Designing predictable behaviour for autonomous delivery vehicles

Master thesis
Design for Interaction

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Preface

Dear reader,

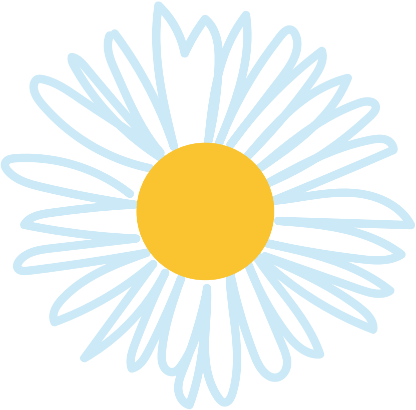
This thesis embodies the dedication and commitment I have put into this project over the past few months. My journey into this topic has been both enriching and rewarding. I take great pride in the thesis that stands before you, and my aspiration is that you find the read to be enriching and rewarding as well. But before you dive in, I'd like to express gratitude to a few individuals who have contributed significantly to the creation of this thesis.

First I would like to thank Nicole, Jered and Jacky for their time, constructive feedback, and illuminating discussions that have enriched this project. Without your expertise and guidance this thesis would not have reached the quality it has now.

I want to thank everyone who participated in one of my tests, without you I would not have been able to draw such enlightening conclusions. A special thanks to my friends and roommates for your listening ears and support. Céline, Charlotte and Xavière for all the coffee and lunch breaks, the great advice and the overall fun throughout the entirety of my thesis. Thanks to my family for their words of praise and especially to Jaïr and Peter for providing me with valuable feedback. And lastly I want to thank Toby for his words of encouragements, for lending me a helping hand when needed and for celebrating every milestone.

Enjoy!

Noa



Executive summary

Technology developments are making it possible to start using alternative ways to transport package in the last mile delivery market. One of these alternative, more sustainable ways is by introducing autonomous delivery vehicles (ADVs), which are small ground vehicles that drive on the pavement and are able to drive without human intervention. The ADVs will be driving in pedestrian rich environments which still appears to be a challenge. The goal of this project is to design a concept of an autonomous delivery vehicle that portrays predictable behaviour for pedestrians.

Literature research, interviews and observational studies showed that the current ADV struggle with interaction problems, such as distrust and unpredictable driving behaviour. Predictable behaviour is the core for on-road communication and without it people are unable to anticipate on each other which can lead to unsafe traffic interactions. A means to solve unpredictable behaviour is to clearly communicate the driving intent of the ADV.

Literature research and pedestrian observations lead to an understanding of how intent is communicated in pedestrian rich environments. Different intent signals have been identified, which are mainly communicated through body language. The goal is to simulate a human-like signal to make the ADV communicate its intent. By doing so we ensure an intuitive understanding of the signals since pedestrians will recognise the signal from previous traffic situations. Therefore, the decision has been made to focus the project on designing predictable behaviour by communicating intent through body language.

In an extensive exploration phase multiple prototypes were tested that embodied different human-like intent signals. Through various iterations insights were gathered and the most promising signal was determined. It became apparent that a simple cardboard box could convey an intent because of anthropomorphism. Participants attributed human-like features to the box. Therefore, they perceived the prototype as an alive player in the traffic environment. Anthropomorphism proved to be an advantage as well as a disadvantage. Certain signal movements the prototype used reminded people of signals that humans use in traffic. However, that movement therefore conveyed a different intent than it was supposed to.

The most promising intent signal, the Looking scenario, is based on a head turning into- or someone looking into their desired walking direction. Participants mentioned that they recognised the movement from past traffic experiences. Therefore, they were able to intuitively understand the signal and anticipate on the driving behaviour of the ADV, since they were able to predict its future movements. The evaluation test shows great promise for the intent signal. Participants mentioned an increase in feelings of safety, trust and comfortability in and with the ADV when it communicated its intent in comparison to when it did not communicate intent. These increased feelings fo safety, trust and comfortability came from the fact that they were able to predict the movements of the ADV and because they felt "seen". The robot reacted to the participants by showing its intent, this reaction gave participants the perception that the ADV has indeed detected them and therefore won't collide with them.

Three design guidelines were created to encapsulate all the insights gathered from the test exploration phase, whilst also providing the opportunity to use these design guidelines in a broader research field. The three design guidelines are based on the interpretation, visibility and relevance of intent signals in general. The conceptual design is rooted in these three principles, complemented by the knowledge on existing ADV designs. The intent signal in the design concept of the ADV makes their behaviour more predictable, gives people a sense of control because they feel detected, which both leads to an increase in safety, trust, and comfortability. Although the intent signal shows great promise in creating a safer and more comfortable traffic interaction between ADVs and pedestrians, additional research is needed to fully understand the impact of integrating this intent signal.

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1. Introduction

Context

The online market of home delivered packages has been growing for years and reached its peak during COVID-19, when 654 million packages were delivered to a Dutch address in 2021 (ACM, 2021). After COVID-19 there was a slight decrease in this last-mile delivery market but the market stayed large. More than 85% of the people in the Netherlands have ordered something online in 2022 (CBS, 2022), and this doesn't only apply to the Netherlands. According to E-Commerce Europe (2022), 75% of the Europeans bought physical goods online in 2022. The last-mile delivery market is still very large and this is not expected to change soon.

Last-mile delivery refers to the last step of the delivery process, aimed at delivering the products from the distribution centre to the final consumer (Lim et al., 2018). According to researchers of the university Politècnica de Catalunya in Barcelona, it's estimated that last mile delivery accounts for more than 20% of pollution in cities (Alcalde & Rennolds, 2022). Therefore, it is interesting and important to look into alternative-, and less polluting ways of transporting these packages.

One alternative way is to introduce Autonomous Delivery Vehicles (ADVs). ADVs are electric and self-driving ground vehicles, which drive on pavements and cross the street, with a limited speed of 5-10 km/h (Marsden et al., 2018 cited in Kapser et al., 2021). They have the capability to deliver parcels, groceries, or food directly to consumers. ADVs are equipped with various sensors, cameras and GPS tracking for safety and security reasons (Kapser et al., 2021) and ultimately they're able to manage all driving tasks without any human intervention in a mixed traffic environment. However, ADVs are currently still driving in closed off environments (e.g. a university campus), because this mixed traffic-environment has its challenges.

Challenge

ADVs mainly drive on the pavement and will primarily interact with pedestrians. Currently, pedestrians don't have any experience with ADVs, which makes predicting the robots behaviour even more difficult, which can lead to an uncomfortable feeling and unsafe traffic interactions (Gehrke et al., 2023). This unpredictability has its foundation in the way pedestrians communicate in traffic. This communication consists mostly of non-verbal (or textual) communication like eye-gaze (connection), pre-sorting (movement), or changing posture (body-language/hierarchical-status). This behaviour provides feedback through communicating their intent which makes it easier for other pedestrians to predict and anticipate (Petersen & DeLucia, 2022). The current ADVs do not have a non-verbal communication technique, which can be confusing for pedestrians and makes it difficult to anticipate on the ADVs driving behaviour (Kruse et al., 2014).

Considering that current pedestrian-traffic is mostly based on non-verbal communication techniques and that pedestrians rely on the ability to anticipate, it is important that the ADVs portrait predictable behaviour to ensure a safe embedding in pedestrian rich environments. The project challenge lies in simulating the non-verbal communication of people in a robots embodiment.

Assignment and Approach

The assignment is formulated as follows:

"Research and design a solution to address the unpredictable behaviour of delivery robots, which is causing safety concerns for pedestrians. The solution will involve creating a better understanding of traffic communication and, by letting the robot simulate this, achieve intuitively understandable behaviour from the ADV to the pedestrians."

The thesis is divided into two main phases, which represent the two diamonds of the Double Diamond Design Process (DDDP): the Research phase and the Design phase. The Double Diamond process is explained on the following page and contains the phases: discover, define, develop and deliver. The reason for choosing this process is because I did not start with any prior knowledge or a clear problem. Therefore, the diverging and converging process of the first diamond will help me pinpoint the most significant interaction problems to centre the design phase on. I also have the tendency to focus on a single solution and the diverging of the second diamond will help with exploring multiple design directions.

During the Research phase literature will be reviewed and the context of ADVs will be explored to understand where the pain points and opportunities lie in the interaction between people and ADVs. To be able to identify these points we first have to know how ADVs currently behave in traffic and how communication is embedded in pedestrian culture. Therefore, the research phase includes: an analysis of how current ADVs behave in traffic and which communication means they employ, pedestrian behaviour and communication in traffic, social navigation methods, observational studies on pedestrian behaviour. This is all part of the discovery phase, after which the define phase includes theories on how to translate these findings into improved ADV behaviour, by presenting communication guidelines for future ADV designs. This phase is concluded in the Design Goal, which marks the transition from the Research phase to the Design phase.

The Design phase includes a test exploration which contains of multiple prototype iterations while following the RITE method. This is part of the developing phase of the DDDP and this phase is concluded into design criteria for the evaluation prototype. The evaluation test marks the beginning of the Design proposal and forms the foundation for the Design guidelines, which is all part of the final stage of the DDDP: deliver. After the design concept is presented, the project will conclude with a discussion that contains the limitations and recommendations of the research.

2. Double Diamond Design Process

The Double Diamond Design Process is a methodology developed by the British Design Council in 2005. It was produced as “a simple graphical way of describing the design process” (Gustafsson, 2019). The Design Council (n.d.) explains that the two diamonds represent a process of exploring an issue (divergent thinking) and then taking focused action (convergent thinking). The method consists of four phases: Discover, Define, Develop and Deliver (see figure 1).

Discover

The Discovery phase explores the context and aims to understand the problem. It involves interviews with experts and immersing into the context through i.e. observational studies. This phase will help me with gaining knowledge in the field of mobility and pedestrian behaviour, and will help with identifying interaction problems.

Define

In the Define phase all these insights are focused towards identified problems and opportunities. This includes pinpointing the current most significant problem areas and finding opportunities to solve them. Additionally, it includes an overview of communication guidelines that future ADV designs can use to ensure a good integration of ADVs within the pedestrian environment.

Develop

The Develop phase starts after the first diamond is concluded in a Design Goal and the overall Design Phase begins. This phase is focused on finding different solutions to the identified problem, which will help with broadly exploring multiple solution areas. This is accomplished by creating various prototypes, testing them, and then revising and iterating on the design to create a new prototype. This prototyping and developing phase is done through the use of the RITE method which will be explained at the beginning of the Design phase.

Deliver

The last phase involves rejecting the prototypes/ideas that don’t work and improving the ones that do. This phase involves building an evaluation prototype based on all the insights from the Develop phase and creating the design proposal. This will help with killing my darlings and focussing on the most promising outcomes.

The Double Diamond method proves very valuable for this thesis because the problem still had to be identified. Additionally, it allowed for a more efficient approach to addressing the design challenge through rapid prototyping and enhancing a user-friendly design.

The structure of this thesis is based on the structure of the Double Diamond Design Process and the different phases are indicated by the images below throughout the thesis.

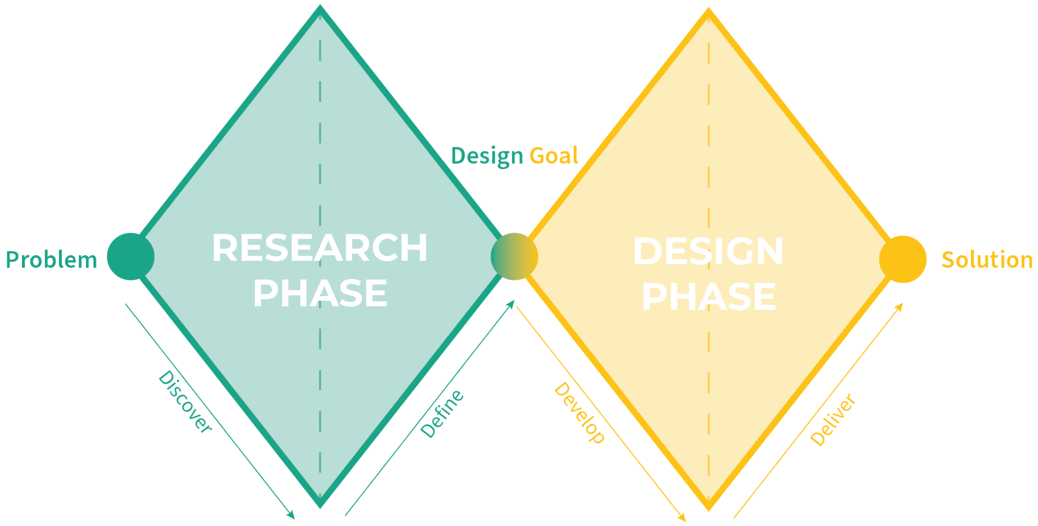
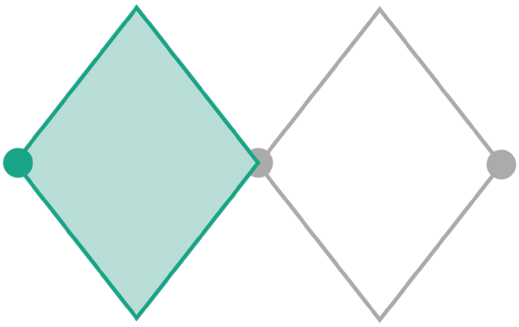


Figure 1, Double Diamond Design Process method.



Research phase

The Research phase resembles the first diamond of the Double Diamond Design Process. It examines various ADV types, exploring their communication methods, studying their behaviour patterns, pinpointing their problem areas, and establishing an interesting solution space. Subsequently, the Pedestrian behaviour chapter focusses on understanding the complexities of how pedestrians behave in traffic, and what signals pedestrians use to communicate with each other. The insights from both chapters will be concluded into the communication guidelines, which will discuss what the exact needs for communication are.

3. ADV interactions

To achieve the aim of making the behaviour of Autonomous Delivery Vehicles (ADVs) less unpredictable, an understanding has to be created on the behaviour patterns of current ADVs. Therefore, this chapter will examine various types of existing ADVs and explore their communication methods. Subsequently, the chapter converges to identify the primary challenges and problem areas associated with the existing ADVs, and proposes guidelines for enhancing the communication capabilities of future ADVs. Following this, the chapter once again diverges by investigating pedestrian behaviour through multiple observational studies. These studies complement existing literature and provide novel insights into how ADVs can communicate more effectively with people. The findings and insights from this chapter are concluded in the next phase: the Design Goal.

Current ADV behaviour

In order to accomplish the objective of reducing the unpredictability of Autonomous Delivery Vehicles (ADVs) behaviour, it is essential to develop an understanding of the behaviour patterns exhibited by existing ADVs. Therefore, existing ADVs will be examined to identify their behavioural patterns. The following section will discuss the methods used to gain more knowledge on the existing behaviour of ADVs and the next section will contain the most significant identified problems of existing ADVs.

