evaluation of this project, and considering aspects of the interaction and reflections that have arisen during the development of the presented design, the following future recommendations list was created. It intends to inspire and guide new and follow up research. The first four recommendations focus on possible improvements or further research needed to refine the presented concept. The rest focus on overall recommendations that escape the scope of this project, but should be considered as well.

1. REFINING COLOR CHOICES

One of the main remaining question marks is the colors to be used, the use of red and green showed to help in the presented design, but there are still some questions to address in terms of consistency (what does each color exactly mean?) and inclusivity (color-blindness).

2. DIRECT THE COMMUNICATION TO VRUS

The design showed to help in communicating awareness of the vehicle, nevertheless, there is still room for improvement in making VRUs feel the target of specific messages, such as the "my space projection" present in scenario C. Results showed that seeing the change between communication stages important for VRUs to feel targeted by it.

3. DETAILING THE DESIGN

The presented design shows the overall behavior of the concept, but there could be some more detailing done, for instance, how abstract should the projection be?, or for how long should the vehicle communicate that is going to start driving? This type of details should be looked into in future implementation.

4. LOOKING INTO BEHAVIORAL REACTIONS

Due to the nature of the study only the perception of the interaction was measured, using the same design in a naturalistic setting would help in evaluating the behavioral response to the design with more accuracy.

5. EXPLOITING FLEXIBILITY AND DESIGNING FLEXIBLE SYSTEMS

The presented design offers flexibility of messages, attitudes, and levels of intrusiveness, considering these three elements a larger number of interactions could be evaluated to unveil the real potential of the design. The creation of flexible systems is crucial to enable communication in different scenarios, which we also need to keep looking into.

6. EFFECT OF eHMI IN THE REST OF TRAFFIC

This research focused on the perception of VRUs, but further research should look into how such system could affect the rest of traffic participants, since traffic flow should not be affected by it.

7. SECOND AND THIRD VEHICLES IN LINE

This research focused on the direct interaction between vehicle and VRU, however, future research should consider the resto of automated vehicles that might also be around, driving behind the called interacting vehicle, for instance.

8. CREATING AN IMPLEMENTATION PLAN

While design and research communities should always attempt to create a system as intuitive as possible, there is always going to be a need for training, as small as it might be. Along with deciding what is needed, there should be efforts made in the direction of implementing such eHMI when the moment comes.

PROJECT CONCLUSION

The design presented in this project can be seen as an alternative example of how automated vehicles could communicate with vulnerable road users in future urban traffic.

This project presents a multimodal design that uses visual and auditory elements. The aim of the design was to be able to communicate in many situations when encountering vulnerable road users. To that end, the visual system presents a flexible design that uses colors and dynamic patterns of bar lights and projections as an alternative way to desinging eHMIs for automated vehicles. This flexibility allowed for targetting differnt scenarios using the same elements.

This design was created through several iteration phases and evaluated in three specific scenarios through a video-based experiment. The desing demonstrated to make people feel safer, due to increased vehicle predictability and knowing how to act around the vehicle in the presence of communication system. However, further research should focus on discovering new use cases and exploit the flexibility that the design provides to ensure safe interactions in different contexts, and futher validate the design. In addition, the colors used in the design should be modified for inclusivity reasons and an implementation plan should be put in place to ease the learning process of the population.

Regarding the limitations of the study, the design was evaluated with a rather narrow group of participants due to convenience sampling. In addition, the evaluation had a perceptual charachter, and no effect on behavior was measured.

REFERENCES

A

Auerswald, R., Busse, R., Dod, M., Fritzsche, R., Jungmann, A., Klöppel-Gersdorf, M., Krems, J. F., Lorenz, S., Schmalfuß, F., Springer, S., & Strobl, S. (2019). Cooperative driving in mixed traffic with heterogeneous communications and cloud infrastructure. VEHITS 2019 - Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems, Vehits, 95–105. https://doi.org/10.5220/0007682900950105

B

Bagloee, S. A., M. Tavana, M. Asadi and T. Oliver (2016). "Autonomous vehicles: challenges, opportunities, and future implications for transportation policies." Journal of Modern Transportation 24(4): 284-303.

Bazilinskyy, P., L. Kooijman, D. Dodou and J. C. F. de Winter (2021). "How should external human-machine interfaces behave? Examining the effects of colour, position, message, activation distance, vehicle yielding, and visual distraction among 1,434 participants." Applied Ergonomics 95: 103450.

Berge, S., M. Hagenzieker, H. Farah and J. de Winter (2021). Do cyclists need HMIs in future automated traffic? An interview study.

Boeijen (van), A., Daalhuizen, J., Zijlstra, J., van der Schoor, R. (2021). Delft Design Guide. Publisher: BIS publishers. Edition: revised 2nd edition.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative research in psychology, 3(2), 77-101.

British Council, (2019). What is the framework for innovation? Design Council's evolved Double Diamond. Retrieved from https://www. designcouncil.org.uk/news-opinion/what- framework-innovationdesign-councils-evolved- double-diamond.

Brooke, J. (1996). SUS-A quick and dirty usability scale. Usability evaluation in industry, 189(194), 4-7.

C

Chakraborty, N. and R. S. Patel (2013). "Intelligent agents and autonomous cars: a case study." Intl. Journal of Engineering Research & Technology (IJERT) Vol 2: 1-7.

Chen, H., R. Cohen, K. Dautenhahn, E. Law and K. Czarnecki (2020). Autonomous Vehicle Visual Signals for Pedestrians: Experiments and Design Recommendations. 2020 IEEE Intelligent Vehicles Symposium (IV).

Cila, N., E. Giaccardi, F. Tynan-O'Mahony, C. Speed and M. Caldwell (2015). Thing-Centered Narratives: A study of object personas. Proceedings of the 3rd Seminar International Research Network for Design Anthropology.

Colley, M., M. Walch and E. Rukzio (2020). Unveiling the Lack of Scalability in Research on External Communication of Autonomous Vehicles. Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems. Honolulu, HI, USA, Association for Computing Machinery: 1–9.

D

Dey, D., A. Habibovic, A. Löcken, P. Wintersberger, B. Pfleging, A. Riener, M. Martens and J. Terken (2020). "Taming the eHMI jungle: A classification taxonomy to guide, compare, and assess the design principles of automated vehicles' external human-machine interfaces." Transportation Research Interdisciplinary Perspectives 7: 100174.

Dey, D., A. Matviienko, M. Berger, B. Pfleging, M. Martens and J. Terken (2021). "Communicating the intention of an automated vehicle to pedestrians: The contributions of eHMI and vehicle behavior." it - Information Technology 63(2): 123-141.

Dey, D. and J. Terken (2017). Pedestrian Interaction with Vehicles: Roles of Explicit and Implicit Communication. Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. Oldenburg, Germany, Association for Computing Machinery: 109–113.

E

Eisma, Y., A. Reiff, L. Kooijman, D. Dodou and J. De Winter (2021). “External human-machine interfaces: Effects of message perspective.” Transportation research part F: traffic psychology and behaviour 78: 30-41.

F

Faas, S. M., J. Kraus, A. Schoenhals and M. Baumann (2021). Calibrating Pedestrians’ Trust in Automated Vehicles: Does an Intent Display in an External HMI Support Trust Calibration and Safe Crossing Behavior? Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery: Article 157.

Faas, S. M., L.-A. Mathis and M. Baumann (2020). “External HMI for self-driving vehicles: Which information shall be displayed?” Transportation Research Part F: Traffic Psychology and Behaviour 68: 171-186.
G

Goldberg, K. (2012). “What Is Automation?” IEEE Transactions on Automation Science and Engineering 9(1): 1-2.

G

Guindel Gómez, C., Garcia Marin, F., Escalera Hueso, A. D. L., & Carmona, J. (2021). Ehmi: Review and guidelines for deployment on autonomous vehicles.

H

Harris, J.S., 1961. New Product Profile Chart. Chemical and Engineering News, Vol. 39, No. 16, pp.110-118.

Hetzer, D., Muehleisen, M., Kousaridas, A., Barmpounakis, S., Wendt, S., Eckert, K., Schimpe, A., Löfhede, J., & Alonso-Zarate, J. (2021). 5G connected and automated driving: use cases, technologies and trials in cross-border environments. Eurasip Journal on Wireless Communications and Networking, 2021(1). https://doi.org/10.1186/s13638-021-01976-6

Hou, M., K. Mahadevan, S. Somanath, E. Sharlin and L. Oehlberg (2020). Autonomous Vehicle-Cyclist Interaction: Peril and Promise. Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. Honolulu, HI, USA, Association for Computing Machinery: 1–12.

L

Limerick, H., D. Coyle and J. W. Moore (2014). “The experience of agency in human-computer interactions: a review.” Frontiers in Human Neuroscience 8(643).

Li, Y., H. Cheng, Z. Zeng, H. Liu and M. Sester (2021). “Autonomous Vehicles Drive into Shared Spaces: eHMI Design Concept Focusing on Vulnerable Road Users.” arXiv preprint arXiv:2104.06916.

Limerick, H., D. Coyle and J. W. Moore (2014). “The experience of agency in human-computer interactions: a review.” Frontiers in Human Neuroscience 8(643).

Liu, Y., R.-H. Liang, Y.-H. Lee, Y. Chuang and L.-L. Chen (2017). Designing the expressiveness of point lights for bridging human-IoT system communications. Proceedings of the Conference on Design and Semantics of Form and Movement-Sense and Sensitivity, DeSForM 2017, IntechOpen.

M

Métayer, N. and S. Coeugnet (2021).

"Improving the experience in the pedestrian's interaction with an autonomous vehicle: An ergonomic comparison of external HMI." Applied Ergonomics 96: 103478.

Moore, D., R. Currano, G. E. Strack and D. Sirkin (2019). The Case for Implicit External Human-Machine Interfaces for Autonomous Vehicles. Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. Utrecht, Netherlands, Association for Computing Machinery: 295–307.

N

Nguyen, T. T., Holländer, K., Hoggenmueller, M., Parker, C., & Tomitsch, M. (2019, September). Designing for projection-based communication between autonomous vehicles and pedestrians. In Proceedings of the 11th international conference on automotive user interfaces and interactive vehicular applications (pp. 284-294).

Nyholm, S., Smids, J. Automated cars meet human drivers: responsible human-robot coordination and the ethics of mixed traffic. Ethics Inf Technol 22, 335–344 (2020). https://doi.org/10.1007/s10676-018-9445-9

O

Özcan, E. and R. van Egmond (2005). Characterizing descriptions of product sounds. Proceedings of the 11th International Conference on Auditory Display.

P

Pruitt, J., & Grudin, J. (2003, June). Personas: practice and theory. In Proceedings of the 2003 conference on Designing for user experiences (pp. 1-15).

R

Rasouli, A., I. Kotseruba and J. K. Tsotsos (2017). Agreeing to cross: How drivers and pedestrians communicate. 2017 IEEE Intelligent Vehicles Symposium (IV).

Rozendaal, M. C., E. v. Beek, P. Haselager, D. Abbink and C. M. Jonker (2020). Shift and Blend: Understanding the hybrid character of computing artefacts on a tool-agent spectrum. Proceedings of the 8th International Conference on Human-Agent Interaction. Virtual Event, USA, Association for Computing Machinery: 171–178.

Rozendaal, M. C., M. Ghajargar, G. Pasman and M. Wiberg (2018). Giving form to smart objects: Exploring intelligence as an interaction design material. New Directions in Third Wave Human-Computer Interaction: Volume 1-Technologies, Springer: 25-42.

S

Sanders, E.B.N., Stappers, P.J. (2012). Convivial Toolbox: Generative Research for the Front End of Design Song, S. and S. Yamada (2019). "Ambient Lights Influence Perception and Decision-Making." Frontiers in Psychology 9(2685).

T

Tabone, W., J. de Winter, C. Ackermann, J. Bärgman, M. Baumann, S. Deb, C. Emmenegger, A. Habibovic, M. Hagenzieker, P. A. Hancock, R. Happee, J. Krems, J. D. Lee, M. Martens, N. Merat, D. Norman, T. B. Sheridan and N. A. Stanton (2021). "Vulnerable road users and the coming wave of automated vehicles: Expert perspectives." Transportation Research Interdisciplinary Perspectives 9: 100293.

V

Verma, H., G. Pythoud, G. Eden, D. Lalanne and F. Evéquoz (2019). "Pedestrians and Visual Signs of Intent: Towards Expressive Autonomous Passenger Shuttles." Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 3(3): Article 107.

Vorderer, P., W. Wirth, F. R. Gouveia, F. Biocca, T. Saari, L. Jäncke, S. Böcking, H. Schramm, A. Gysbers and T. Hartmann (2004). "Mec spatial presence questionnaire." Retrieved Sept 18: 2015.

W

Weisstein, E. W. (2004). Bonferroni correction. https://mathworld. wolfram. com/.

Wong, B. (2011). Color blindness. nature methods, 8(6), 441.

Wooldridge, M. and N. R. Jennings (1995). “Intelligent agents: theory and practice.” The Knowledge Engineering Review 10(2): 115-152.

Y

Yuen, K. F., F. Ma, X. Wang and G. Lee (2021). “The role of trust in influencing consumers’ adoption of automated vehicles: An application of the health belief model.” International Journal of Sustainable Transportation 15(11): 837-849.

Appendix

APPENDIX A: PROJECT BRIEF

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Marqués Ortega 5369
initials: M.D.C given name: Carmen
student number: 4938348
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ( ) IPD (★) Dfl ( ) SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ( ) Honours Programme Master
specialisation / annotation: ( ) Medisign
( ) Tech. in Sustainable Design
( ) Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Marco Rozendaal dept. / section: HCI-HICD
** mentor: Ilse van Zeumeren dept. / section: HCI-DA
2nd mentor: Angelique Tinga
organisation: SWOV
city: Den Haag country: Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

Procedural Checks - IDE Master Graduation

TU Delft

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Marco Rozendaal date 22 - 11 - 2021 signature

Digitally signed by tudelft.protect Jamf Protect CSR Identity Date: 2021.11.22 11:33:40 +01'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 32 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 26 EC

List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed

NO missing 1st year master courses are:

name c. van der Bunt date 15 - 11 - 2021 signature C. van der Bunt

Digitally signed by C. van der Bunt Date: 2021.11.15 10:06:10 +01'00'

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ★ APPROVED NOT APPROVED

Procedure: ★ APPROVED NOT APPROVED

comments

name Monique von Morgen date 23 - 11 - 2021 signature

External Human Machine Interface for an Expressive automated vehicle — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 04 - 10 - 2021 — 20 - 02 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The automotive industry changes rapidly, not only in technological advancements but also in the interaction qualities and user experience that vehicles can provide. Autonomous vehicle seem to be gaining protagonism research in this area is continuously happening. The Society of Automotive Engineers (SAE) describes six levels of automation, from human control (level 0) to some driving assistance technologies (levels 1 and 2), to fully automated driving (levels 4 and 5).

While the research on the human-driver relationship is now well advanced, there has been a raise in awareness about the relationship of the autonomous car with other road users. The concept of the connected vehicle, together with the automation, has the potential to leading to the elimination of accidents, and therefore constitutes a big advancement in safety. Autonomous Vehicles can communicate with other road users through both implicit (speed, driving mode) and explicit communication in the form of deliberate signals. The need to design an external Human Machine Interface (eHMI) has been raising interest in the recent years (Métayer, N., & Coeugnet, S. 2021). This eHMI should be able to express state, intention and capabilities of the automation in order to facilitate certain decisions, such as crossing the road or not (M. Faas et. Al 2021). Other lines of communication, such as passenger-to-vulnerable road user will be Also explored.

This project will take into consideration existing knowledge about human perception and communication between humans and smart systems. To fulfill the necessary knowledge, the main stakeholders involved will be SWOV (Dutch Institute of Road safety) and the Expressive intelligence Lab at the IDE faculty. Both organizations will contribute to the design of an external interface that will ensure an effective communication between the autonomous vehicle and the vulnerable road user.

References:

Métayer, N., & Coeugnet, S. (2021). Improving the experience in the pedestrian's interaction with an autonomous vehicle: An ergonomic comparison of external HMI. Applied Ergonomics, 96(March). https://doi.org/10.1016/j.apergo.2021.103478

M. Faas, S., Kraus, J., Schoenhals, A., & Baumann, M. (2021). Calibrating Pedestrians' Trust in Automated Vehicles. 1, 1–17. https://doi.org/10.1145/3411764.3445738

space available for images / figures on next page

introduction (continued): space for images

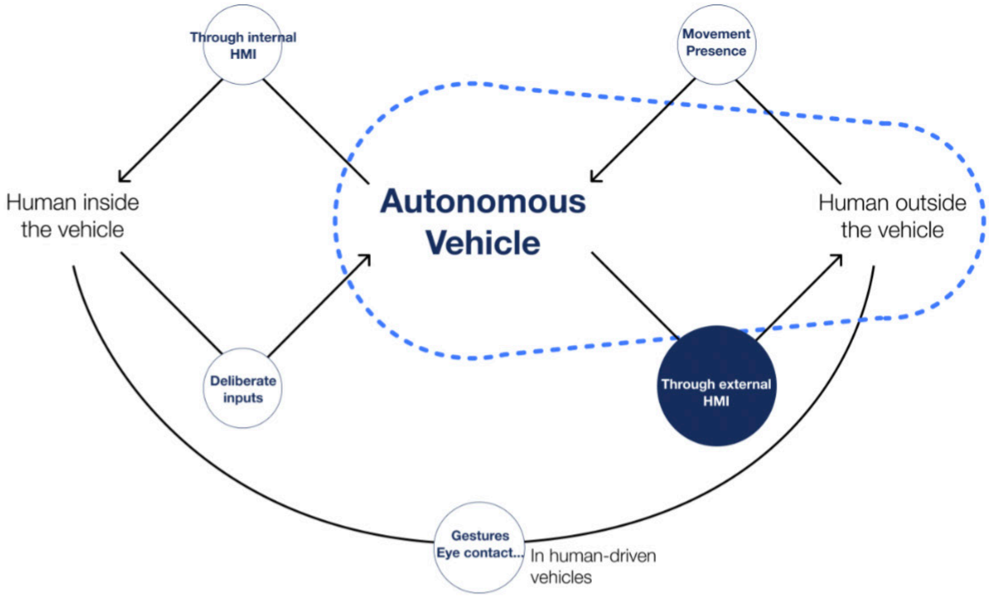


image / figure 1: Autonomous vehicle in traffic, communication map

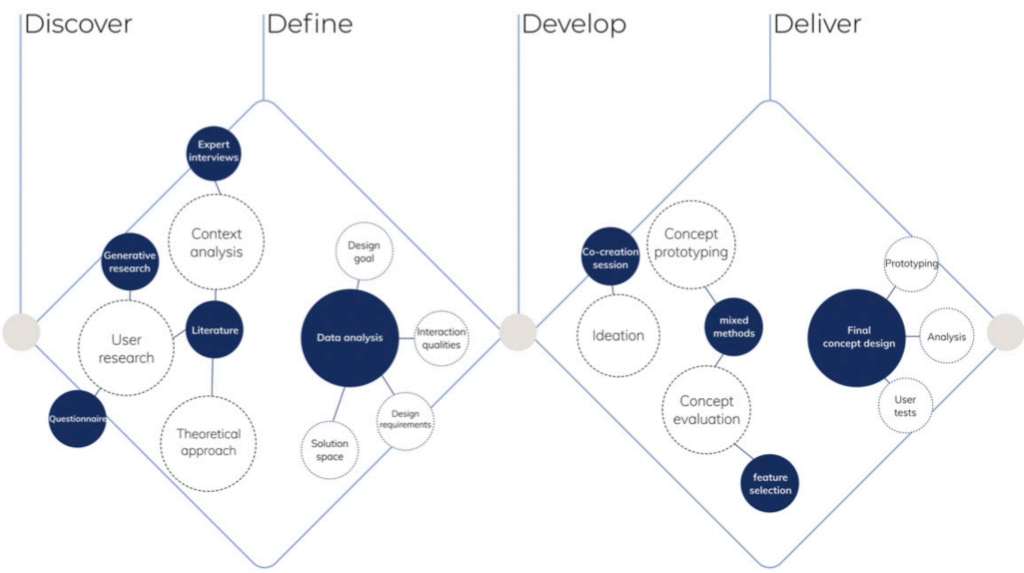


image / figure 2: Project approach and activities

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Up to autonomous driving level two (SAE classification) the communication between the car and other road users relies on the driver, who is responsible for the awareness and interpretation of the outside context. Drivers communicate with other agents using both: elements of the car, such as turn signals, hazard lighting and horns, and body expressions such as eye contact, hand gestures and face expressions such us smiling (Li. Y. et. Al, 2021).
In higher automation levels (3 to 5) there is a shift in the role of the driver, becoming a passenger, and it is not contemplated in their responsibilities to be aware of the road situation. Therefore, the communication with the outside relies on the car. This becomes specially compromising for pedestrians and bike riders, since they are a more vulnerable agent in the case of an accident or crash. There is a need to developing a communication interface that allow pedestrians and bicyclists to know about the current state, perception and intention of the autonomous vehicles they encounter on the road.

Some of the research questions that will be addressed are the following:
- In what situations does a pedestrian or bike rider need the vehicle to communicate?
- What information does the AV need to express to other road users such as pedestrians or cyclists?
- How should this information be communicated?
- When should this information be communicated?