Driving behaviour of ADVs - Method

Unfortunately, ADVs such as the Starship Technologies, Serve Robotics and Kiwibot are mostly deployed in America, which made it more difficult to experience the ADVs first hand. Nonetheless, alternative sources such as social media, literature, and insights from interviews with experts have proven to be valuable substitutes. Therefore, the analysis on the driving behaviour of current ADVs consists of four parts: analysing online video footage, reviewing literature, an observational study, and expert interviews.

Online video footage

Thanks to social media it is easy to find video footage of ADVs that are driving around i.e. campuses in the USA. There are many videos on i.e. YouTube of people vandalising/teasing the robots or helping the robots get unstuck (see figure 3 on the next page for examples of these YouTube videos). Companies like Starship Technologies, Kiwibot and Serve Robotics also have their own YouTube accounts where they explain and show-off their product.

Reviewing literature

Extensive research has been conducted on autonomous delivery vehicles and additionally on automated vehicles in general. The used references can be found in *Driving behaviour of ADVs - Results.*

Observational study

To experience the interaction between ADVs and pedestrians first hand I borrowed a robot (the Jackal robot of Clearpath Robots, see figure 2) and drove around with it for a day. I had to stay close to the robot, resulting in diminishing the autonomous illusion, but it still provided insights in how ADVs are perceived.

Figure 2, the Jackal robot of Clearpath Robotics (Clearpath Robotics).

Expert interviews

In order to gain insights into the latest developments within the field of autonomous vehicles, I conducted interviews with three people in this area of expertise.

Diane Cleij // SWOV // Expert human factors in vehicle automation

Ilse van Zeumeren // The Future Mobility Network // Expert human behaviour change within mobility

Joost de Winter // Technical University Delft // Expert cognitive Human-Machine Interaction

After analysing multiple videos of ADVs, reviewing literature, an observational study, and interviews I identified the main challenges of integrating autonomous delivery vehicles in traffic. I categorised the identified problems into two themes: **interaction problems** and **technical problems**, a schematic overview of the identified problems can be found in figure 4 on the following page.

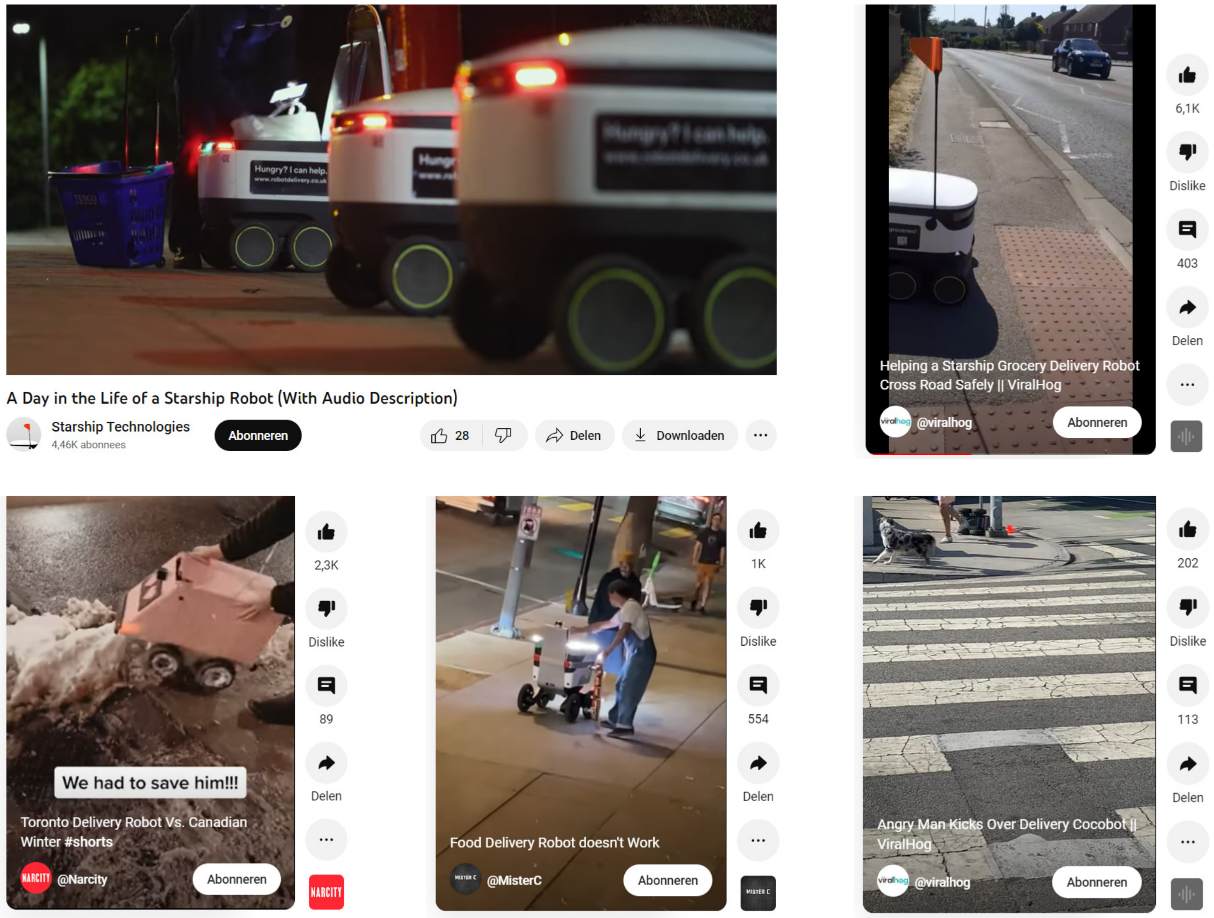


Figure 3, videos of interactions with different delivery robots on social media.

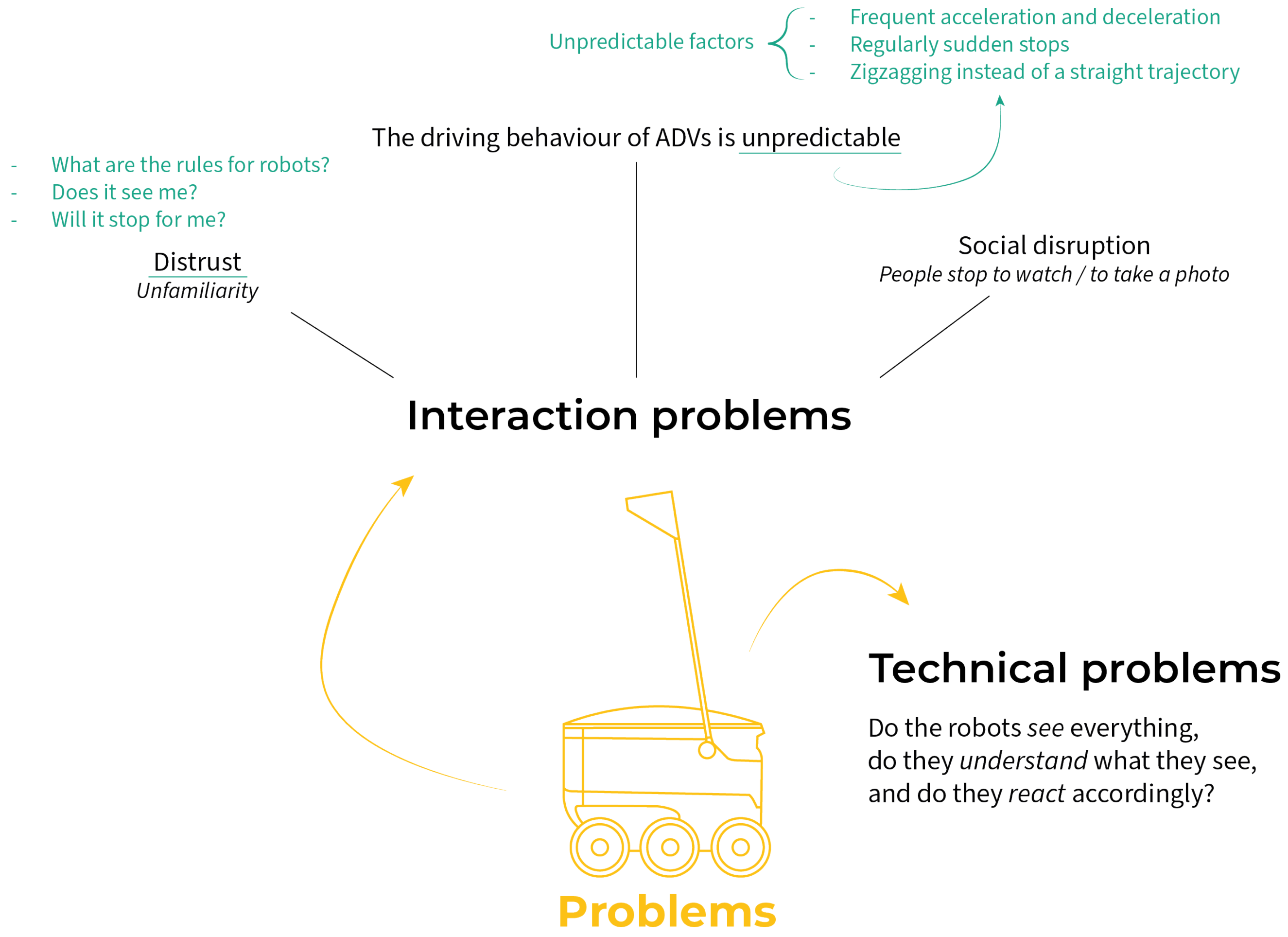


Figure 4, schematic overview of the main identified problems of current ADVs.
The Starship Technologies robot is used as a visual representation of all ADVs, this research is not solely based on the Starship Technologies delivery robot.

Driving behaviour of ADVs - Results

Interaction problems

Data on the driving behaviour of ADVs is collected through literature, social media, observations and expert interviews. Three interaction problems were identified and will be discussed in the following sections. The three interaction problems are distrust, unpredictable driving behaviour and social disruption.

Distrust: literature shows that people are still uncomfortable with autonomous vehicles because there is no trust in the system (Bezai et al., 2021; Joiner, 2018; Winter et al., 2018). Distrust is correlated with unfamiliarity (Singla, 2015), which also became apparent during the expert interviews. ADVs raise questions such as “Does it see me?”, “Will it stop for me?” and “What are the traffic rules for the ADV?” Hence, there is a problem concerning the distrust in- and the unfamiliarity with the technology of ADVs. Literature supports that the current trust of AVs (Automated Vehicles) is low because of *capability concerns*, desire for a *sense of control* (Lee & Kolodge, 2020), and the need for *system transparency* (Choi & Ji, 2015). The distrust and unfamiliarity in the technology results in making people uncomfortable with sharing their pedestrian environment with autonomous vehicles. Nonetheless, Domeyer et al. (2020) state that the level of trust can be enhanced by improving on-road communication, which will additionally results in a higher acceptance rate.

Unpredictable driving behaviour: there are still several challenges when observing the current driving behaviour of the ADVs. Overall the driving of the ADV lacks smoothness, primarily due to frequent acceleration and deceleration, sudden stops, and zigzagging instead of maintaining a straight trajectory. These factors combined contribute to the unpredictable behaviour of the ADV. The problem with unpredictable driving behaviour in traffic is that this makes it difficult for people to anticipate on it. Domeyer et al. (2020) highlight the importance of behaviour: “Behaviour is the basis, and a critical component, for on-road communication”. And according to Diane Cleij (SWOV // Expert human factors in vehicle automation): “People drive mostly on anticipation and robots much more on reactions”. Therefore, unpredictable behaviour can communicate wrong intentions, which makes it difficult for people to anticipate, which can cause dangerous traffic situations. That being the case, it is important to ensure that ADVs communicate their intent correctly, through predictable behaviour, for a safe traffic implementation.

Social disruption: when looking at video footage and driving around with a robot you notice that the robot disrupts the social environment. The sound of the ADV initially draws the attention. This is not necessarily a bad thing, since the sound alerts pedestrians of the presence of the ADV. When noticing the robot, people often stop what they’re doing and watch- or take pictures of the ADV. It is expected that over time people will get used to the presence of the ADVs and that this disruption will decline. Therefore this disruption will become less significant over time.

Technical problems

The technology of ADVs is evolving and becoming more accurate and independent, but there are still challenges when implementing them in social environments. These challenges can be divided into three phases:

- Does the robot detect everything?
- Does the robot understand what it detects?
- Does the robot act appropriate and accordingly to the situation?

The ability of the ADV to perceive and detect its surroundings is only the first step. Beyond that, it must be able to understand the information it receives, be able to predict future movements of other traffic participants, and respond appropriately and adjust its behaviour accordingly.

The goal of this research is to determine interaction pain-points which can be solved by redesigning the current ADVs. Therefore the technical detection issues won’t be the focus of this project.

Current ADV behaviour conclusion

To be able to design an ADV that can safely and smoothly be embedded into the pedestrian environment, the current problem areas have to be solved. Before you can solve problems, you have to identify them, which is what the previous sections have accomplished. Two problem areas were identified: interaction problems and technical problems. To ensure this smooth embedding of ADVs within the pedestrian context it is important to look at the interaction problems that current ADVs are facing. Therefore, the technical problems won't be the focus of this project.

There were two significant interaction problems identified: distrust and unpredictable behaviour. Literature suggests that better communication can enhance the level of trust (Domeyer et al., 2020) through system transparency and by giving pedestrians a sense of control (Choi & Ji, 2015; Lee & Kolodge, 2020). Furthermore, does predictable behaviour form the basis of on-road communication (Domeyer et al., 2020). Therefore, portraying predictable behaviour is an essential aspect of ensuring seamless traffic communication. Additionally, will predictable behaviour and good communication solve both interaction problems of current ADVs. To let the ADV portrait more predictable behaviour it has to clearly communicate its intent to make it easier for other traffic participants to anticipate on its movements (Petersen & DeLucia, 2020).

To conclude, communication can serve as a solution to solve both the unpredictable behaviour of the ADVs as the distrust people have in the technology of ADVs, while facilitating a smoother integration of ADVs into society since more trust leads to a higher acceptance rate (Domeyer et al., 2020; De Groot, 2019). To design an innovative ADV design that communicates well with its surroundings, it is important to look at competitors. Therefore, the next sections will focus on examining existing ADVs and analysing their communication means.

Different types of ADVs

Numerous Autonomous Delivery Vehicles (ADVs) are currently being developed and deployed on the roads. To be able to design more predictable behaviour for future ADVs it is important to understand the interaction and communication techniques of existing ADVs. Analysing these techniques used by ADVs can offer valuable insights into which interaction means are generally used, which means cause problems, and which means have potential for improvement.

Starting with the Starship Technologies delivery robot (figure 5). De Groot (2019) did a study where participants had to rank nine different ADVs based on appearance, and the Starship Technology delivery robot was ranked the highest. Hence, this delivery robot is selected to visually represent ADVs throughout the entirety of this thesis.

Figure 5, Starship Technologies delivery robot (Starship Technologies, n.d.).

Starship Technologies has thousands of delivery robots operating globally everyday (Starship Technologies, n.d.) and they claim to be the global leader in autonomous delivery. There are multiple online videos of customers rating their services, recording them driving around or videoing their malfunctions (and helping the ADV or not).