References:
- Li, Y., Cheng, H., Zeng, Z., Liu, H., & Sester, M. (2021). Autonomous Vehicles Drive into Shared Spaces: eHMI Design Concept Focusing on Vulnerable Road Users. http://arxiv.org/abs/2104.06916
- Métayer, N., & Coeugnet, S. (2021). Improving the experience in the pedestrian's interaction with an autonomous vehicle: An ergonomic comparison of external HMI. Applied Ergonomics, 96(March). https://doi.org/10.1016/j.apergo.2

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

This project will potentially contribute to knowledge about human communication with Autonomous vehicles through the concept development of an external Human-Machine interface. The final result could be used to inspire future research in the topic of AV-human interaction and policies regarding external HMI of autonomous vehicles.

The assignment consists of a complete design process, from literature, to interviews (both with experts and road users) and generative research. The analysis of the context of the autonomous vehicles, a conceptualization phase and a final design stage in which a concept will be delivered and validated through user testing.

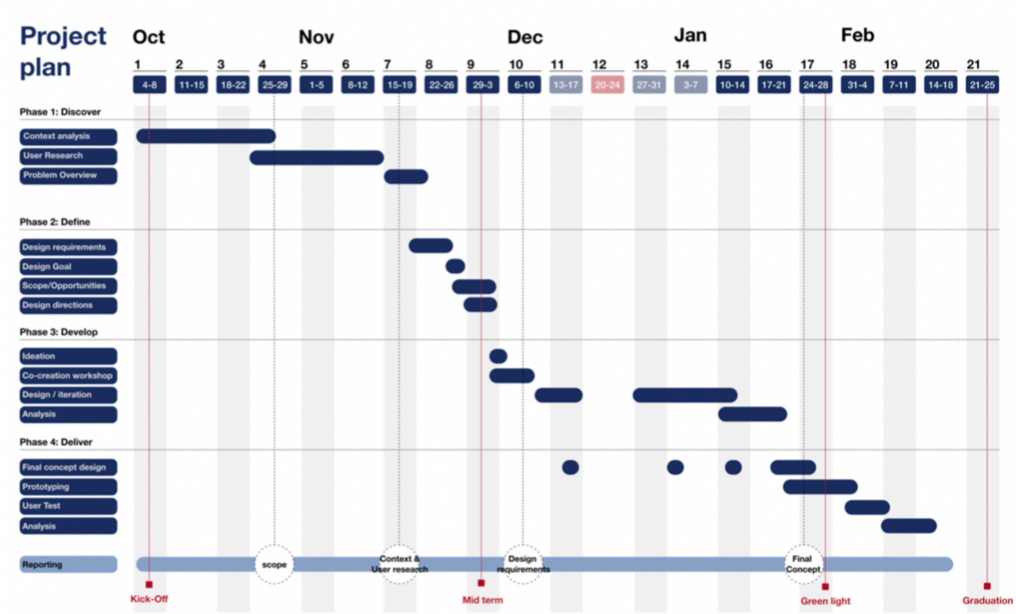
Working with SWOV will also mean getting support from industry professionals to share their knowledge, other experts involved could be my graduation team (Marco Rozendaal, Ilse van Zeumeren and Angelique Tinga) and other experts from TU Delft, such as Marten Wijntjes, expert in human perception and communication design.

An important part of this project is also the final user test conducted for the concept proposed, this will be prototyped in the highest level of fidelity possible given the time, and tested to make recommendations for future development.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 4 - 10 - 2021 | 20 - 2 - 2022 end date



The project will take 100 working days since 4th of October 2021 until March 4th 2022, when I plan to present and defend my project. I will work 5 days per week until the end of the project. For a number of weeks (marked in softer blue) I will be in Spain, and therefore I will make use of online tools to do the concept testing and iteration phase, I also marked five days as free to ensure I get some rest during the project.

The graduation period planned is divided in 4 project phases, the activities are described in Fig.2:

1- Discover: In this phase, the main goals are to approach the context, the user and the expressiveness of thee vehicle from both a theoretical yet hands on approach. This first phase will contain literature review, expert interviews and generative research giving insight into the context of the future traffic and communication between the autonomous vehicles' external HMI and the human agents (being pedestrians and cyclists the main subjects of the research). The research will then focus on the pedestrians/cyclists perception of the information communicated by the external-HMI. Moreover I will get into detail about current developments and what the vehicles are able to perceive. (This phase will take around 6 weeks)

2- Define: Insights and findings from phase 1 will be interpreted and used to formulate a design goal, finalize the scoping of the project and determine interaction qualities of this graduation project. (3 weeks)

3- Develop: First ideas and concepts will be generated in this phase of the project. Concepts will be prototyped and tested to identify their strengths, weaknesses and potential successful features to be implemented in the final design. In this phase I would like to facilitate a creative session to broaden the individual ideation. (around 6 weeks)

4- Deliver: After the evaluation of the different concepts, a decision will be made of wether develop one of the concepts further or take different elements of the concepts evaluated and create a final design based on them. This final concept will be prototyped, tested, and evaluated based on the outcomes. (5 weeks)

TUDelft

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Two of my main goals as a designer are creating social impact with the projects I get myself into, and contribute to the development of smart technology with a human-centered approach. Collaborating with SWOV (Dutch institute of road safety) seems like the perfect place to create an impact, since the project could inspire future Autonomous vehicle regulations, and looking into how a smart agent such an autonomous vehicle communicates with people and contributes to human safety definitely fulfills my second ambition.

Moreover, I feel personally attracted to working in the automotive industry one day, and I feel doing my graduation project in this field could help me approach that goal and allow me to experience how it would be like to do so in the future, familiarizing myself with the current knowledge and design process, and applying knowledge I already have.

In between my ambitions I would really love to further practice different research techniques learned during my master such as furthering develop my data analysis skills in different parts of the research (quantitative analysis of questionnaires and thematic analysis of interviews). Furthermore, I would like to facilitate a creative session with some researches at SWOV in the concept phase of my project. This would help me improve my interpersonal skills of public speaking and gain inspiration from industry professionals for my design. Last but not least, I want to pay attention to my stakeholder management capabilities, since I will have a number of different inputs from different perspectives in my project.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

APPENDIX B: A CONNECTED FUTURE

LEVELS OF CONNECTIVITY

Vehicle connectivity or the concept of the connected vehicle refers to the possibility that an automobile has to connect to the area network. This means that in-vehicle devices allow the vehicle to share with and receive information from different agents in the surrounding area, such as other vehicles or the infrastructure. There are five levels of connectivity described and being researched widely (Tepe, R., 2020).

Vehicle to infrastructure connectivity allows the vehicle to recognize not only information about traffic regulations in the area but also about environment-related data that could have an effect on safety, this can go from bad weather conditions to lack of visibility from other reasons.

Vehicle-to-vehicle connectivity allows for wireless data exchange about speed and position with other connected vehicles. Some of the feedback cues used in the receptor are alerts in the form of sound, visual cues, or vibrations. This actively helps to avoid crashes in human-driven cars.

Vehicle to cloud connectivity allows for information exchange between vehicles without an area limit. This connection needs for proper collaboration in the network. Auerswald, R., et al., (2019) point out the importance of this level to increase the reliability of the information shared. Since data collected by the cooperative vehicle might be incomplete or not completely accurate. Cloud connectivity could then confirm the information before informing the rest of the road users.

Vehicle to pedestrian allows for information exchange between vehicles and vulnerable road users (VRU), such as pedestrians and cyclists, through the use of personal devices such as mobile phones or smartwatches and their wireless technology. Danger or intention information could be sent from the vehicle to the VRU through sound signals or haptic feedback.

Vehicle-to-everything connectivity allows for data exchange among all types of vehicles, infrastructure, and road users. Hetzer, D., et al. (2021) present a system in with the cooperative vehicle detects a possibly dangerous situation, sends a number of relevant data to the server, which gets confirmation from infrastructure management. This information is then sent to other vehicles present in the relevant area and that might have to adjust driving decisions. The receptor will receive different types of warnings when approaching a possibly unsafe situation.

Up to level 3, there are already cars on the roads with these capabilities (reference), but the major challenges lie in the technological readiness of most countries networks, the great financial needs to arrange this kind of infrastructure, and the privacy issues concerning the vehicle to pedestrian and vehicle to everything connectivity.

Project implications:
For the purpose of this project, there is a need to take into account the technological readiness of whatever is designed. That is why, it will not be possible at this point to use Vehicle to pedestrian connectivity principles, since for the concept to be feasible, It would be necessary for all vulnerable road users to have access to this technology on their personal devices. This is a line of research worth exploring in the future, especially taking into account pedestrians with visual or hearing disabilities.

APPENDIX C: HOW DO AVS WORK?

HOW DO AVS SEE?

Like many other intelligent machines, AVs see and understand the world through a set of sensors that gather data from the environment, (Yeo 2021) give an overview of the different sensors used in autonomous vehicles. Figure X presents an overview of the placement of these sensors.

Cameras: Cameras are among the most adopted technologies to perceive the environment. They produce an image of the surroundings and are able to detect both static and moving objects. These allow the vehicle to perceive road signals, traffic lights, road lane markings, and other barriers such as other vehicles on the road or other articles in the case of off-road vehicles. Most advanced cameras provide also a sense of depth to the image, which helps the vehicle further understand the environment.

LiDAR: the name stands for Light Detection and Radaring, and it has been historically used in the field of aeronautical or aerospace mapping. It is currently one of the core perception technologies used for Advanced Driver Assistance Systems (ADAS) in partially autonomous vehicles. LiDAR technologies allows for the estimation of distances by generating a 3D representation of the environment in the form of a point cloud. Due to its broader field of view, LiDAR provides a reliable mapping of the environment during day and night, nevertheless, and opposite to camera systems, LiDAR does not provide color information.

Radar: Radars use electromagnetic waves to determine the relative speed and position of the detected obstacles, but have a more limited resolution in calculating velocity and angles. In AVs, radars are invisibly integrated into several locations such as the top of the windshield, behind the vehicle bumpers, or brand emblems. In general, radar sensors in vehicle automation are used to provide the precise perception of obstacles, since their functioning is not affected by weather or light conditions.