The Starship Technologies ADV makes use of the following interaction/communication means (Starship Technologies, 2022; Starship Technologies n.d.):

- Light interaction: it has white headlights on the front at the bottom and a red tail light on the back on top. Both are always on. In between the red tail light there is a green light that indicates where you can open the lid. The orange flag also has little lights in it to make the robot more visible. And on the side of the wheels is a reflective yellow line to enable visibility in the dark.
- Verbal communication: it says “Thank you” after you help it get unstuck, “Have a nice day” after delivering your food and even “Excuse me, would you please let me pass?” when someone is blocking its path.
- Sound interaction: it has a build-in alarm that goes off when someone tries to lift-, tamper with- or take the ADV.

The verbal communication is focussed on politeness and the sound interaction is focussed on security. Only the light interaction is focussed on communicating useful information for traffic situations (e.g. braking), but even this is mostly focussed on visibility (e.g. lights in the flag, head lights).

There are multiple ADVs that used similar interaction means as the Starship Technologies delivery robot, such as the Amazon Scout delivery robot (figure 6) and the Marble delivery robot (figure 7) (Keesmaat, 2020). Unfortunately the Amazon scout robot programme has been cut back (Soper & Day, 2022) and Marble Robot, Inc. has been bought by Caterpillar, who bought the company for the knowledge of its employees (Caterpillar, 2020). Therefore there is not much information that can currently be found about the status of both ADVs, most likely because of the termination of both programmes.

According to Keesmaat (2020), the Marble delivery robot (figure 7) had one feature that the Starship robot doesn’t have: it would clearly turn its front wheels to indicate in which direction it would move into.

Figure 6, Amazon Scout (Scott, 2019).

Figure 7, Marble delivery robot (Marble).

Despite the negative growth of the Marble delivery robot and the Amazon Scout, are there also ADV companies that are still growing. One of those companies is the Colombian start-up Kiwibot (RTN, 2023).

The Kiwibot (figure 8) also has head and tail lights and additionally has a screen interface which displays eyes. The eyes blink, wink and simulate the robots emotions such as happy or sad. When a pedestrian blocks the road, the eyes of the Kiwibot turn into X's and when delivering the food its eyes turn into little hearts (Kiwibot, 2017). The screens are mainly for appearance and 'greeting' purposes and it might have a positive impact on declining the amount of vandalism/teasing, because of its 'cute' appearance. However the screen doesn't help in (unclear) traffic interactions.

Figure 8, Kiwibot (Kiwibot).

The Serve Robotics (figure 9) also has head and tail lights and a screen interface that shows its eyes. The eyes serve the same purpose as that of the Kiwibot and it has the same feature as the Marble delivery robot in the sense that the front wheels clearly turn to indicate its driving direction (Serve Robotics, n.d.). The company also expended their partnership with Uber Eats which means there will be up to 2000 of the Serve Robotics ADVs driving across the USA (Bellan, 2023).

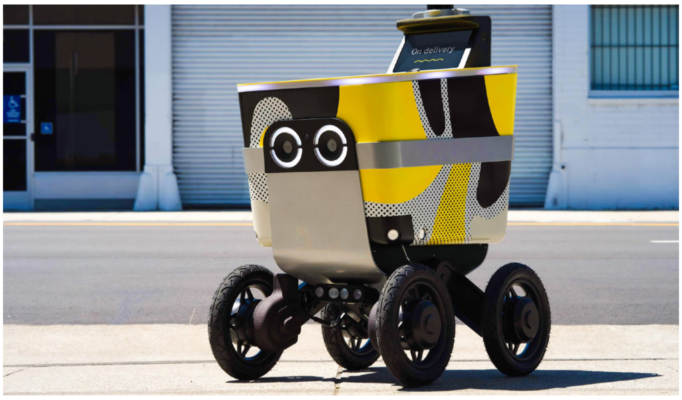


Figure 9, Serve Robotics delivery robot (Serve Robotics).

The DeliRo (figure 10) is a delivery robot stationed in Japan and it has mostly the same functions as the Kiwibot, however it also interacts via verbal communication. The robot says e.g. "Excuse me, coming through" (the Japan News, 2023), "Hi!" and "Turning left" (ZeroMomentPoint, 2019) while driving. The DeliRo is more social than the other ADVs which might be more preferable in the Japanese culture, however this could intervene with the goal of the ADV. The goal is to deliver goods efficiently and safe and limit social disruption. Therefore making the robot very approachable can have a downside, e.g. the Japan News (2023) mentioned that kids love playing with the DeliRo, which can cause longer delivery times.

Figure 10, DeliRo (ZeroPointMoment, 2019).

To summarize, the current ADVs mainly interact with other traffic participants through lights. Other interaction means that are used are: verbal communication (e.g. asking for help or to socialise), sounds (alarms that go off when in danger), and vehicle movement (e.g. clearly turning the front wheels), but these are mainly used in extreme situations.

The interaction design of the current ADVs is clearly inspired by cars (head- and tail lights, brake lights, overall shape), while the ADVs drive on the sidewalk. Therefore, their most encountered traffic participant are pedestrians. To ensure a comfortable and safe embedding of ADVs in traffic, it is important to look into ways to enhance the integration of the interaction means of ADVs within the pedestrian context. Furthermore, good integration can lead to a better ADV-pedestrian interaction, which will maximize the acceptance rate (De Groot, 2019).

The current communication techniques of ADVs prove not to be very effective in the pedestrian context, considering the identified interaction problems. Therefore, it is important to understand what the needs for communication are. What do pedestrians communicate to each other and how can that be translated into communication guidelines for ADVs. Hence, to be able to establish communication guidelines for ADVS, the following chapter will focus on understanding the pedestrian environment, analysing pedestrian behaviour and identifying communication signals that are used in this context.

4. Pedestrian behaviour

To achieve communication guidelines for ADVs that can solve the current interaction problems of ADVs, an understanding has to be created on the context in which the ADVs will exist. Considering that ADVs will drive on the pavement, their main context will be the pedestrian environment. Understanding the pedestrian environment, their behaviour patterns and their main communication means, will help with designing communication guidelines that fit this specific context. Therefore, this chapter focusses on understanding pedestrian behaviour and identifying communication signals. An understanding on behaviour is created by: analysing the Social force model of Helbing & Molnár (1995), in combination with a study of Keesmaat (2020), and by conducting two observational studies. The first observational study will focus on testing the Social force model theories, and the second study is focussed on finding communication signals that pedestrians use in traffic situations. The insights from chapter 3 and 4 will be summarised in the communication guidelines that are presented in the following chapter.

Social force model

To be able to design an ADV that embeds smoothly into pedestrian environments, we have to understand the general pedestrian behaviour they will encounter. Helbing & Molnár (1995) state that pedestrian behaviour is mostly automatic because they are familiar with most situations due to past experiences. Whether pedestrians walk on 'auto-pilot' depends on the complexity of the situation. If the complexity is low the behaviour of the pedestrian is pretty predictable and their direction can be modelled with the social forces model.

While walking in a low complexity situation, pedestrians are still influenced by internal motives and "social forces" from their surroundings, which will influence their direction. These social forces can be divided into attracting forces and repulsive forces. Points of interest in the environment create attracting forces, while other pedestrians and boundaries generate repulsive forces (Helbing & Molnár, 1995). We can combine the social forces together with the predicted favourable direction of the pedestrian in a social force model. This model will show the sum direction of the pedestrian, as shown in figure 11 (De Groot, 2019). The social force model can help with predicting the future movements of pedestrians and provides the ability to map out pedestrian trajectories in specific environments.

However, there are limitations to the social force model as it is based on a simplified version of the real world, e.g. walking speed isn't changed based on pedestrian density, ground was considered as ideal pavement, and cultural- and social conventions such as keeping right/left wasn't taken into account. Therefore, the predicted trajectories of pedestrians in specific environments might not be as accurate as Helbing & Molnár presented.

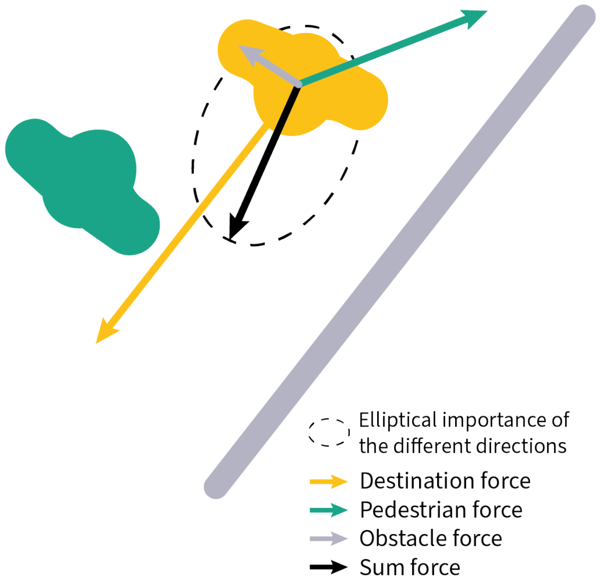


Figure 11, example of a pedestrian situation and its social force vectors (De Groot, 2019, p.35).

Therefore, undertook Keesmaat (2020) an additional study to examine and understand pedestrian dynamics based on observations in real life, videos, and interviews. Keesmaat (2020) investigates three situations: passing, overtaking and crossing, which can be found in figure 12 on the following page.

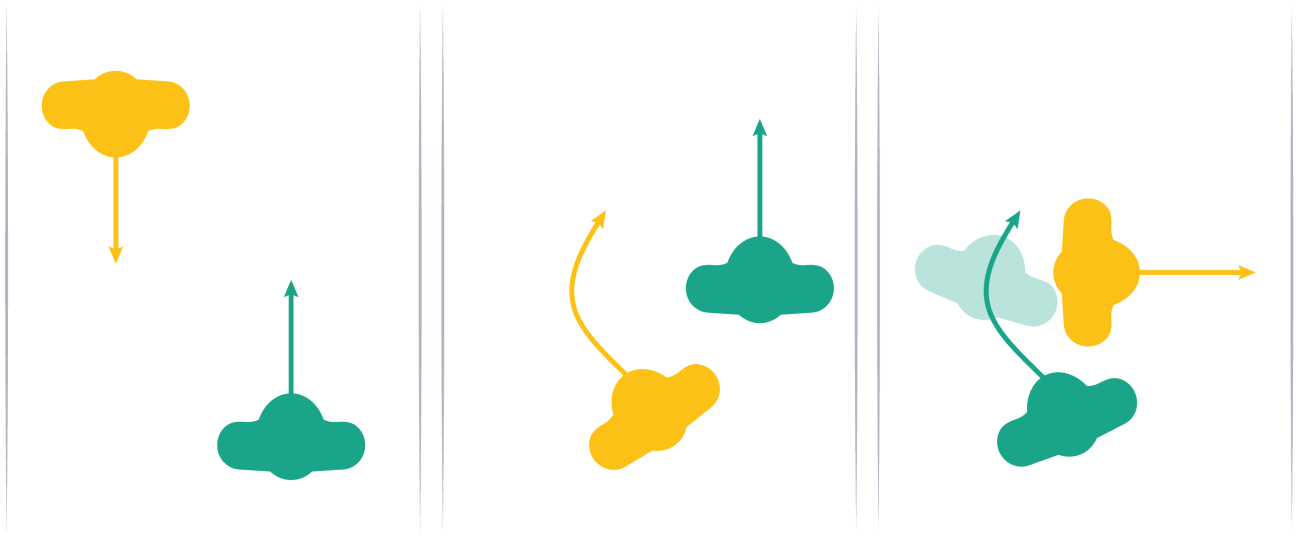


Figure 12, different walking situations (Keesmaat, 2020, p. 16&17), from left to right: Passing, Overtaking and Crossing.

Keesmaat (2020) found that Dutch people typically remain to the right half of the path in a normal walking situation. This is not surprising because it in line with the vehicular traffic in the Netherlands. Furthermore, does this 'right hand rule' also apply in passing and overtaking situations. For crossing it is more complicated, because there is no priority here based on the relative position of the other pedestrians. If maintaining the current speed will lead to an uncomfortable close position we will decelerate or/and change our heading. In most cases, the one who decelerates/changes heading is the one crossing behind the other. Who is going to adjust their speed/path depends on the velocity, time until crossing, the empathy or dominance both give off. Therefore, from Keesmaats study it can be determined that for passing and crossing situations Dutch people mainly follow the right hand rule. Additionally, it is important to note that this tendency to keep to the right is embedded in the Dutch society and will differ in-between differ cultures.

Social force model conclusion

The findings of Keesmaat (2020) and Helbing & Molnár (1995) highlight the 'right hand rule'-of thumb that is embedded in the Dutch society and that we adjust our paths based on social forces. Additionally, Helbing & Molnár (1995) discuss the theory of walking on 'auto-pilot', which is what happens in low complexity situations. Nevertheless, even in such situations, are we influenced by social forces, which De Groot (2019) visualised in figure 11. Keesmaat (2020) challenges the social force model and exposes its limitations, due to the simplified situation the model is based on. He discusses different pedestrian situations, such as passing, overtaking, and crossing and highlights again the right-hand rule that is embedded in the Dutch culture.

The Social force model and the study that are discussed provide theories on how pedestrians behave, which creates a bigger understanding of how pedestrians move within their environments. However it does not point out the signals that people give to communicate their 'pedestrian force'. Therefore, two additional observational studies ere conducted for the purpose of this thesis to examine what the signals are that pedestrians give to communicate their destination and/or walking direction. Understanding the communication signals pedestrians use in traffic can provide valuable insights for the redesign of current ADVs to better align with the pedestrian context and to provide information on how to design intuitively understandable intent signals, which both are needed to design a safe, comfortable and predictable ADV-pedestrian interaction.

Observational studies

When designing an intuitive intent signal it is useful to look to existing traffic signals for inspiration. Therefore, two observational studies are conducted for the purpose of this thesis. The first study focuses on examining the significance of eye contact between pedestrians and on testing the auto-pilot theory of Helbing & Molnár (1995). The second study centres around testing the effectiveness of the 'right-hand' rule (of the research of Keesmaat, 2020) and investigating various types of e.g. intent signals that pedestrians use to communicate with each another.

First study: eye contact and auto-pilot

The first study aims at testing the amount of eye contact there is between pedestrians and the 'auto-pilot' theory of Helbing and Molnár (1995). This emphasis on eye contact comes from my personal prejudice that eye contact plays a big part in pedestrian behaviour and I want to determine if this is true. In addition, the study also aims to examine the broader idea of pedestrian connections, considering factors beyond only eye contact.

The study was located outside on a broad and long sidewalk. It is typical in the Dutch culture to remain to the right side of the road (Keesmaat, 2020) and to pass each other like shown in figure 12. Therefore, it is also common and expected that someone would move more towards the right to let someone else pass. At the start of the study I walked in the opposite direction of other pedestrians and we passed each other by keeping to the right. I noticed fairly fast that there was little to no eye contact between me and other pedestrians during this simple passing. Thus, to challenge this connection more I decided to be a bit more provocative and interactive with the other pedestrians.