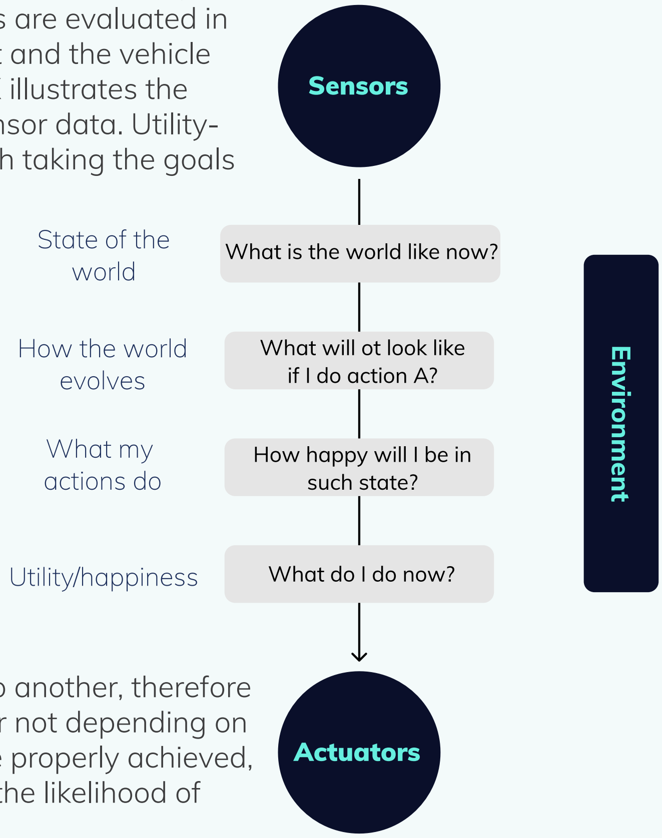
FAMILIARIZING

To better understand how AVs see the world, a small desktop search was done looking for the UI presentations of vehicles with automation level 2 or 3, the images on the right present the UI that the driver of a Tesla (model) can see on the central display.

Already today the images created are pretty accurate, but the car may sometimes fail. It is expected that the sesing technology will also improve in the future, ehich gves the opportunity for better communication experinece. The more accurate the sensing technology is, the better the car can predict VRUs movements and act ccordingly.

HOW DO AVS PLAN?

Being AVs utility-based agents, the information gathered by the sensors is processed and a number of actions are evaluated in terms of how they will affect the environment and the vehicle level of happiness with the outcome. Figure X illustrates the inner logic of the AV when processing the sensor data. Utility-based agents combine "seeing" functions with taking the goals of the agent into account, but also have the possibility to prioritize their goals when not all can be fulfilled. Eg. An autonomous taxi not only has the goal to arrive fast and safely to a destination but also looks for economizing the trip (monetarily and environmentally speaking). For this purpose, AVs have the possibility to assess different worlds based not their actions and determine the degree of "happiness" that an action or another could bring (Chakraborty et al. 2013).

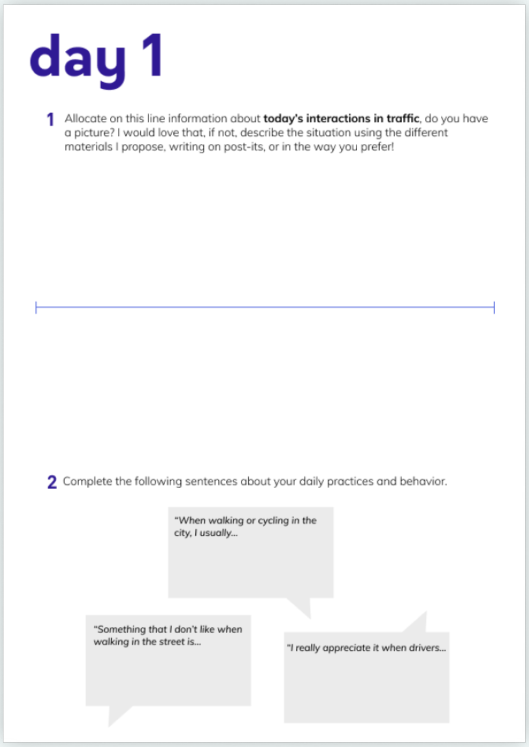


The level of happiness refers to the degree to which a state after an action is preferred to another, therefore considering that goals can be given priority or not depending on the situation. In the case that no goals can be properly achieved, a utility-based agent will decide considering the likelihood of success when taking a route or the other.

The decision taken by the vehicle changes the environment accordingly, affecting other road users. In order to ensure situational awareness of the rest of the traffic participants, communication of current and future actions is displayed.

APPENDIX D: EHMI CONCEPTS FROM MANUFACTURERS

APPENDIX E: GENERATIVE RESEARCH, SENSITIZING PACKAGE



day 1

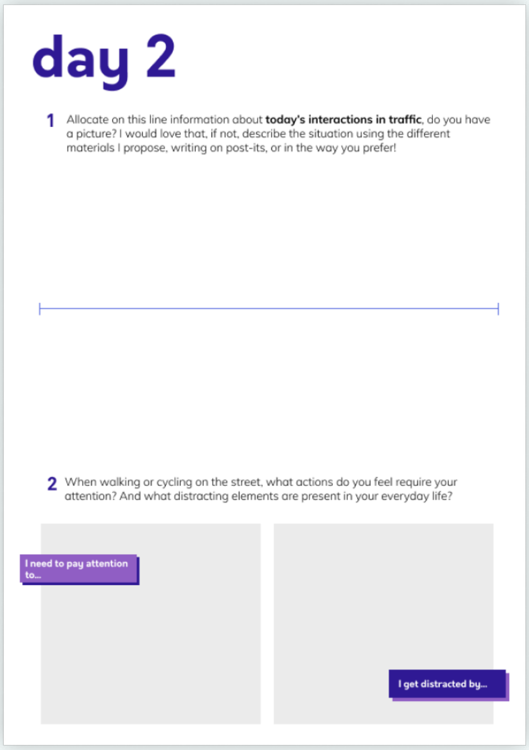
1 Allocate on this line information about **today's interactions in traffic**, do you have a picture? I would love that, if not, describe the situation using the different materials I propose, writing on post-its, or in the way you prefer!

2 Complete the following sentences about your daily practices and behavior.

"When walking or cycling in the city, I usually...

"Something that I don't like when walking in the street is...

"I really appreciate it when drivers...



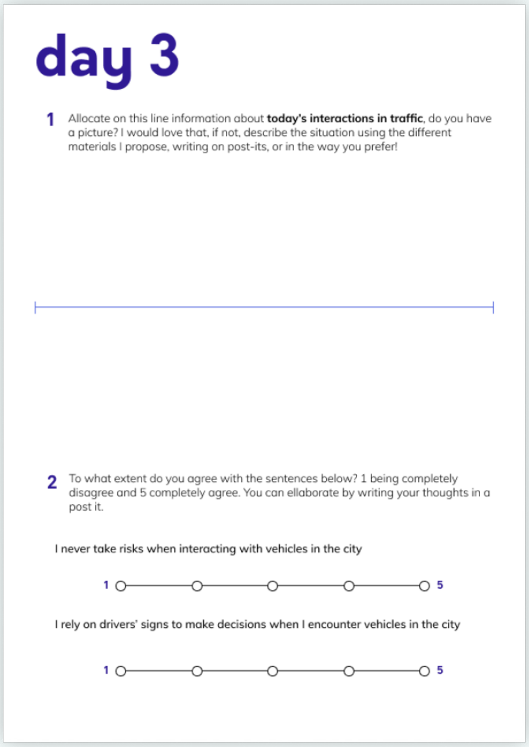
day 2

1 Allocate on this line information about **today's interactions in traffic**, do you have a picture? I would love that, if not, describe the situation using the different materials I propose, writing on post-its, or in the way you prefer!

2 When walking or cycling on the street, what actions do you feel require your attention? And what distracting elements are present in your everyday life?

I need to pay attention to...

I get distracted by...



day 3

1 Allocate on this line information about **today's interactions in traffic**, do you have a picture? I would love that, if not, describe the situation using the different materials I propose, writing on post-its, or in the way you prefer!

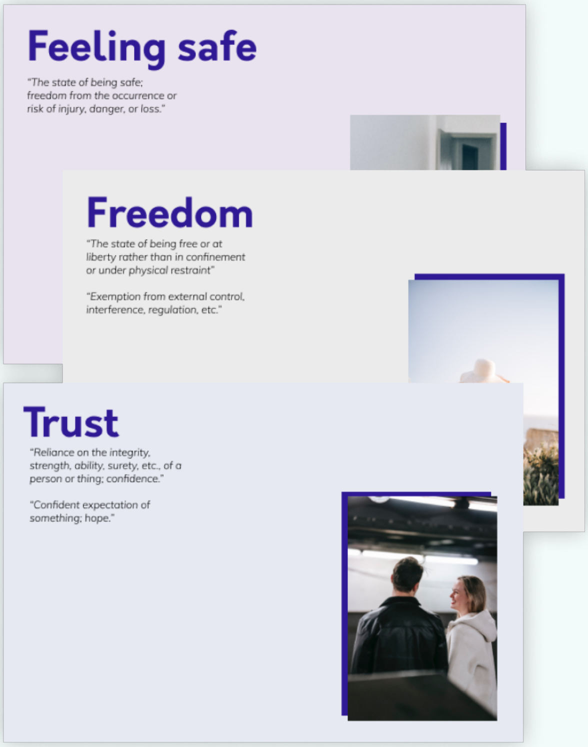
2 To what extent do you agree with the sentences below? 1 being completely disagree and 5 completely agree. You can ellaborate by writing your thoughts in a post it.

I never take risks when interacting with vehicles in the city

1 ○—○—○—○—○ 5

I rely on drivers' signs to make decisions when I encounter vehicles in the city

1 ○—○—○—○—○ 5



Feeling safe

"The state of being safe; freedom from the occurrence or risk of injury, danger, or loss."

Freedom

"The state of being free or at liberty rather than in confinement or under physical restraint"

"Exemption from external control, interference, regulation, etc."

Trust

"Reliance on the integrity, strength, ability, surety, etc., of a person or thing; confidence."

"Confident expectation of something; hope."

APPENDIX F: GENERATIVE RESEARCH. SESSION SCRIPT

0. Sensitizing workbook

Send all participants the material and arrange the sessions

1. Introduction and agenda

Welcome everyone to this generative research session.

First of all, I will ask you to sign the consent form so I can record this session, the recording will only be used to look back at it when I am analyzing the insights.
I am not going to introduce much about my graduation because today is about you and the experiences that you have lived in urban traffic. This session is going to help me a lot in the project, and for that I will already thank you for being here, and tell you that everything you say will be very much valuable, for that I ask you to speak up your mind and add comments at any time during the session.

This type of activity is very useful since it will inspire my design process from a very early stage, that is why I want to ask you to postpone judgement, do not ask yourself wether something makes sense or not, there are no right or wrong answers. I would like you to simply focus on the experiences and memories that you share with the rest of us.

But before starting I want to show you a small agenda for today and hopefully, we will be done in no more than 2 hours:

Does anyone have any questions?
Today we are also going to work in Miro, the same tool you used to fill in your workbook. I have sent you the link in the chat.

2. Workbook reflections. Interaction journey

Now, I would lie you to, one by one, Introduce yourselves, and explain the main experiences you found by filling in the first activity of each one of the days. Also if you have any remarks about the material I sent you, this would be a good time to share that.
- Did you find anything surprising that hadn't thought about before?

3. Collage Making

As you can see, I put together some material and words for you to make a collage about "Encounters with vehicles in traffic" You can use both the materials I provide or find your own, which means you can add your own words, use emojis you can find in Miro or get images from the internet to help you convey your ideas. I created a frame with some structure, but feel free to delete the line and the circle if they don't help you.