Figure 13 provides a schematic representation of the tested situation. In this situation I am the yellow person (Y) and the opposing pedestrian is green (G). Since the sidewalk was so broad and long, you could spot opposing pedestrians from far away. It is important to note that the green pedestrians were individuals who were unaware of the study, and that therefore their responses and reactions were entirely natural.

Person Y and person G started in a position in which their paths were not colliding if they continued walking in a straight line. To challenge the interaction, person Y moved horizontally (from top view) towards person G until their paths were in direct collision (see figure 13, situation 2). What was remarkable to see was that person G automatically changed its path to the right or, in some cases, towards the most convenient side (which could also be the left). Person Y would continue to make their paths collide until person G was almost falling off the sidewalk, at which point person G would make eye contact with person Y to communicate a surprised and sometimes even irritated emotion. As mentioned the sidewalk was fairly broad (approximately 3.5 meter, Google Maps, n.d.), and it is understandably considered provocative to keep 'pushing' someone to the side when there is enough space to pass each other.

Since the sidewalk was so broad, person Y changed its path multiple times before person G would reach the end of the pavement. What was astonishing was that person G automatically adapted its path without making eye contact or even looking in the direction of person Y. Apparently we can see others from the corners of our eyes and estimate our new direction unconsciously, this is also supported by the surprised faces that would look up when almost falling off of the sidewalk.

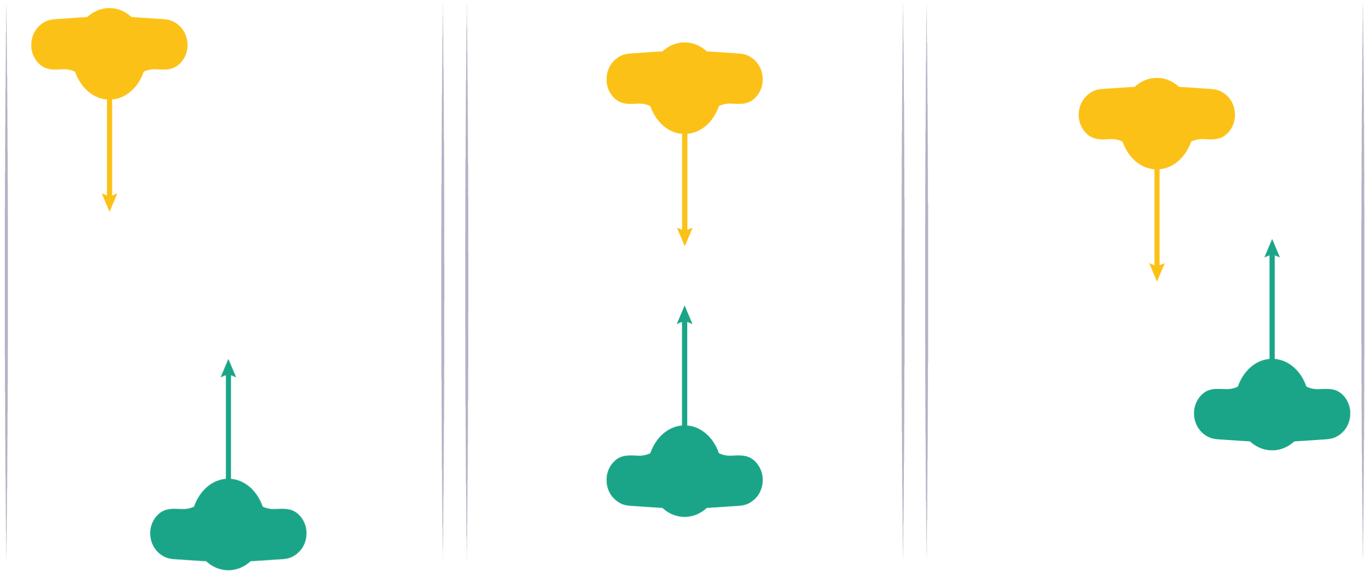


Figure 13, schematic results of observational study 1, read from left to right: 1 = encountering each other, 2 = being opposed, 3 = changing direction.

This study proves three things: overall we follow the right-hand rule of thumb, eye contact doesn't play an important role in pedestrians communication/interaction, and pedestrians behave on auto-pilot in simple and recognisable situations. The next step is to focus on discovering the signals pedestrians use to convey intent or walking direction, for inspiration on designing intent signals for the ADV. The following section discusses the second study, which focuses on the identification of these signals.

Second study: communication signals

The second study is focused on discovering the signals pedestrians use to communicate, to create a starting point for designing intent signals for ADVs. This study was conducted indoors within a busy pedestrian environment. I observed from a higher point of view to ensure optimal visibility on a large amount of pedestrians simultaneously. A schematic overview of the pedestrian environment is sketched in figure 14.

What was surprising was that I was able to accurately predict whether the pedestrian would turn left or right at the end of the straight path. This observation needed a closer look to discover the exhibited signals by pedestrians that I automatically and unconsciously interpreted correctly. What was intriguing was that after discovering the signals, they could be categorized into three phases due to their increasing expressiveness over time. These phases are based on the amount of distance between the opposing parties, e.g. when the opposing pedestrians are still relatively distant from each other, their behaviour differs compared to when they are closer.

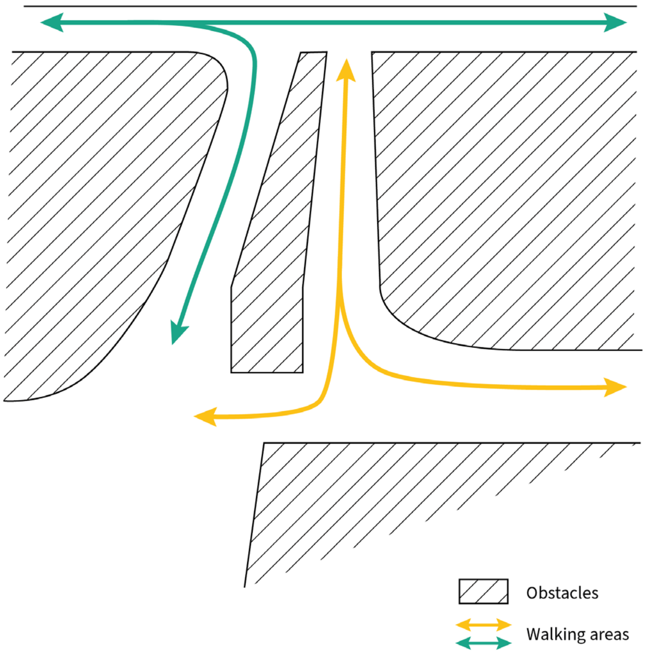


Figure 14, pedestrian environment study 2.

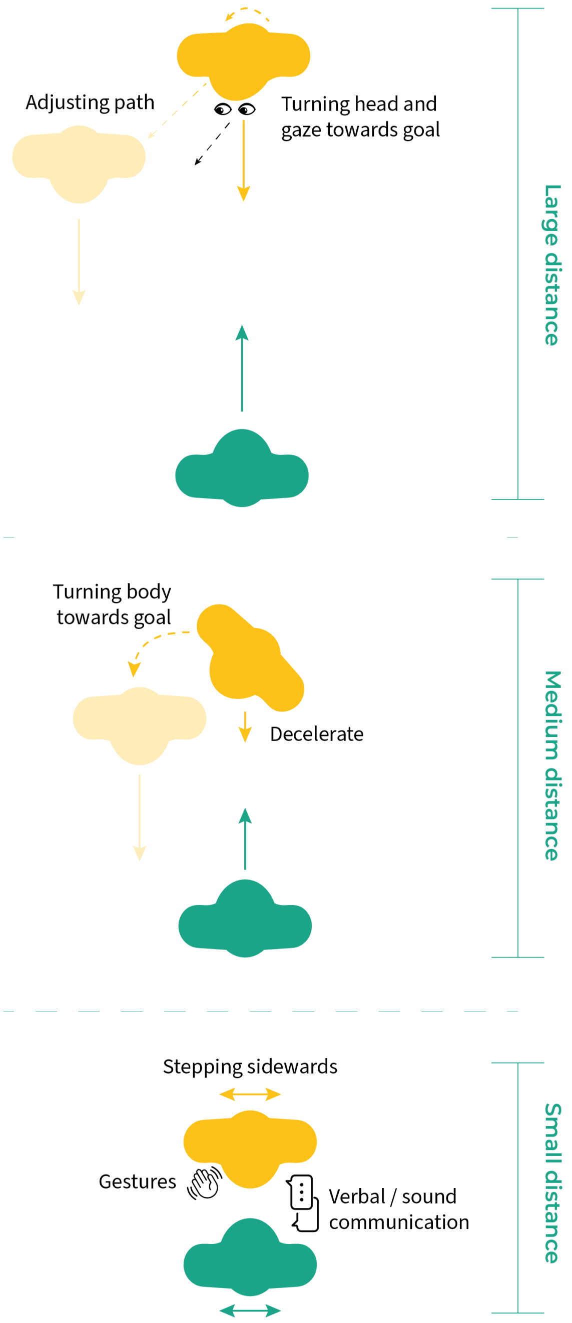


Figure 15, pedestrian signals.

The identified signals are displayed above in figure 15. When there is still a fairly large amount of distance between opposing pedestrians, we communicate by: already changing our paths (like in the first observational study) or by turning our gazes and/or our heads towards the desired direction. From the first study it became apparent that eye contact isn't important but we do communicate through our eyes in a different way. Our gaze plays an important role in communicating intent, recognising someone's presence, negotiating and desired walking direction.

When the distance between two pedestrians decreases, the communication signals become more apparent. Instead of only turning their heads or their gaze, they turn their entire body towards the desired direction/goal. This movement is often combined with a reduction in speed.

The very small distance situation is something we all try to avoid. It involves awkward sidestepping, arm gestures, and even forms of "verbal" communication, typically consisting of unintelligible sounds rather than actual words.

Pedestrian behaviour conclusion

Pedestrian behaviour has been analysed to create an understanding of the context in which ADVs will exist in. This pedestrian environment provides insights on how pedestrians behave and communicate. By adapting the ADVs behaviour and communication pattens to the patterns employed by pedestrians, ADVs will be more integrated into the pedestrian environment. A better integrated design will be easier to implement and will therefore be more easily accepted.

This chapter analysed pedestrian behaviour by discussing the Social force model, a study of Keesmaat, and two observational studies. The purpose of the observational studies was to put the theories of Helbing and Molnár (1995) and Keesmaat (2020) to the test. In addition, the study aimed to identify the communication signals used by pedestrians to interact with each other in traffic to create a foundation for communication guidelines for future ADV designs.

The first study focussed on the auto-pilot theory in combination with the level of connection/interaction between pedestrians in traffic, specifically focusing on eye contact. The study established that eye contact doesn’t play a significant role in pedestrian communication/interaction, and pedestrians behave on auto-pilot in simple and low complexity situations. It is noteworthy that while eye contact may not have a significant role, pedestrians occasionally do gaze towards one another as a form of acknowledgement. Hence, the future ADV design does not have to include 'real' eyes, that can 'physically' look at pedestrians, to achieve a comfortable pedestrian connection.

Both studies proved the right-hand rule theory of Keesmaat (2020). In most cases, Dutch pedestrians will keep to the right side of the road and will overtake and cross on the left side. Therefore, it is possible that this will be expected of the ADVs as well. If this is expected of them as well, it is important that this will be integrated into the programming of the robots and that it is adapted per culture.

Furthermore, the second study aimed to uncover the communication signals that pedestrians use to interact with one another. The signals get more apparent when the distance between the pedestrians decreases. Starting with gazing/looking at- and turning their heads in the desired direction, then turning the entire body and lastly using awkward gestures, sidesteps and incomprehensible noises to communicate and avoid an actual collision. What became apparent is that pedestrians primarily use body-language, gestures and eye gaze as means to mainly communicate their intent/walking direction.

To design a trustworthy and predictable ADV, their communication has to be improved. Better communication can help in solving the current distrust and unpredictable behaviour in - and of ADVs. To be able to design communication guidelines for ADVs it is important to understand the employed communication means in the current pedestrian environment. Future ADVs could potentially use the same signals to convey the same messages as pedestrians. The insights from chapter 3, ADV interactions and chapter 4, Pedestrian behaviour, will be summarised in communication guidelines for future ADVs to a better and safer future embedding of ADVs into the pedestrian environment. The following chapter will discuss the communication guidelines, which will include a definition of communication for this project, the target audience of the communication, and the specific aspects that the ADV needs to communicate to solve the distrust and unpredictable behaviour.

5. Communication guidelines for ADVs

Chapter 3, ADV interactions, and chapter 4, Pedestrian behaviour, provided insights into the behaviour patterns of ADVs and pedestrians. It highlighted the most significant interaction problems of ADVs: distrust and unpredictable behaviour. Communication was established as an interesting means to solve both problems. Pedestrian behaviour and communication patterns were analysed to create an understanding of the environment in which the ADVs will exist. All these insights provide the foundation of possible communication guidelines. Therefore, this chapter will focus on communication and will determine what the needs of pedestrians are of ADV communication. This chapter starts with explaining the meaning of communication in this project, and which specific aspects the ADV should communicate to solve the distrust and unpredictable behaviour of current ADVs.

What is communication?

The focus on communication comes from the benefits it offers. As mentioned before, good communication can lead to system transparency and a higher sense of control for pedestrians (Choi & Ji, 2015; Lee & Kolodge, 2020). This can be used to solve the distrust people have in ADVs. Furthermore, by displaying better communication, the behaviour of the ADVs will become more predictable for other traffic participants (Domeyer et al., 2020). Communication is important, which makes it essential to understand the different forms of communication in traffic and the definition of communication within this thesis.

Hybels & Weaver (2001, as cited in Bolarinwa & Olorunfemi, 2009) describe communication as "any process in which people share information, ideas and feelings, and that it involves not only the spoken and written word but also body language, personal mannerism and style." When looking at the traffic context, communication refers to the exchange of information, signals, and cues between different traffic participants to facilitate safe and efficient driving behaviour. It includes different forms of communication, i.e. verbal and non-verbal communication, visual signals, gestures and body language. These communication forms play an important role in facilitating overall traffic interactions, negotiations, and anticipations among traffic participants.

To summarise, communication in the traffic context includes the sharing of information, ideas, and feelings through various channels including verbal and non-verbal communication, visual signals, gestures, body language, and other forms of expressive behaviour. It encompasses spoken and written words, and non-verbal cues such as visual signals, gestures, and other body language. It is important to be aware of the different communication forms that are already used in traffic, since one of these forms could be used to convey what the ADV wants to communicate.

Communicate to whom?

All individuals or entities that actively engage in traffic activities are referred to as: traffic participants (CBS, n.d.). This includes e.g. pedestrians (alone, together, in a group, walking a dog, in a wheelchair etc.), cyclists, drivers of motor vehicles (cars, motorcycles, trucks), and passengers. ADVs will be implemented in this existing environment full of different traffic participants, which will be the target audience of the ADVs communication. Since the ADVs will drive mainly on the sidewalk, pedestrians will be the main traffic participant they encounter.

There can be different perspectives on whether pedestrians qualify as "genuine" stakeholders, as they may not be the primary users of- or have a significant interest in the service of the ADVs. Rosenthal-von der Pütten et al., (2020) present a compelling argument for considering pedestrians as an important stakeholder in the context of ADVs. A specific term has been given to describe this group of individuals: InCoPs (incidentally copresent persons).

InCoPs

The incidentally copresent persons (InCoPs) in this context are e.g. pedestrians walking down the street who encounter an ADV, someone looking out of the window of a cafe or a driving car. InCoPs may not necessarily align with the target audience of ADV companies, because they might not be interested in - or even users of - the services ADVs provide. This often results in their needs being overlooked and neglected (Rosenthal-von der Pütten et al., 2020).

However, all pedestrians will be affected by the implementation of ADVs in pedestrian environments, not just the people who use the service of the ADV. Therefore, it is important to design for all pedestrians, including the InCoPs, to ensure a holistic and human-centred approach to the redesigning of the ADVs.

What should the ADV communicate?

Good communication can help make the ADV more predictable and solve the distrust people currently have in the technology of ADVs. To determine what has to be communicated to solve these problems, I conducted interviews with experts in the field of autonomous mobility. By combining the findings from these interviews with existing literature, three different communication needs were identified: the driving state, the intent, and the goal.

Driving state

The state communicates the condition the ADV is in, for example: ‘I am driving autonomously’, ‘I am controlled remotely’, ‘I am turned on’, ‘I am turned off and/or waiting.’ Communicating the state and the intent of an AV makes the system more transparent and gives people a sense of control (Lee & Kolodge, 2020, as cited in Domeyer, 2020). When people have a bigger sense of control, they have more trust in the overall system (Skinner & Spira, 2003). And as mentioned earlier, a higher level of trust is beneficial for acceptance and therefore embedding of ADVs in traffic.

> “*When encountering an ADV for the first time, I would want to know its state. Including its activation, perception of my presence, and intention to stop.*”
>
> **- Joost de Winter // Technical University of Delft**

Intent

The intent can be defined as: “a relatively clear perception that the act or result will come about, coupled with an indifference toward that outcome” (Crump, 2010). Crump (2010) also says that intent is “a conscious desire to [..] bring about the result.” In the context of traffic, the ability to communicate intent means that the ADV is able to make a decision about its own trajectory based on what the pedestrian will do, and then send a message to the pedestrian to try and guide their behaviour to avoid collision (Matthews et al., 2017).

To be able to design for predictable behaviour you need to design an intent signal. Pedestrians adjust their own path based on their perceptions and predictions of other pedestrians’ movements and intentions (Helbing & Molnár, 1995). This prediction is based on the signals of intent that other road users express and if road users fail to correctly predict, collisions might occur (Petersen & DeLucia, 2020). Pedestrians, cyclists and drivers all communicate their intentions in traffic through e.g. body language and gestures, vehicular position, speed and acceleration.

“The communication of intent is inseparably connected to an intuitive and comfortable human-robot interaction” (Risto et al., 2017, as cited in Keesmaat, 2020). Pedestrians will encounter an ADV unexpectedly on the streets without any instructions. Therefore, it is important that pedestrians intuitively understand the behaviour of the ADV, which can be achieved by evidently communicating the intent.

> “*Misunderstandings in traffic can be solved by communicating your explicit intentions and goals.*”
>
> **- Ilse van Zeumeren // Future Mobility Network**

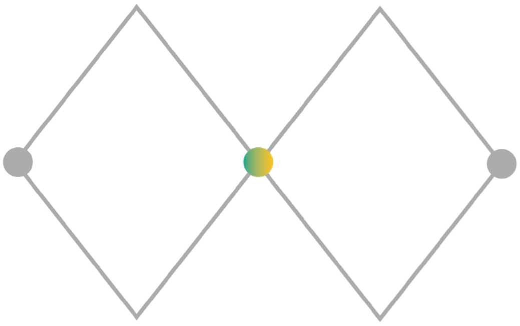
Goal

The concept of goals in traffic can be explained on two levels: the final destination and the current direction. While pedestrians are moving towards their final destination, they establish intermediate goals, such as “I am moving to the right because I plan to cross in a few meters.” Although the significance of goals was highlighted by interviewees, limited literature was found to support this communication need. This might be due to the natural connection that the intent and goals share in a traffic context. Expressing or communicating your intent is impossible without having a goal to move towards. Therefore, it makes more sense to view the goal as an aspect of the intent, rather than treating them as separate entities.

Future communication guidelines conclusion

In conclusion, effective communication is crucial for addressing the interaction problems current ADVs are facing. It is important to take the InCoPs into account during the design phase, because they are the primary traffic participant in interaction with the ADVs. The ADVs can, by communicating their state and intent, enhance system transparency, give a sense of control, build trust and make the driving behaviour of ADVs more predictable. Which will result in safer, more comfortable and more efficient traffic interactions (Petersen & DeLucia, 2020).

Pedestrians also constantly communicate their intent with each other in traffic. Therefore, to ensure that the ADVs integrate well within the pedestrian environment, it is preferable to make the ADVs communicate their signals in a similar way to make the signals more intuitively understandable. Especially, because it is expected that pedestrians don't have a lot of time to anticipate on the ADV, when they encounter each other in traffic. The following chapter will converge all the insights from chapter 3, 4 and 5 into a design goal that will serve as the foundation for the design phase.



Design goal

All insights have been combined into one design goal which marks the end of the research phase and the beginning of the Design phase. The design goal highlights the key components to provide a framework for meeting user needs. A design scope will be used to narrow the focus of the design goal, which highlights the most crucial features and testing scenarios for future ADV designs.

6. Design goal

To accomplish an ADV design that effectively solves the problems that current ADVs are struggling with, a design goal is formulated to provide boundaries and a foundation for the design phase. Throughout the research phase, valuable insights have been obtained which have been compiled into a clear design goal, serving as the foundation for the upcoming design phase. In chapter ADV interactions (chapter 3) it became apparent that current ADVs struggle with unpredictable behaviour and distrust and that a means to solve both problems is to communicate the driving state and the intent of the ADV. Therefore, to create an ADV that is predictable and trustworthy it is important to communicate the state and intent. The highlighted keywords of the design goal will be explained in the coming paragraphs. The design goal is formulated as follows:

Design a delivery robot that *communicates* its **state** and **intent** to make its behaviour more intuitively *predictable* for pedestrians.

Communication

Chapter *Driving behaviour of ADVs - problems & results* highlighted the problems that current ADVs are facing. The most challenging being distrust in the technology of ADVs and the difficulty of predicting and anticipating on the driving behaviour of the ADVs. Literature supports that these challenges can be tackled by improving communication (Domeyer et al., 2020; Helbing & Molnár, 1995; Matthews et al., 2017; Petersen & DeLucia, 2022; Skinner & Spira, 2003; Winter et al., 2018). Hence, communication is chosen as the means for resolving the existing problems of current ADVs.

State

The state refers to the driving state of the ADV which could be, e.g. 'the ADV is turned on and waiting'. Communicating the state enables more transparency from the ADVs towards the pedestrians which will address the current distrust in the ADV technology (Lee & Kolodge, 2020, as cited in Domeyer, 2020). Additionally, it will give pedestrians more sense of control which also addresses the distrust (Skinner & Spira, 2003).

Intent

By communicating the intent, ADVs will exhibit more predictable behaviour, which makes it easier for pedestrians and other traffic participants to anticipate on its future movements. Communicating intent is also inseparably connected with an intuitive and comfortable human-robot interaction which is necessary in traffic situations (Domeyer et al., 2020; Kruse et al., 2014; Petersen & DeLucia, 2022; Risto et al., 2017, as cited in Keesmaat, 2020).

Intuitive and predictable

ADVs interaction with pedestrians should be low effort and intuitive. InCoPs do not want to adjust their behaviour dramatically for a service they don't use (De Groot, 2019). Predictability expresses how easily an uninstructed person can estimate future states/movements of the robot from observation, which contributes to safety and acceptance (De Groot, 2019; Kruse et al., 2014).

Due to the inability to read a manual beforehand and the time constraints for decisions in traffic, the behaviour has to be intuitive. Thus, the predictable behaviour of the ADV should reflect the intuitive knowledge of pedestrians.

Pedestrians

A decision had to be made regarding the target group of this thesis's design goal. ADVs will interact with many different traffic participants, however due to time restrictions, not all of these interactions could be thoroughly studied. Pedestrians were selected as the primary target group because they are the traffic participant which the ADVs will most frequently interact with. All pedestrians will be taken into account during the design phase, this includes InCoPs.

Design scope

I have decided to create a focus point within the design goal, since I believe that this design scope will help in achieving an ADV design that displays predictable behaviour and creates a safer and more comfortable ADV-pedestrian interaction. The design goal explained the reasons for focussing on state, intent, communication, pedestrians, and predictable and intuitive behaviour. The most important aspect of the ADV is that it is going to display predictable behaviour, since this interaction problem is immediately connected to traffic safety. Therefore, the focus will be on communicating the intent, because intent communication is linked with predictable behaviour. Multiple human intent signals are examined in chapter 4, Pedestrian behaviour, and most of these signals rely on body language. Therefore, to create an ADV that is predictable it is important to communicate the intent, and to make these signals intuitive it should be based on body language. These insights in combination with the decisions that are highlighted below, lead to the following design scope:

Design a delivery robot that *communicates* its **intent** through **body language** to make its behaviour more intuitively *predictable* for pedestrians.

Intent instead of state

Behaviour is the basis for on-road communication (Domeyer et al., 2020). Therefore, it is important we portrait predictable behaviour. Pedestrians adjust their path on predictions and perceptions (Helbing & Molnar, 1995) and this is based on the signals of intent that other road users express (Petersen & DeLucia, 2022). By communicating the state, the distrust in the technology of the ADVs could be solved. This is however considerably less important because when the intent is wrongly predicted actual collisions can occur.

Therefore, intent is the most important aspect to focus on to ensure safe embedding of ADVs in traffic. To be able to test the intent I will focus on communicating the intent of either passing a pedestrian left or right.

Which intent?

In the course of walking and driving we convey numerous different intentions, e.g. turning left, changing lanes, and stopping. One intent is selected to focus on in order to effectively assess whether the future ADV design could convey the correct intent. The chosen intent is whether the ADV is going to pass an opposing pedestrian on the right or left side. This scenario was picked since it will be one which the ADV will run into frequently and because it represents an intent that pedestrians regularly communicate.

Body Language: *Any movement-related "gestures" used by the vehicle to convey a message (e.g., acceleration, kneeling or braking, shapechanging interfaces, or changing body panels) (Dey et al., 2020).*

Body language

There are multiple communication means that can be deployed in traffic communication, an overview can be found in figure 16. Therefore, it's essential to concentrate on one mean of communication in order to scope the design goal.

Dey et al. (2020) analysed 70 different eHMI (= external Human Machine Interfaces) concepts and found the following: 97% of the eHMI concepts uses visual modality as communication tool. Of this 97%, 69% uses abstract visual information such as lights and displays, therefore we can say that the most used eHMI is based on abstract visual communication. Only 4% of the concepts uses body language of the vehicle as communication means, even though, literature (Dey & Terken, 2017; Moore et al., 2019) and the observational studies on pedestrian behaviour (see chapter: *Pedestrian Behaviour*) show that we mainly communicate with our body movements in traffic situations. Therefore, further research into the use of vehicle body language as a communication modality is necessary. Hence, I chose to concentrate on body language as a communication tool with the focus on 'changing body panels'.

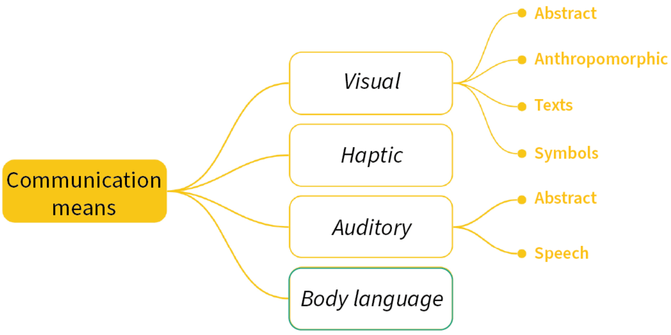
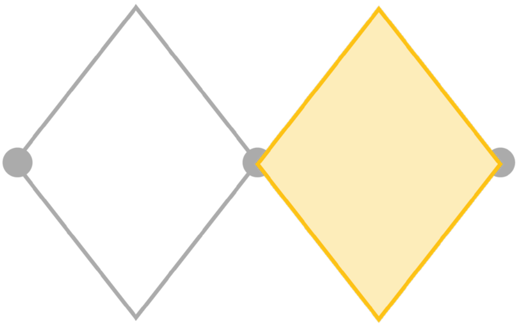


Figure 16, different communication means (inspired on a visual of Dey et al., 2020).



Design phase

The Design phase resembles the second diamond of the Double Diamond Design Process. This phase begins with diverging through four different test explorations, from which insights are gathered to establish design criteria. These criteria, together with additional decisions, lead to the design of the evaluation prototype. The evaluation prototype is tested in the evaluation test, which further refines the benefits of letting ADVs communicate intent and the effectiveness of the designed intent signal. The results of the evaluation test mark the end of the design phase and the start of the design proposal.

7. The RITE method

The RITE method will be used to go through the design phase. RITE stands for Rapid Iterative Testing and Evaluation and it is a usability design tool in which rapid prototyping and testing play an important role (Medlock et al., 2002). RITE allows for rapid prototyping by focusing on fixing designs rather than only finding problems (Tinga et al., 2023). Additionally it is a useful method for exploring a large design space, because the prototype can be adapted quickly in between tests and there aren't many test-participants needed for the desired outcome (Medlock et al., 2002).

The RITE method is a good fit for the purpose of this research, since the time is limited and the goal is to explore multiple different directions within the given design scope. In general the RITE method involves evaluating a design with 1-3 participants, e.g. by letting them think aloud. It involves changing the design immediately when an issue occurs and the solution to that issue is easily implemented, this can already be after testing with one participant. These issues can be categorised into three different categories: A) issues have an obvious case and can be fixed quickly, B) issues have an obvious case but can't be fixed quickly, C) there is no obvious case to the issue. In the case of category B, the prototype will be adapted in between test days and for category C the prototyping exploration will continue until the issue can be promoted to category B or A (Lenneville et al., n.d.).

After making the changes the design is evaluated again by 1-3 participants, this process will repeat itself time and time again until the final design takes shape (Medlock et al., 2002). The process of the RITE method is visualised in figure 17, to highlight the differences of this method it is visualised next to the process of "standard" testing.

Traditionally, according to Medlock et al. (2002), the RITE method works best when used by a team consisting of an usability engineer and a development team. All the tests for this thesis will be conducted independently, making me responsible for both the role of the usability engineer and the development team. However, this approach still seems feasible due to the relatively low number of required participants and if the prototypes are low-fidelity it will be easy to adapt them quickly in between test rounds/test days.