4. Discussion

Now, as we did before, I want each one of you to shortly explain your collages.
Deepening questions to ask during the explanations:

- What does that mean for you?
- Why do you think this happens?

5. Situations

Ok, so for the next activity, I chose a couple of situations you describe in your workbook, now we are going to share some ideas about them, along with the discussion, I will change some of the conditions of the scenario, and we will keep discussing it.
Deepening questions to ask during the explanations:

- How do these encounters feel?
- What makes the feeling be like that?
- What affects these feelings?
- What would be a desirable outcome?
- How are the situations solved?

6. Brainstorming

Now that we have discussed all of these things, we are going to brainstorm about possible solutions to the problems we find today when encountering vehicles. But, since we are talking about the future, we are going to think of possible solutions taking into account the introduction of driverless vehicles.
So, what I want you to brainstorm is Autonomous vehicle with superpowers! That helps solve the issues we have with vehicles now.

- What are the superpowers it has?
- What are the intentions?
- What is his attitude towards VRUs?
- What is the media used to achieve its goals?

7. Concluding

Time's up! Now what we are going to do is look at the different solutions that we have come up with in the previous exercise and see what are the most said or important features that could fill in the following gaps.

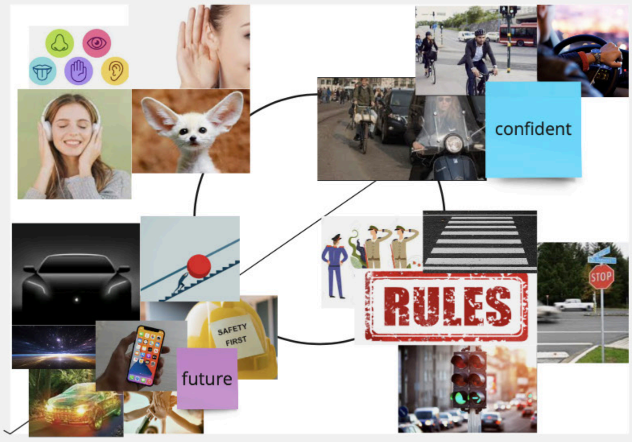
Deepening questions to ask during the discussion:

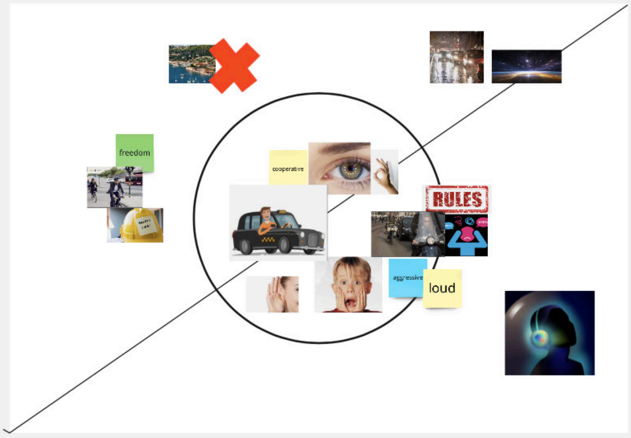
- What attitudes does the vehicle have?
- What intentions does the vehicle have?
- What media does the vehicle use to communicate?

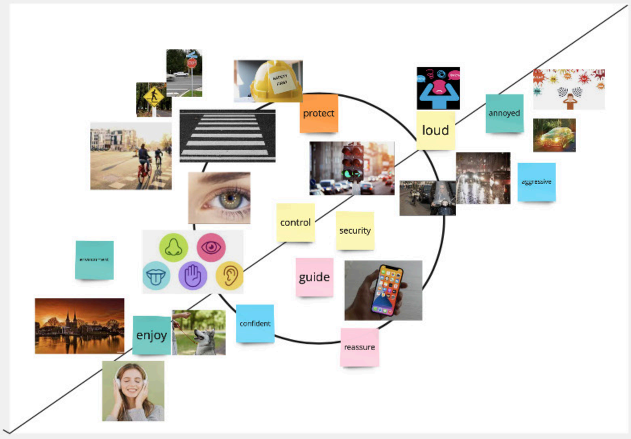
We are done, guys! I would like to thank you all again for assisting in this session, I hope you enjoyed the process, and I would like you to freely express your final thoughts about the session, the homework I gave you, or anything you would like to add.

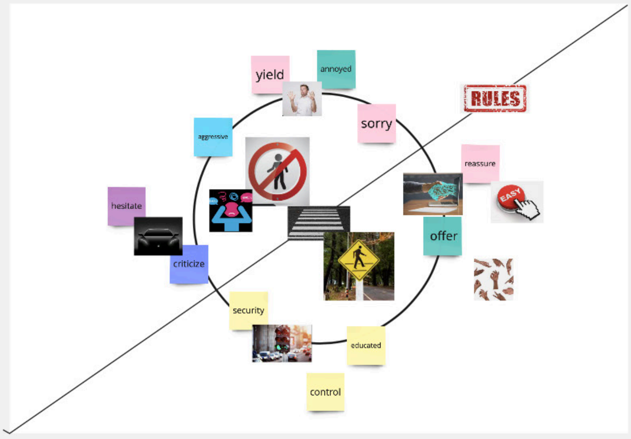
APPENDIX G: GENERATIVE RESEARCH. MIRO RESULTS.