The RITE method is implemented in the following tests by adapting prototypes immediately when issues occurred and by rapid prototyping in between tests to ensure a large exploration within intent communication through body language. Four test days have been conducted to explore and validate the prototypes in this thesis.

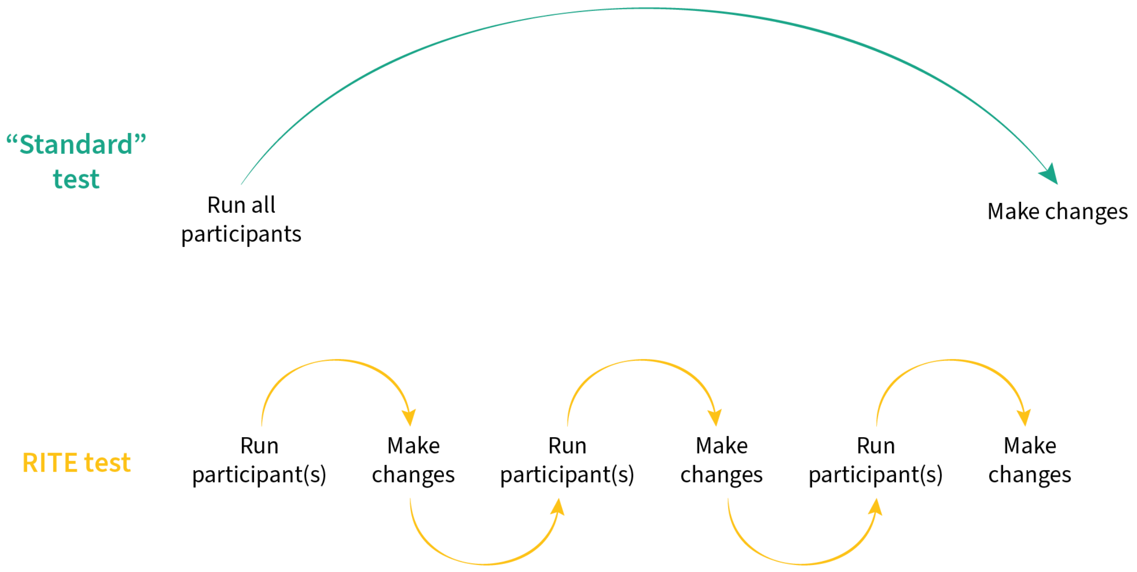


Figure 17, the RITE method versus standard usability testing (Drachen, 2019).

8. Design exploration

This chapter delves into the Design exploration phase, which corresponds to the diverging phase of the second diamond, known as the Develop phase. It begins with a comprehensive test exploration, guiding you through four distinct tests conducted using the RITE method. Each test is presented with its unique test set-up, prototyping scenarios, main insights, and next steps. The chapter concludes with a summary in both textual and visual formats. Following the test exploration, the criteria for the evaluation prototype are established and presented. Additional research will be done considering certain aspects of the evaluation prototypes such as the timing of the intent and the size of the signal. The evaluation prototype will then undergo an evaluation test which results are the start of the Design guidelines which are presented in the next chapter: the Design Proposal.

Test exploration

Testing techniques

Usability testing and evaluating prototypes involves the testing the of users' interaction with the prototype. Some of the basic techniques used to do so are think-aloud, observations, interviewing and questionnaires (Nielsen et al., 2002). All of these techniques are used in the following sections where prototypes are tested and evaluated. By letting users think-aloud, for example, it is easier to understand what their honest perceptions are of the interaction with the prototype.

Another technique that has been applied in the test exploration chapter is the Wizard of Oz method. This methods definition is: "The Wizard of Oz method is a moderated research method in which a user interacts with an interface manned by a human who controls the system responses" (Ramaswamy, 2022). Basically, what this means for the following tests is that the ADV prototype is actually remotely controlled, but the participants think that it is driving autonomously.

The following sections are build up by first introducing the research question of that test. It is followed by explaining the test set-up and the prototyping scenarios. Then the main insights are discussed followed by the next steps for further research. The testing techniques are not always specifically mentioned but the following tests all include the thinking-aloud, interviewing, observations and Wizard of Oz techniques and methods.

Test day 1

The intent that the ADV should be able to communicate is whether it will pass the pedestrian on the left or right side and it will do so through the use of body language, in particular by changing body panels (see chapter 6 for the Design scope). Multiple different options are explored to understand which changing body panel communicates the correct intent.

Test set-up

The first test day aims to answer the following question:

What types of body panel changes can be designed to intuitively communicate the robot's intended direction (left or right) around a pedestrian?

This is explored by making a prototype that resembles an ADV and by changing the orientation of the different body panels, to communicate a desired direction.

In this test the participant stands face-to-face and directly in front of the prototype (referred to as the ADV). To test whether the participant correctly understands the intended direction that the ADV is communicating, the participants are asked whether the ADV is going to pass them left or right. To avoid the possibility of random guessing, participants were also asked to indicate their level of confidence regarding the determined direction the ADV was intending to go in. They were asked to rate their confidence on a scale of 1-5, with 1 being not confident and 5 being very confident.

Prototyping scenarios

This prototype was fairly simple, consisting of a smaller box on wheels, representing the frame of the wheels, and a larger box positioned on top, which simulates the body of the ADV (the most left picture in figure 18).

Six different scenarios were tested with seven participants. The different scenarios can be found in figure 18 and are: Neutral, Turning Wheels, Shove, Angle, Looking, and Pre-sort. In each of the scenarios presented below, the ADV is positioned in a face-to-face orientation with you, and its intended direction is towards the right side. Neutral and Pre-sort serve as reference points within the test. The Neutral scenario means that the prototype is placed directly in front of the participant without any intent indication. The Pre-sort scenario involves the prototype performing the action without communicating any intent. These are important scenarios to include to be able to test whether having any intent communication improves the situation.

Main insights

Three out of the seven participants indicated that the ADV would pass them on the right side in the Neutral scenario. Two of them were even confident (scored a 4 on a scale of 5) about this indication. This demonstrates how deep rooted the right-hand rule is in the Dutch culture, so much that we even expect robots to adhere to this rule.

All seven participants could correctly predict the intended direction of the ADV for the scenarios: Turning wheels, Angle, Looking and Pre-sort. This shows that the scenario Shove isn't displaying a clear intent signal and will therefore not be subjected to further testing.

Six participants gave the Pre-sort scenario a 5/5 confidence score (average of 4.86 confidence score) and five participants gave the turning wheels scenario a 5/5 (average of 4.71 confidence score). Consequently, participants exhibit the highest level of confidence in perceiving the intended direction of the ADV when they observe actual wheel movements towards that direction. The best scenario that doesn't display wheel movement is the Looking scenario (average of 3,64 confidence score). The confidence score for all scenarios can be found in appendix A.

All participants consistently referred to the box as a male entity, using words like "he" and "his face" and "he is going right." It is worth noting that the prototype lacked any human-like features and was simply a regular cardboard box (as shown in figure 18). This observation suggests a strong tendency among people to anthropomorphise the ADV, which means attributing human characteristics and behaviour to an object, in this case the ADV.

Three participants mentioned that they got the impression that the ADV had *seen* them because it reacted to them. The impression that the ADV sees the participant, gives the participants a safer feeling, because if the ADV has seen them it will probably not hit them.

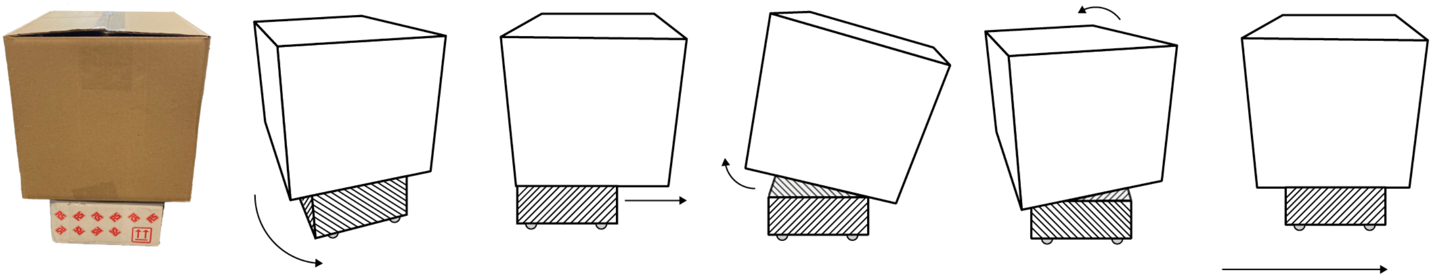


Figure 18, picture of the prototype and the prototyping scenarios of test 1, from left to right: Neutral, Turning wheels, Shove, Angle, Looking, and Pre-sort.

Next steps

Valuable insights have been obtained regarding which changing body panels effectively communicate the intended direction, as well as those that do not. In the upcoming tests, the scenario involving the turning of the wheels will be omitted, because it does not rely on communicating intent through changing body panel cues. The Shove scenario will be left out as well, since it doesn't clearly communicate the intended direction. The Neutral and Pre-sort scenarios will be retained as reference points and further exploration will be conducted into additional body language signals that can potentially communicate the desired intent.

Since people already assume that the robot will keep to the right it will be interesting to see if they will understand the communicated intent when it won't keep to the right. For the tests to come the ADV will communicate its intended direction towards the left.

This test was very passive, therefore the participants had a lot of time to think about their answers and to understand the intent signal. This diminishes the intuitiveness of the reaction of the participants, thus the next tests will be more dynamic.

> **“He sees me, so he is going to respond to me.”**
>
> *- Participant 1.6, responding to scenario Angle*

> **“He is saying to me: ‘I am probably going this way’.”**
>
> *- Participant 1.7, responding to scenario Shove*

Test day 2

It was important that this test was more dynamic to be able to assess whether the participants were able to intuitively understand the signals that the ADV communicates. Therefore the prototype was redesigned to be able to move ‘autonomously’ (in reality the prototype was remotely controlled).

Test set-up

The second test aims to answer the question:

How effectively and intuitively are the changing body panels perceived when the ADV is moving?

In order to assess the intuitiveness of the prototype, both the prototype and the participant were moving, creating a time-limited scenario that required quick and intuitive reactions and perceptions of the signals. Due to this time constraint, participants could only rely on their intuitive reactions, providing insights into the effectiveness of the changing body panels in communicating the intended behaviour.

This was executed by letting the participant walk from one side of the room towards the other, and the ADV would drive in the opposite direction towards the participant. The ADV would ‘weave’ around the participant in the direction of its communicated intent (with the exception of the Neutral scenario). In the context of this thesis, the term ‘weave’ refers to the ADV's movement of driving around the participant in a curved and smooth manner. In the first test day it became apparent that people automatically assume that the robot will keep to the right side, as this is seen as normal, therefore the ADV communicated a left direction in all scenarios.

After the ADV and the participant would pass each other, the participants had to fill in a questionnaire. The body panels are changed in between the scenarios whilst the participants filled in this questionnaire, and after completion there were additional open questions.

The questionnaire was based on the System Usability Scale (SUS) with adapted questions to fit the testing context. The SUS questionnaire and the results are available in appendix B, although it should be mentioned that the number of participants limits its validity as conclusive evidence.

Prototyping scenarios

In addition to testing the intuitiveness of the changing body panels, it was aimed to investigate whether using the same signal by changing a smaller body part would offer similar results. This is done for the scenarios Looking and Angle by only moving the top part of the prototype.

Five different scenarios are tested with six participants, all the tested scenarios are shown in figure 19 and are: Neutral, Looking, Ears, Angle, and Pre-sort. Again the ADV in the figure is standing face-to-face with you and it indicates that its direction will be towards the right. In the Neutral scenario, the ADV would drive towards the participant without any intent communication and without altering its path. In the Pre-sort scenario the ADV drives towards the participant without any intent communication but it adjusts its path and drives around the participant.

In order to improve test results, several small prototype changes were implemented using the RITE method. I.e. the first participant had trouble with indicating which side of the prototype was the front of the ADV, therefore a black stroke was added at the front (see figure 19). This is based on the appearance of other ADVs, such as the Starship Technology- and the Amazon Scout ADV (see figures 2 & 3).

> **“He is still driving towards me for a long time and only in the final moment he moves out of the way but because of the signal I am confident that it is going to work out well.”**
>
> *- Participant 2.5, responding to scenario Looking*

Main insights

Every participant referred to the box as a male entity again, the participants said things like “his face”, “he is looking around” and “he sees me”, but they also called the black stroke “his eyes.” This emphasises the conclusion of the first test, that people anthropomorphise ADVs. The Looking scenario is also named this way because the participants consistently described the motion as “looking around.”

The signals were rated on: predictability, ability to understand the motion quick and easy, intuitiveness, confidence in the traffic interaction, and on how complex the movement was. Overall the Ears scenario scores best on these categories, a full overview of the asked questions and the scores of the different scenarios can be found in appendix B. However, it is worth noting that the three scenarios (Looking, Ears, and Angle) received positive ratings in comparison to the Neutral and Pre-sort scenarios. Additionally, the Looking, Ears, and Angle scenarios received similar ratings overall, but the Angle scenario was a bit confusing for 3 participants. They mentioned that they expected that the ADV would exhibit a larger movement, which is possibly influenced by the dynamic nature of vehicles, i.e. motorcycles often lean or angle themselves during sharp turns to maintain balance. It is interesting to test this hypothesis in the coming test.

It is important to emphasize that all three scenarios mentioned above have a positive impact on all the tested categories compared to the no-intent communication scenarios (Neutral and Pre-sort). This shows that by communicating the intent, the predictability of the behaviour of the ADV enhances and people feel overall more comfortable during ADV interactions.

> **“Everything in the Netherlands is right, so I would move to the right and I would expect the robot to do the same.”**
>
> *- Participant 2.1, responding to scenario Neutral*

> **“He is looking in that direction, I see that black part as the eyes of the robot.”**
>
> *- Participant 2.2, responding to scenario Looking*

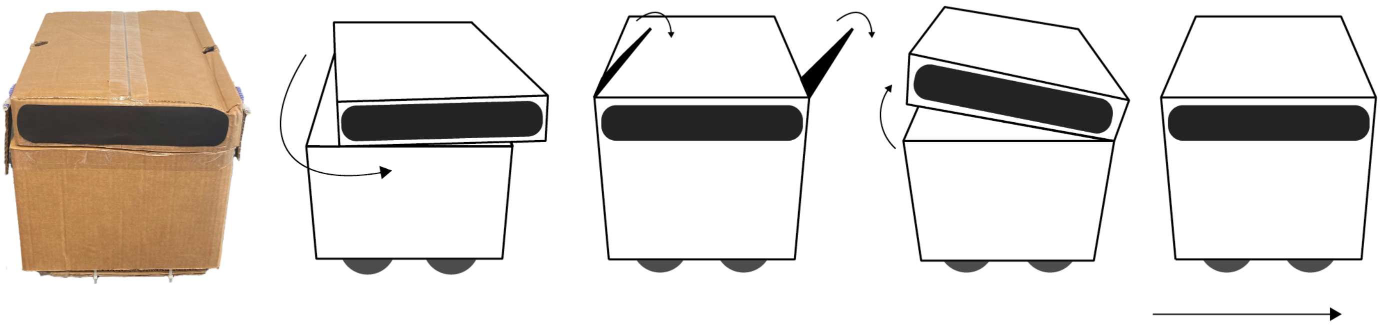


Figure 19, picture of the prototype and the prototyping scenarios of test 2, from left to right: Neutral, Looking, Ears, Angle and Pre-sort.

Next steps

This test proved that in more dynamic situations the changing body panels still communicated the correct intended direction, even when participants had limited time. However, the switching of the body panels in between tests was still visible and could have an impact on the intuitiveness and visibility. Therefore in the following test there will be a solution to make the changing of these body panels in between tests less visible.

This test also demonstrated that even when only a specific part of the body is in motion, such as in the Looking and Angle scenarios, the intent communication remains apparent. The Looking scenario didn't receive the highest ranking in this test, but it is important to consider that other factors might have played a role in that. The sequence of this test was always the same, first the Neutral scenario and then Looking etc. Therefore it is suspected that Looking is ranked lower on certain aspects because it was one of the first scenarios tested and participants got more comfortable with the prototype over time. To eliminate these factors the sequence for the following tests will be randomized and the SUS questionnaire will make place for open-ended questions.

The Ears were ranked as the 'best' scenario, but there was also some confusion regarding the Ears. Two participants mentioned that if the test would have been conducted outside they might believe that the Ears are influenced by the wind. Therefore the next test will be conducted outside.

The added black stroke gave interesting insights into how the human mind fills in blank spots. The black stroke was based on other ADVs without any direct intention but the participants saw "eyes". Participants mentioned that they felt safer because they had the idea that the ADV "saw" them. This was also impacted by the fact that the ADV "responded to seeing them". For the following test, however, the black stroke is left out to see whether the movement of the changing body panels alone is enough to convey the correct intent and give participants more feeling of confidence and comfort.

Test day 3

Test day 2 provided valuable insights, but it also had certain limitations. One limitation was the fixed sequence of tested scenarios for every participant, which could have influenced the results. This fixed sequence was due to the use of the SUS questionnaire, which in hind sight wasn't ideally aligned with the RITE method; the SUS questionnaire requires a larger number of participants for validation, whereas the RITE method is effective with around three participants. Therefore the following tests won't make use of the SUS questionnaire but will use open-ended questions, observations, and thinking-aloud techniques to gain a deeper understanding of how each scenario is perceived and whether it effectively communicates the correct intent. Additionally, other aspects that could have had an influence on the results have been adapted as well, including: testing outside, removing the black stroke, randomizing the sequence, and changing the body panels out of sight.

Test set-up

The goal of test day 3 was to address the following question:

How do participants intuitively perceive and react to the changing body panels of the robot when encountered unexpectedly and without prior information?

To be able to test the intuitiveness on a higher level, a surprise element was introduced in this test. The inclusion of the surprise element in this scenario creates a situation where participants have a constrained time-frame to respond, even more so than in the previous tests. This time limitation aims to receive an intuitive reaction and allows for clarity on whether the intent communication is clear and effective. Furthermore, the intent signals are changed when the participants are behind the corner, resulting in a lack of unintended guidance regarding where to direct their attention.

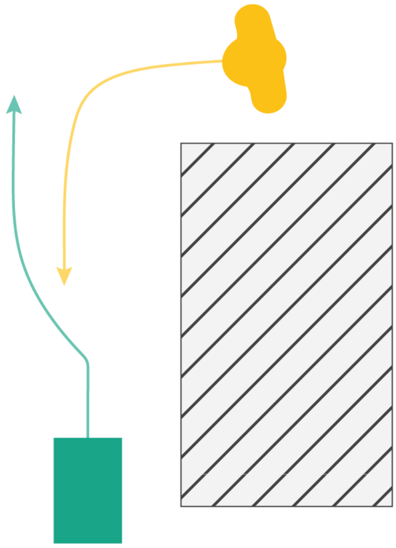


Figure 20, test situation 3

This is executed by letting the participants wait behind a corner and giving them no prior information about the test. The participants had to walk around the corner, where they would encounter the driving ADV (as shown in figure 20). The ADV already displays an intent signal when the pedestrian encounters it and the ADV drives towards the participants and weaves around them at the last moment. The weaving happens as late as possible because the participant and the ADV had to be face-to-face for a moment to give the participant the opportunity to notice the signal and intuitively react to the situation.

The test was conducted outside and after every scenario there were some open questions regarding what the participants just experienced. The questions were formulated without leading the participant, aiming to capture their actual thoughts in the heat of the moment.

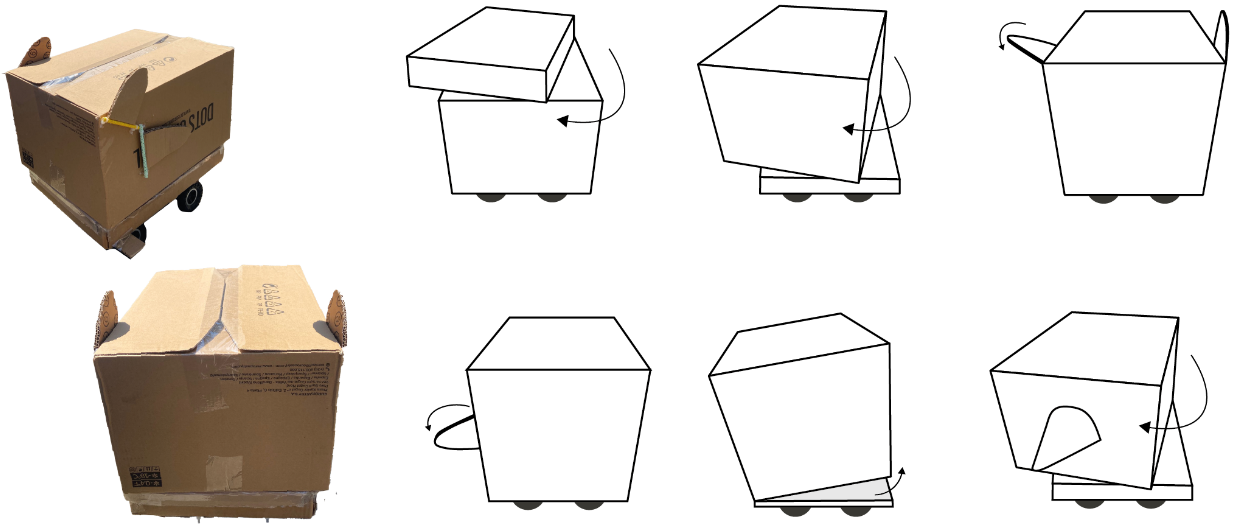


Figure 21, picture of the prototype on the left and the prototyping scenarios of test 3, from left to right: Looking small, Looking big, Ears, Wings, Angle and Nose.

Prototyping scenarios

The scenarios Neutral and Pre-sort aren’t part of this test anymore, since this test was focussed on whether the signals could be intuitively perceived in a split second or not. There are however some new changing body panel scenarios explored. Six scenarios were tested with three participants, the scenarios can be found in figure 21 and they are: Looking small, Looking big, Ears, Wings, Angle and Nose. In figure 21 the ADV is facing you and intents to move towards the left side.

The Looking scenario is split into three scenarios: Looking small, Looking big, and Nose. This exploration focussed on whether a smaller ‘looking’ signal was as effective as a larger one. Additionally it is explored whether adding a nose to the front would help the participants to determine the orientation of the ADV.

All body panels were changed in between the scenarios while the participant would wait behind the corner. The real surprise effect would wear off after the first scenario since the participants now know what to expect but they still had limited time to respond when turning the corner. Therefore the intuitiveness of the reaction of the participant in the situation remained.

Main insights

Participants found the Nose confusing and mentioned that they didn’t understand the added value. The Nose was added to give more sense of the direction of the ADV, and since the eyes worked very well in the previous test it was interesting to see whether a nose could have a similar effect. I anticipate that the Nose does not have the same impact as the eyes for the following reasons. In traffic, humans use eye-gaze for communication, whether it be gazing in the desired direction to communicate intent or by gazing towards someone to indicate acknowledgment. Therefore, eyes play a more significant role in communication than the nose. Additionally, participants mentioned feeling “seen” by the ADV when the black stroke was added to resemble eyes. This perception of being seen gives people a sense of safety and comfort, which the Nose scenario doesn’t seem to provoke.

Participants mentioned that the Looking scenario demonstrated a high level of clarity because the entirety of the ADV moved. This clarity was due to the fact that the moving surface enhanced the visibility from an overhead perspective. Given the ADVs relatively lower position compared to the eye-level of pedestrians, it is highly beneficial for the intent communication to be visible from above. This gives the Looking scenario an advantage in comparison with the other scenarios. Additionally, all three participants mentioned that the Looking scenario was the most clear and their preferred scenario, with no clear preference for the small or big Looking scenario.

The Wings gave two participants the idea that it was going to make a left turn. They both mentioned that this was due to the fact that it resembled sticking out your hand when you want to make a turn while riding a bike, a signal deeply ingrained in the Dutch culture. As this scenario was tested for the first time and not all participants mentioned the turn intent, it is valuable to conduct another test to further validate this insight.

The Angle gave all three participants the idea that there was going to be a big movement change, such as a turn. This also became apparent during the second test day and this intuitive interpretation is probably due to the dynamic nature of vehicles, such as the motorcycle example (motorcycles often lean or angle themselves during sharp turns to maintain balance). Moreover, apart from the issue of communicating the wrong intent, there are additional complications associated with the feasibility of this scenario. The ADV would require a powerful motor to execute the angling movement, given its substantial weight including the package inside. Furthermore, this angling action could result in the shifting of the goods inside every time the ADV would communicate its intent. And last but not least it would potentially impact the overall stability of the robot, which is not desirable considering the already existing tendency of these robots to fall over without angling themselves on purpose.

Something that stood out was that the signal of the Ears scenario wasn’t noticed by 2/3 participants. Something to mention was that for one of these participants the Ears was the first scenario they encountered, which could play a part in the lack of visibility, but for the other participant the Ears scenario was half-way through. This lack of visibility could be due to the fact that the participants didn’t see the movement of the signal, because the body panels were put in position before the encountering.

> **“If you look at it from above it is still clear.”**
>
> *- Participant 3.1&3.2, responding to scenario Looking small*

> **“He is looking that way so that is the way he is going to go in.”**
>
> *- Participant 3.2, responding to scenario Looking big*

> **“It seems like he is going to turn right”**
>
> *- Participant 3.1, responding to scenario Wing & Angle*

Next steps

By confronting the participants unexpectedly and without prior knowledge it became clear which intent signals were apparent and which weren't. The Ears were a top contender in the previous test but now 2/3 participants didn't notice the signal at all. It was too delicate to notice in the split second the participants stood face-to-face with the ADV. The lack of movement of the signal could have an impact on the visibility of the Ears, therefore in the next test a means will be found to show the movement of the signals while the ADV is driving towards the participant.

The Looking scenarios, both big and small, proved to be highly effective and clear for all three participants. The movement of the entire surface in these scenarios made the intent communication highly visible, even from an overhead perspective. However the Nose scenario didn't have the same positive effect as the black stroke had in test day 2. It was expected that the Nose would help with indicating the direction of the Looking, but this wasn't the case. My hypothesis on this is that eyes play a significant role in pedestrian traffic communication, while noses do not. It was observed that participants feel a greater sense of safety when they perceive that the ADV has 'seen' them, a perception which the Nose does not evoke. Therefore the decision has been made to not further investigate the effects of implementing a nose and this scenario will not be tested again in the following test day.

The Wing and the Angle scenarios both gave the participants the idea that the ADVs was going to make a turn. For both scenarios this is based on other traffic behaviours. For the Wings it is related to the behaviour of cyclist who want to make a turn and for the Angle scenario it is how the dynamics work of i.e. motorcyclists who make a big turn. Both scenarios communicate an incorrect intent and the Angle scenario also has feasibility complications which are stated earlier. Due to the challenges and consistent outcome of communicating the wrong intent, the Angle scenario will be excluded from further tests. However, the Wing scenario will be retested to validate the concerns regarding the communication of the wrong intent, since this scenario has only been tested once.

Test day 4

The purpose of this test is to determine if the Looking scenario continues to be the most effective or if another signal conveys the intent more effectively when the body panels are in motion. To investigate this aspect, the same prototype from the previous tests was utilized. However, in this iteration, an invisible rope was attached to the body panels, allowing them to be moved discreetly while the ADV was in motion.

Test set-up

The last test day is focussed on answering the following question:

To what extent does the visibility of the moving body panels impact participants' intuitive interpretation of the communicated intent signals?

In the previous test, the body panels were already positioned in a certain way, and the participants did not observe the movement of these changes. To create the intended illusion of an autonomously driving vehicle, it is necessary to remake the prototype in a way that allows the body panels to be discreetly moved while the ADV is in motion. This is crucial because directly changing the ADV's body panels in front of the participants can potentially affect the visibility and perception of the signals. To be able to move the body panels discreetly, small and invisible threads have been attached to the different body panels. This allowed me to move the panels unnoticeable while also controlling the driving motion of the prototype.

The test took place in a long hallway, the participants would face the ADV at a distance of around 10 meters and they had to walk to the other side of the hallway. The behaviour sequence of the ADV would be as follows: the ADV drives towards the participant, the intent is communicated by pulling on the thread of the body panel, the ADV starts weaving around the participant, and the participant and the ADV pass each other.

Following each scenario, participants were presented with open-ended questions designed to gather their feedback without leading their responses in any particular direction. This approach aimed to assess the intuitiveness of the scenarios without influencing the answers of participants.

Prototyping scenarios

This test uses the same prototype from the previous test, see figure 21 for a picture of this prototype. The previous test concluded that the Angle and the Wings scenarios communicate a different intent than expected. In both scenarios participants expected the ADV to make a turn instead of weaving out to the communicated side. The Wings scenario was only introduced in the last test, while the Angle scenario has been through multiple validations. The Wings scenario is included in this test to validate the results from the previous test but the Angle scenario is left out.

Since the Looking scenario has been effectively and correctly communicating the intended direction in the past tests, a new Looking scenario has been introduced. The purpose of this addition is to determine whether the effectiveness of the Looking scenarios comes from the fact that the entire surface is moving. The Looking scenario has been described as a turning head in past tests, therefore this Looking mini scenario resembles a turning head.

Four different scenarios are tested with three participants, the scenarios can be found in figure 22 and are as follows: Looking small, Looking big, Ears, Wings, and Looking mini. In the figure all ADVs are facing you and are intending to move towards the left side. After every scenario the participants were asked open-ended questions about what they just experienced.