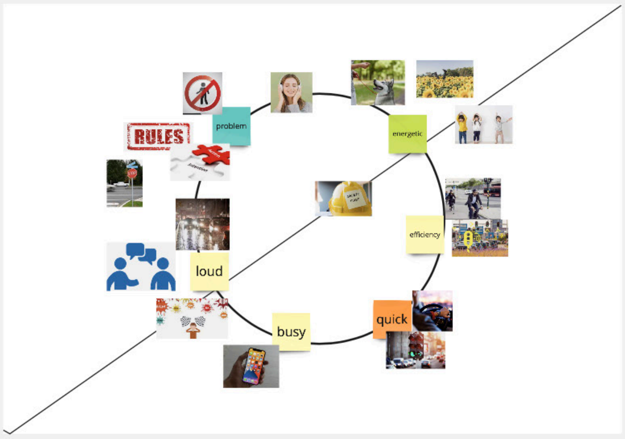
COLLAGES



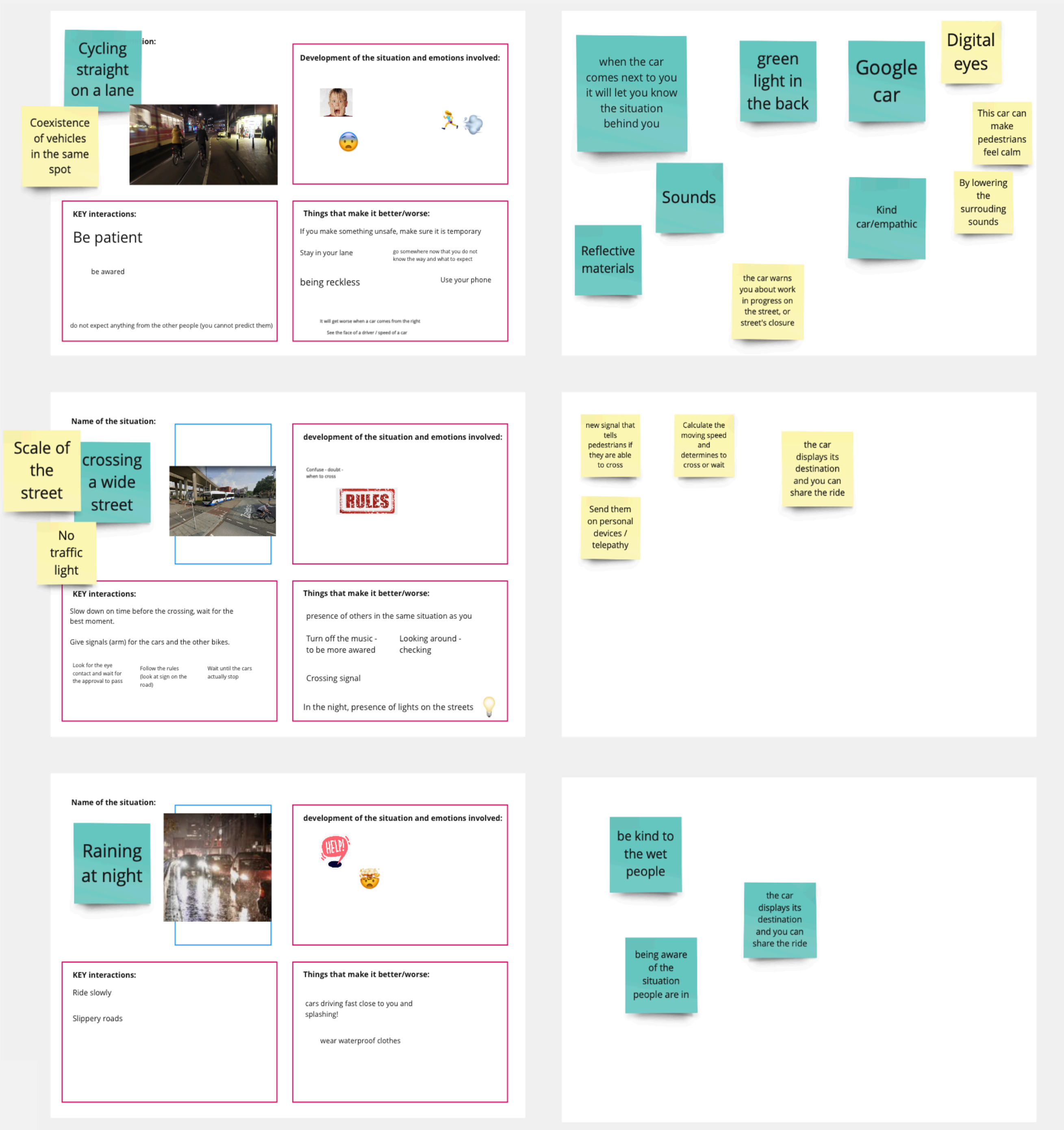




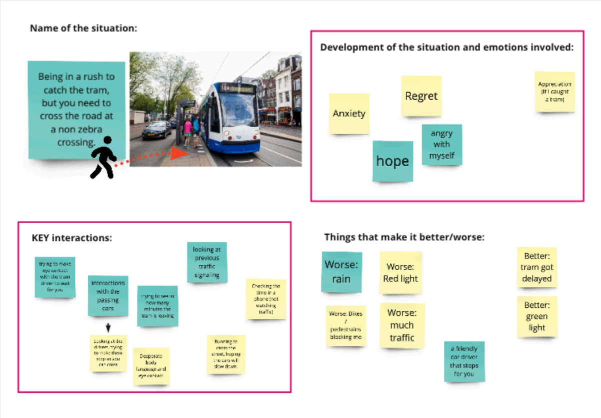


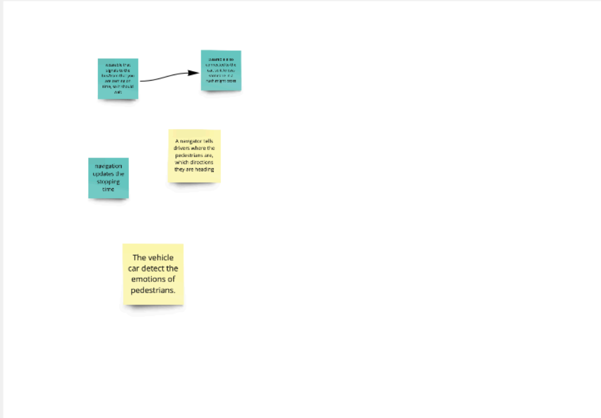


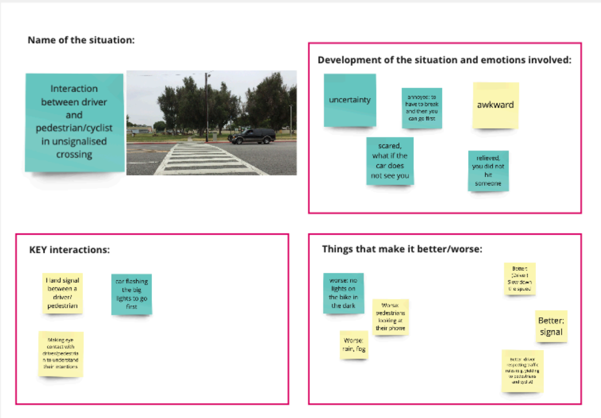
SITUATION FINDING AND BRAINSTORMING SOLUTIONS GROUP 1

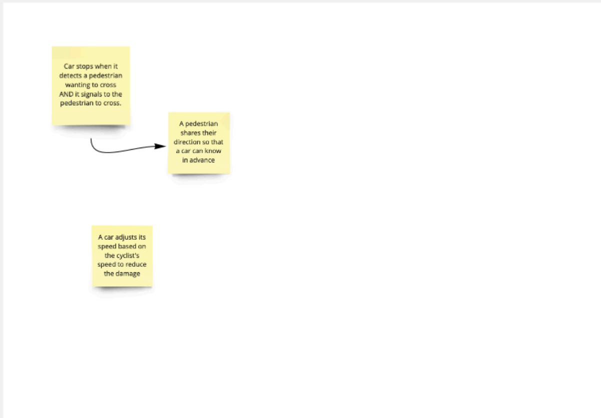


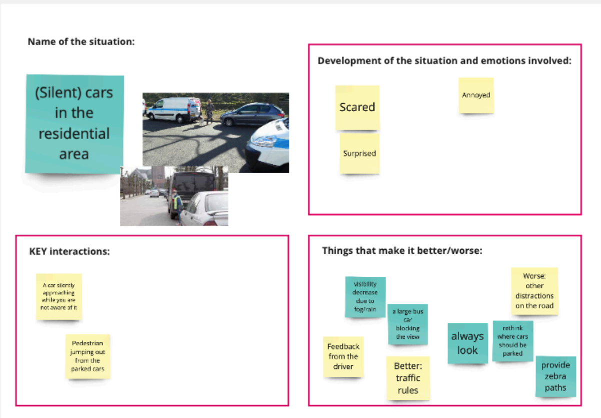
SITUATION FINDING AND BRAINSTORMING SOLUTIONS GROUP 2

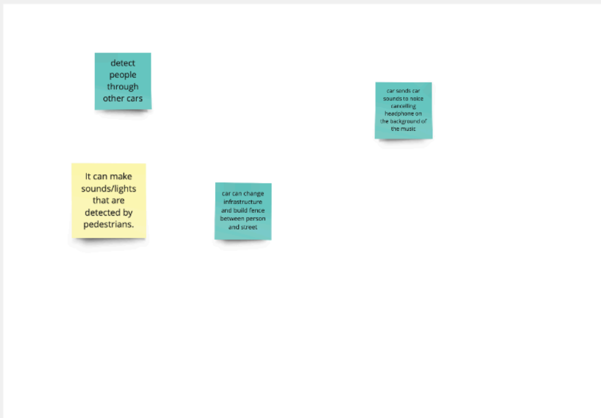




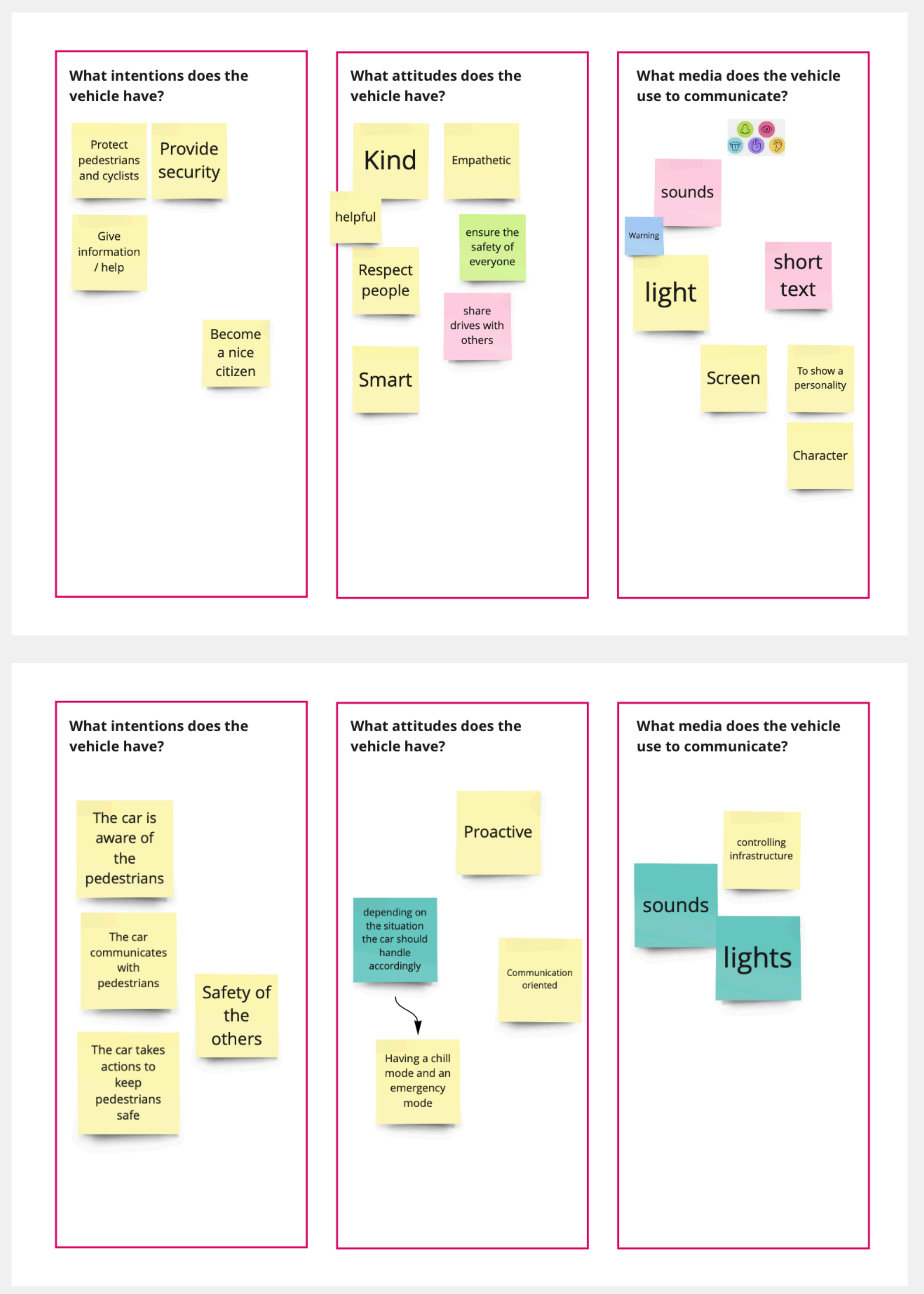








DESIRED VEHICLE ATTITUDES, BRAINSTORMING



APPENDIX I: IDEATION SESSION & RESULTS

SESSION PLAN

0. Welcome and intro

Good afternoon everyone, thanks a lot for being here and participating in this session, in which you will actively participate in my project by giving me ideas on how to design for expressing different attitudes through a number of media.

1. Explaining the problem and energizer.

First of all, I would like to introduce my project so you have a better idea about the problem that we are trying to solve today.

- Explain the project with some slides (5 minutes)
- Show prototyped derived from phase 1, make it clear that is not a final design, but it includes the media that the vehicle can use to communicate (light, sound, and body language).
- Explain the different communication lines and the different attitudes that the car takes.

Now that I have explained a bit of the project, I would like to start a small brainstorming about things that can express these different attitudes, like colors, shapes, move characters, body expressions... anything you can think of, really.
(10 minutes for brainstorming)

3. Brainstorming solutions. Diverging

Well that was good, now on to our next activity, and we are going to start talking about cars now, so I prepared some templates so you don't have to keep drawing cars, don't worry. We're going to do an activity called, the crazy eights. So, I will make a question in the form of How may we...? And you will have 2 minutes to portray each one of your 8 ideas onto the templates (you can use more than one per idea, so no boundaries here). Think of how to solve the question with Light, Sound, and Body language!

How may the car communicate the Intention to stop for someone to cross and the action of waiting for them to cross in a calm/friendly/submissive way?

Now I would like each one of you to present your ideas to the rest.
16 minutes for brainstorming
10 minutes for sharing ideas

How may the car claim its own right of way to prevent being taken advantage of in an assertive/ dominant way?

Now I would like each one of you to present your ideas to the rest.
16 minutes for brainstorming
10 minutes for sharing ideas

How may the car communicate to acyclist that is going to be overtaken?

Now I would like each one of you to present your ideas to the rest.
16 minutes for brainstorming
10 minutes for sharing ideas

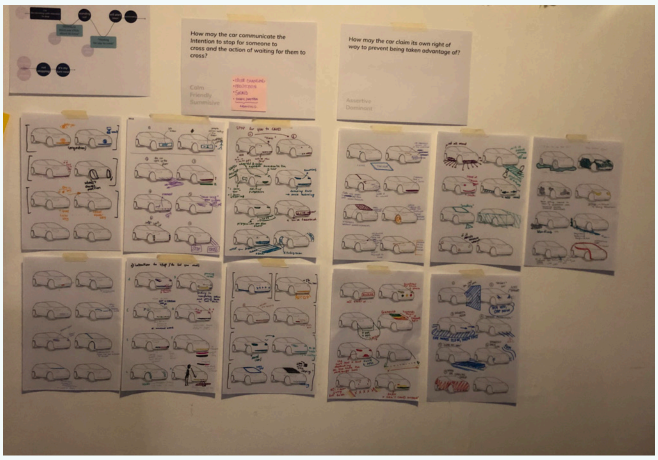
4. Reverging

Now that we have all of our ideas on the wall, we are going to look at them and freely make clusters on how the different ideas relate to each other, putting together both attitudes.
15 minutes for spontaneous clustering

5. Converging

Okay so we have made some more complete designs, now, each one of you has 3 votes to choose the best designs. And then we will have a final discussion about these.

SESSION PICTURES & OUTCOMES



IDEATION SESSION

At the beginning of the conceptualization phase, a creative session was organized with five fellow master students (3 of them from Design for Interaction, 1 from Strategic Product design and 1 architecture student working in the automotive industry) in order to generate a large number of ideas that would fit the design goal. The goal of the creative session was to explore different communication modalities and qualities of the same that would fit all the requirements of the project to inspire and kickstart the iteration design phase.

The session was facilitated by the author of this project and the method used to carry it out refers to a couple of different techniques present in the Delft Design Guide (REFERENCE), such as brainstorming and drawstorming.

The participants were given a small presentation about the project at first to get them in the right mindset and know which were going to be the topics of the session. After explaining the project, a first activity was conducted to introduce the attitudes that the car can take, for this, participants were asked about things that they relate to different attitudes. After this first activity, we moved to brainstorm solutions for the two main questions, together with these, the attitudes linked to them, so they would inspire solutions that would fit not only the communication purposes but also the communication mode.

“ How may the vehicle communicate its intentions and actions in the following moments?”

Giving the right of way to a pedestrian
submissive, gentle, calm

Claiming its right of way
assertive, dominant

Overtaking a cyclist
neutral, gentle

The session plan and the visual outcomes can be found in appendix X. Table X shows the summary of all the different ideas and outcomes that came out in the session.

Use of color
The use of differnt colors that are not yet present in cars could be used to indicate the different attitudes of the car

Green-ish or Blue-ish for the submissive attitude

Red-ish for the dominant attitude.

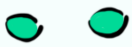
To check wether this would actually help to give an idea of the vehicle's attitude.

Adding human expression
Positioning of the lighting system could create expressiveness by imitating human expression.

Supports expressiveness

"You can go"

"My turn now"



Would there still be room for branding if shapes were to be standard?

Use of sound
Manipulation of engine sound can play a communicative role in AV-VRU interaction, and other sounds could be added to complete information

Engine sound can anticipate actions of the vehicle:

- Engine sound starts a bit before car is going to start driving
- Engine sound reduces a bit before car completely yields

Volume changes when car wants to be noticed by others or be discreet

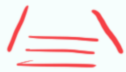
Extra gentle beeping for"waiting" and faster when state changes

Supporting sound signals will enhance visual communication.

Direct & Clear feedback
Forms of very clear feedback through displaying text or symbols. Displayed on the car or projected on the ground

Symbols

Projected



Text

Displayed

This would constitute a very clear way of communicating, but is subjected to language barriers and cultural differences

Your space/My space
Projecting on the ground the "personal" space of the car or VRUs to indicate who has the right of way

My space, I'm starting to drive

My space, I'm stayinh here

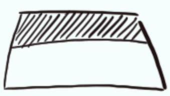
Very clear way of indicating how safe it is to cross for VRUs, but projections are subjected to visibility issues

Windshield / Full car alteration

Altering very visually dominant parts of the car such as windshield of the full car surface to maximize visibility

Full car changes color

Winshield dimming to show sleep/awake mode



Manipulating big portions of the car can increase visibility, but could conflict with light conditions and car styling

Abstract light position & patterns
Focusing on abstract lighting, with minimal shape, to be visible from everywhere (needed) and communicating through patterns and color

This might be the simplest way of conveying messages and some expression of the car

Make car look big or small through light
Stratgically position the lighting system so the visual effect of looking at the car will ake it look bigger to show dominance and small to look submissive

Submissive

Dominant

Could be a good strategy added to the full concept. Might be limiting due to having to add new elements to express only one thing

Use of body language
Humanize car by addign body language to it

Wheels change positioning to indicate "I'm not going to move"

Car can move backwards or forward a little bit to show intention to wait or stard driving.

While we cannot change how cars work mechanically, movement or suspension alteration could work to indicate different states.

Explanations of ideas

Personal reflection on the ideas

APPENDIX J: FILMING SET UP FOR ITERATION PHASES 1 & 2 .

APPENDIX K: CONCEPT EVALUATION PHASE 1. QUESTIONNAIRE AND INTERPRETED RESUTS.

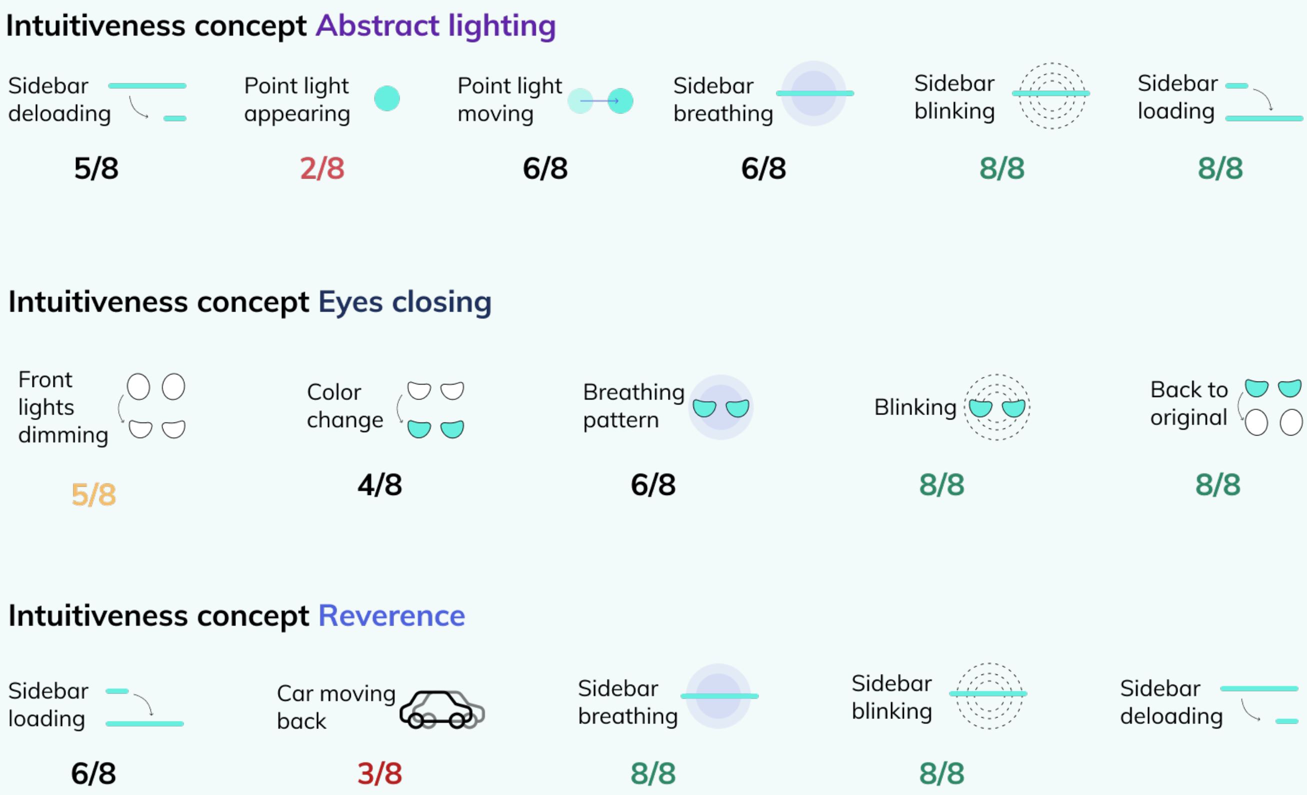
After watching each one of the videos, participants were asked questions in three blocks, the first one corresponding to the evaluation of intuitiveness of the different elements of the concept. Each one of the items was formulated as "The eHMI element doing behavior communicates..." The figure below shows the results, counting how many of the participants understood the message without being guided.

The second block of questions corresponds to the overall concept acceptance, strengths and weaknesses, some open questions were asked, these were:

- What do you think about this concept?
- What do you like about this concept? Why?
- What do you not like about this concept? Why?
- When encountering this vehicle in traffic, when would you decide to cross?

After, a set of Likert Scales were presented to them, while completing the questionnaire, they would speak about the reasons why they answered what they did.

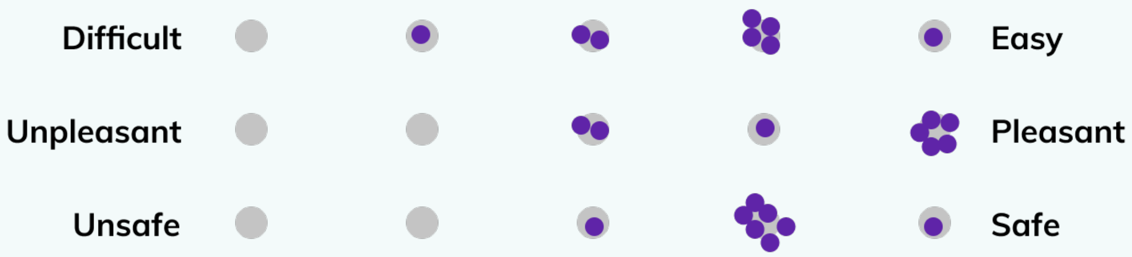
BLOCK 1, INTUITIVENESS



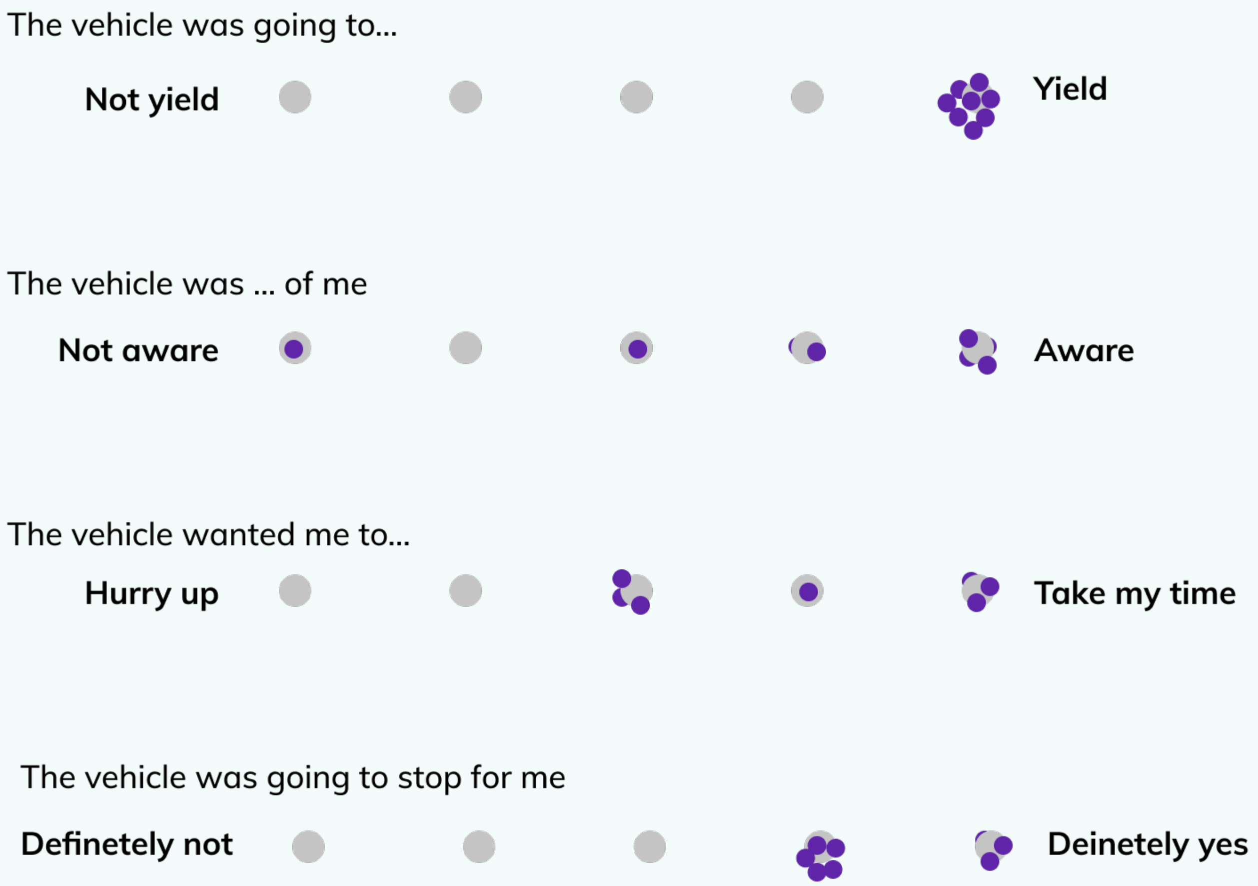
BLOCK 2, OVERALL PERCEPTION, EXPERIENCE, MUTUAL UNDERSTANDING

CONCEPT ABSTRACT LIGHTING

Interaction scales

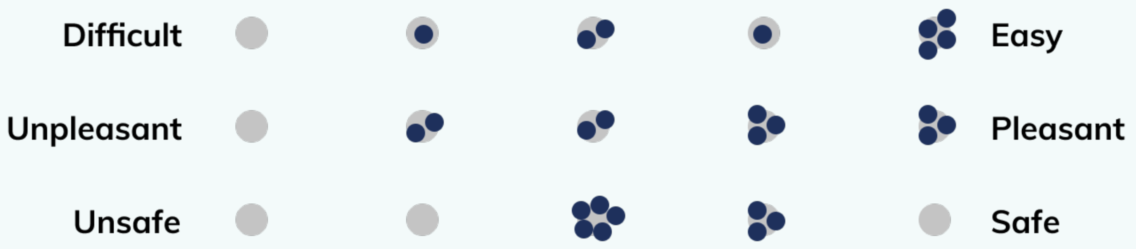


Intent recognition scales



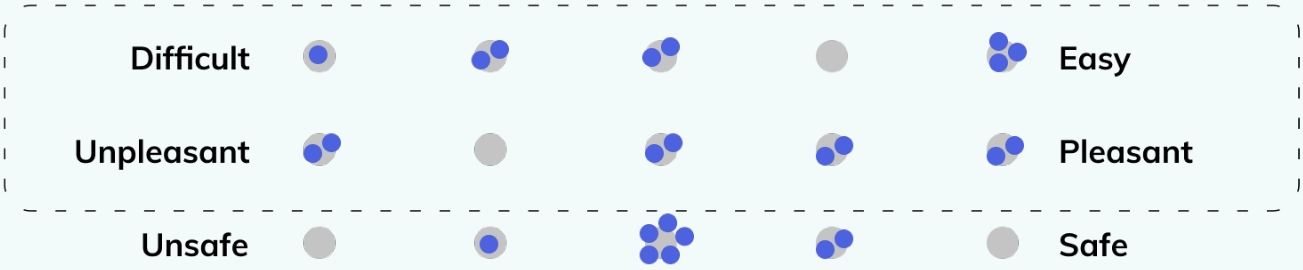
CONCEPT EYES CLOSING

Interaction scales



Intent recognition scales

Interaction scales



Intent recognition scales

BLOCK 3, EMOTIONAL RESPONSE

BLOCK 4, SPATIAL PRESENCE:

Total score: 3,83

APPENDIX L: CONCEPT EVALUATION PHASE 2. QUESTIONNAIRE RESULTS.

OPEN QUESTIONS:

What do you understand from what the car does and communicates?

What do you think about the integration between the visual and auditory information shown by the car?

LIKERS SCALES QUESTIONNAIRE (4 POINT SCALES):

The design of this communication system would prevent me from taking a risky action when interacting with this car

Sound and light systems help me in understanding that I should stop walking/cycling

I think I would be able to perceive the communication from the car from different perspectives

The communication system would make the vehicle stand out in a normal traffic situation

The design of the communication system conveys a dominant attitude from the car

The design of the communication system would be easy to integrate with the design of the first video I say today

ANSWERS PER CONCEPT:

Concept 1

--	-	+	++
			6
			6
	1	2	3
		1	5
	2	1	3
		1	5

Concept 2

--	-	+	++
1		3	2
	3	3	
1		3	2
	2	2	2
3	2	1	
2	1	2	1

Concept 3

--	-	+	++
	1	1	4
	1	1	4
	1	2	3
		3	3
		2	4
	1	2	3

-- Completely disagree
++ Completely agree

SPATIAL PRESENCE: Total score: 3,5

APPENDIX M: FINAL CONCEPT EVALUATION QUESTIONNAIRES

WELCOME MESSAGE

Welcome to this user test that will culminate my graduation project by evaluating this design. Today we are talking about the future of urban traffic and how you imagine the interaction with automated vehicles to be as a vulnerable road user. This means, you, as a pedestrian or cyclist, will interact with automated vehicles in the street as you do now with human-driven vehicles.
During the test, you will be shown a set of videos portraying real traffic scenarios, keep in mind that the vehicle you will be seeing, is an automated vehicle, therefore, there is not a driver holding the steering wheel. In the videos you will see the scene as you would in a real scenario. so take the point of view from the camera to be your own sight.

Remember that:

1. Your opinion is always very valid and we are here to evaluate the designs, not your answers.
2. You can ask me anything at any time if you have a question regarding anything in the test.
Let's go!

· *The next questions will all be asked before the start of the test.*

DEMOGRAPHIC QUESTIONS:

- How old are you: (Number Input)
- What is your gender (male, female, neither, I prefer not to say)
- To what extent would you say you trust automated vehicles? (7 point scale between 1-I don't trust them at all, to 7-I really trust automated vehicles)

· *The next question groups will all be asked after each video has been displayed.*

GEQ GENERAL EXPERIENCE QUESTIONNAIRE (AFTER EACH VIDEO - 7 POINT SCALES):

Being in the situation shown in the video...

- I would feel safe in the interaction with the vehicle I saw in the videos (definitely not/definitely yes)
- I would understand the intentions of the vehicle (definitely not/definitely yes)
- I would understand what the vehicle is perceiving (definitely not/definitely yes)
- I would know what is expected from me as an X in the interaction with the vehicle (definitely not/definitely yes)

VIQ VEHICLE INTENT QUESTIONNAIRE (SPECIFIC PER SITUATION, USED AFTER BASELINE AND EHMI VIDEOS- 7 POINT SCALES) :

Specific for situation A (car gives the right of way to a pedestrian, videos S1N & S1Y):

Being in the situation shown in the video...

- I would have felt the vehicle was aware of my presence (completely disagree, completely agree)
- I would have understood that the vehicle was going to stop to let me cross the street (completely disagree, completely agree)
- When looking at the vehicle, I would have been inclined to continue walking (completely disagree, completely agree)
- When I started crossing, I would have understood the vehicle wanted me to take my time (completely disagree, completely agree)

Specific for situation B (Car claims right of way, videos S2N & S2Y):

Being in the situation shown in the video...

- I would have felt the vehicle was aware of my presence (completely disagree, completely agree)
- I would have understood the car was not going to stop for me to cross the street (completely disagree, completely agree)
- When looking at the vehicle, I would have been inclined to stop walking (completely disagree, completely agree)

Specific for situation C (overtaking a cyclist, videos S3N & S3Y):

Being in the situation shown in the video...

- I would have felt the car was aware of my presence (completely disagree, completely agree)
- I would have been aware that the car was going to pass me (completely disagree, completely agree)
- I would have been inclined to continue cycling (completely disagree, completely agree)

· The next question groups will all be asked after all videos have been displayed and all previous questionnaires answered.

- After watching the different videos presented, to what extent would you say you would trust automated vehicles now? (7 point scale between 1-I don't trust them at all, to 7-I really trust automated vehicles)

OQ OPEN QUESTIONS INTERVIEW WITH SUPPORTING IMAGES (SCREENSHOTS FROM THE VIDEOS TO GIVE VISUAL MATERIAL, IMAGE VISUAL OQ):

- In the scenarios that you saw in the videos, what is your impression of the way the car communicates in the presence of the light system?
- Considering the scenarios that you saw in the videos, would the presence of the light system affect the way you behave as a pedestrian or cyclist? In which situation(s)? Why?
- Is there any element of the light system that you think was unclear? Which one(s)? Why?
- Is there any element of the light system that you especially liked when watching the videos? Why?

SUS SYSTEM USABILITY SCALE QUESTIONNAIRE (AT THE END OF THE TEST- 5 POINT SCALES)
- I think that I would like to use this system frequently
- I would find such a system unnecessarily complex
- I would think the system was easy to use
- I think that I would need the support of a technical person to be able to use the system
- I would find the various functions in this system to be well-integrated
- I would think there was too much inconsistency in the system
- I would imagine that most people would learn to use the system very quickly
- I would find the system very inconvenient to use
- I would feel very confident using the system
- I would need to learn a lot of things before I could get going with this system

SP SPATIAL PRESENCE QUESTIONNAIRE (AT THE END OF THE TEST- 5 POINT SCALES)
- I felt like I was a part of the environment in the videos.
- I felt like I was actually there in the environment of the videos.

- I felt like the objects in the videos surrounded me.
- It was as though my true location had shifted into the environment in the videos.
- I felt as though I was physically present in the environment of the videos.
- It seemed as though I actually took part in the action of the videos.

END MESSAGE:
Thank you so much for your participation in this user test, everything you rated and said today is of most value to me and the project.