> **"I have 100% more confidence in the situation compared to when he doesn't communicate anything."**
>
> *- Participant 4.3, overall response*

> **"Very clear, he is already moving his body in that direction because he is going to move into that direction. People do the same when walking."**
>
> *- Participant 4.3, responding to scenario Looking small*

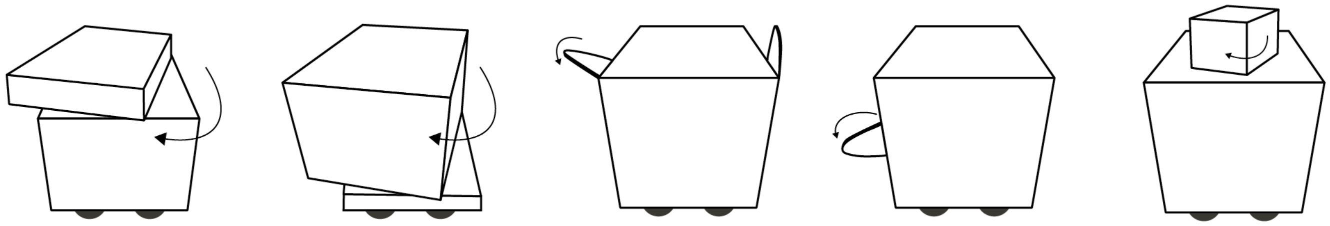


Figure 22, the prototyping scenarios of test 4, from left to right: Looking small, Looking big, Ears, Wings, and Looking mini.

Main insights

Participants expressed confusion regarding the Looking mini scenario. Despite the intention for it to resemble a head, one participant perceived it more as a building. In response, the position of the mini box was adjusted to be more forward, resembling a dog or cat body-head ratio. However, another participant commented that it did not evoke the sense of a head at all, leading to further confusion. Additionally, one participant felt that it appeared unstable and mistook it for the “package” on top. Considering the overall confusion experienced by both participants, it was determined that the Looking mini scenario would be excluded from the next test.

All participants noticed the Ears signal, so the movement of the changing body panels definitely has an impact on the visibility. However, two participants mentioned that the Ears seemed more as a decoration aspect rather than something that has an important function. It is important to note that by giving the ADV Ears, it could potentially be perceived more ‘cute’ and ‘approachable’, which could lead to more people trying to interact with the ADV. This is not necessarily preferable since the ADV should be able to deliver its packages as efficiently as possible.

All three participants mentioned that the Wing scenario meant that the ADV would make a turn. Together with the results of the previous test it can be concluded that the Wing scenario communicates the intent of making a turn.

All three participants could effectively and intuitively indicate the direction of the Looking small and big scenarios. Whether the entire box moves or a smaller section doesn’t matter for 2/3 participants. One participant mentioned that they would prefer the smaller Looking scenario, since they thought that it would keep the robot more agile, because only a part of the robot was turned away, which would be/feel safer.

Next steps

This test aimed to explore whether the visual perception and previous outcomes differ when participants could observe the movement of the changing body panels while the ADV was in motion. Overall the intent signals were more apparent compared to the previous test in which the body panels were already in position when the participants encountered the ADV. Despite the enhanced visibility of all signals, there was still a difference in the level of apparentness among the different scenarios.

Upon closer examination of the Ears, it is evident that their movement is too subtle. Participants do not perceive it as clearly and consider it more of a decorative feature rather than a functional one. Additionally, considering the unintended consequences, such as the ADV becoming too approachable, it is not advisable to further pursue this scenario.

The Wing scenario is clear and intuitive but it communicates the wrong intent. It can be concluded that people interpret the Wing scenario as a turn-intent, therefore it is not a preferred scenario for further prototype development.

The effectiveness and visibility of the Looking scenarios can be attributed to the movement of the entire surface of the ADV. In contrast, the Looking mini scenario proved to be confusing and did not effectively convey the intended intent like the Looking small and big scenarios. Interestingly, one participant expressed a preference for the small Looking scenario over the big Looking scenario, because it was perceived more agile which enhanced the feeling of safety for that participant. The Looking big and small scenarios are both interesting scenarios to move forward with in a future prototype.

Test exploration conclusion

In this chapter, the test exploration phase was conducted according to the RITE method, consisting of four distinct tests. After each test, key insights were gathered, and next steps were determined. The following text provides an overview of all the insights and next steps obtained throughout the four tests. Additionally, a visual summary will be presented, capturing the essential findings regarding the prototype's physique.

Test day 1

The first test aimed to identify effective changing body panels that could convey the correct intent of moving towards the right/left side. The most promising changes of body panels, that rely on body-language, were the Angle scenario and the Looking scenario. Beyond these outcomes, it was observed that participants demonstrated strong anthropomorphism towards the ADV, and that participants had a tendency to assume that the ADV would keep to the right side.

Anthropomorphism can play an interesting role in the design of ADVs. While ADVs are not intended to function as social robots and primarily serve functional purposes, there is a delicate balance between appearing less threatening and appearing too socially approachable. People are known for attributing human characteristics or behaviours to i.e. objects (anthropomorphism) and ADVs are no exception according to a survey done by De Groot (2019) and by Starship Technologies. Respondents of the survey of De Groot (2019)called the ADV 'him' and gave it human-like characteristics such as 'cute' and 'friendly'. Of the respondents of the Starship Technologies survey, half said "thank you" or "excuse me" to the robots, more than a third gave the robot a pat after the delivery and 75% of the respondents called the robot 'friendly' or 'cute' (Yellig, 2022). Similarly, participants in this thesis' tests frequently referred to the ADVs as "him" and assigned human attributes like "looking" and "eyes" to them.

Utilizing this anthropomorphic tendency can enable the ADV to blend more seamlessly with pedestrians while maintaining its distinct non-human appearance. Additionally, communicating the intent by simulating human-like movements may not be effective if pedestrians don't recognise these movements. Anthropomorphism can help in ensuring the recognition of the movements and their intended meaning.

The limitations of the first test were mainly due to the passiveness of the test set-up, which gave participants a lot of time to interpret the intent signals. Therefore, the next test had to be more dynamic to be able to test the intuitiveness of the communicated intent signals.

Test day 2

In the second test, the prototype incorporated dynamic movements to communicate intent through body language. The Angle and Looking scenarios were retested with smaller body panel changes to assess their effectiveness. It was evident that even smaller body panel changes conveyed the intent effectively. The Ears scenario performed the best overall, followed by the Looking and Angle scenarios. The scenarios were tested in the same sequence for every participant, with the Looking scenario as the second tested scenario. This fixed sequence could have had an influence on the overall score of the different scenarios, since participants might felt more comfortable with the prototype over time. Therefore, the Looking scenario might come in second after the Ears, because it was one of the first scenarios the participants tested with. Additionally, the participants had another concern regarding the Ears scenario, that they might be affected by the wind.

All three scenarios had a significant positive effect on all tested aspects when compared to the scenarios that did not communicate the intent (Neutral, Pre-sort). And the addition of a black stroke made participants feel more "seen" by the ADV, enhancing their sense of safety. This outcome can be attributed to the ADV's anthropomorphic features. The black stroke was perceived as eyes, creating a feeling of being "seen" by participants. Eyes are not only significant in overall human communication but also in traffic. The observational study indicated that while direct eye contact might not be critical, eye gaze can play an important role. Pedestrians use their eye gaze to communicate their intended direction. Additionally, this test may prove that eyes also contribute to acknowledging someone's presence, which is interconnected with feelings of safety in traffic scenarios. This correlation between acknowledgment and safety can be attributed to the principle that if someone has recognized your presence in traffic, this significantly reduces the likelihood of a collision.

The main limitations of this test were the visibility of the changing body panels in between scenarios, which unintentionally guided participants' attention and focus, and the fixed sequence of the scenarios. To address this, it was decided to make the changing of body panels less visible in order to evaluate the true intuitiveness of the signals and the sequence of the scenarios changed per participant.

Test day 3

The third test aimed to assess the intuitiveness of the signals when participants encountered the ADV unexpectedly and without prior knowledge. However, it was observed that the Ears scenario was not very noticeable, this can be due to the fact that participants saw the ears more as a decorative addition rather than a functional addition. Therefore, they probably did not focus on the ears during the surprise interaction. The feasibility of using a Nose to indicate the direction of the ADV was explored, but it did not prove successful. Both the Ears and the Nose are human attributes and it was expected that they would help with anthropomorphising the ADV and communicating the intent. However, in the context of body language communication, ears and noses don't play a significant role. Unlike eyes, human ears and noses do not typically move individually to convey messages. Therefore, the Nose and Ears might not prove as effective as the "eyes" in terms of body language communication. Furthermore, eyes offer the added advantage of making people feel acknowledged and seen, and consequently, safe. Hence, as a result of this study, noses and ears appear to be not as effective as eyes are in anthropomorphising objects and communicating traffic intentions. However, whether noses and ears could play a role in anthropomorphising and communication needs further research.

Both the Angle and Wing scenarios communicated a turn instead of a weave. This is due to the fact that both movements reminded participants of movements used in traffic to indicate a turn. The Angle was perceived as the vehicular dynamics of a cyclist who angles themselves to make a turn, and the Wing was perceived as how a cyclist sticks out their hand to indicate a turn. These scenarios prove that anthropomorphism can also have a downside. Therefore, you have to be aware of which signals you use to communicate certain intents, because you don't want to (unintentionally) pick a signal that already resembles another meaning.

Both the Looking small and Looking big scenarios were very clear and effective in communicating the intent. This was also due to the fact that both scenarios are very visible from an overhead perspective. Given that pedestrians tend to look down to observe the robot, the top and front upper part are the most visible points of the robot. Tests further indicated that individuals prefer to see the wheels, as their movement provides valuable information about the intended direction. Nonetheless, the wheels are positioned quite low and are not easily noticeable. Therefore, it is important that the most visible spot of the ADV communicates the intended direction.

One significant limitation of this test was that the participants did not observe the movement of the changing body panels, which could impact the visibility of the signals. As a result, the scenarios will be retested to validate the effect of movement on signal visibility.

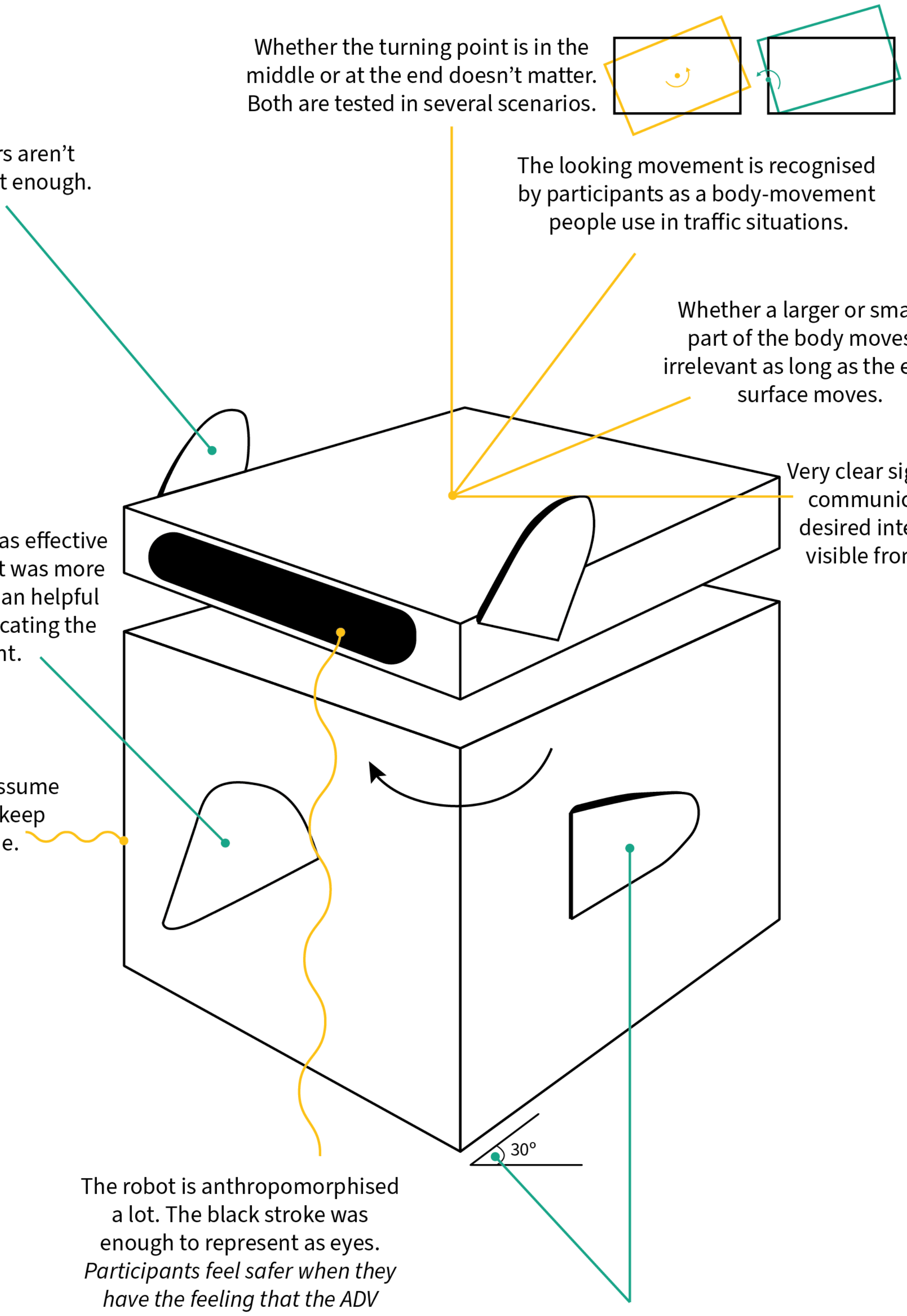
Test day 4

The fourth test focused on communicating the intent while the ADV was moving, instead of before. When examining the Ears it is clear that their movement is too delicate. Participants do not find it sufficiently apparent and perceive it more as a decorative aspect rather than something functional, i.e. some participants mentioned that the Ears potentially are being affected by the wind. In the second test the Ears were given a colour to make them stand out, this was applied half way through the fourth test as well. Even though this increased their visibility, the movement of the Ears remains small. To address this, one could enlarge the Ears, but this might have a negative impact on safety considering the limited space in certain situations. As discussed in ***test day 3*** of this conclusion chapter, the ears might also not be an effective communication means since humans don't use their ears during body language communication. Additionally, it could be argued whether the Ears and the Wings are actual body-language movements.

On the other hand, the wing movement is easily understood and intuitive; however, it conveys a different intent than what is desired. The use of flaps on the side that extend occasionally, just as with the Ears, could potentially become a safety issue. Even though ADVs have 360-degree vision and they would be able to determine whether it would be safe to put the movement in motion, it still extends rather far beyond its current body restrictions. The Wing and Angle scenario both communicate a different intent than intended. Therefore, both scenarios will be left out of the evaluation prototype. The Ears and Nose scenarios are both not as effective as the eyes are in anthropomorphising the robot and having a supporting function in communicating the intent. Hence, the Nose and Ears won't be part of the evaluation prototype.

The Looking scenario has consistently been one of the most intuitive and correctly interpretable movements throughout the test exploration. Whether a larger or smaller part of the body moves is irrelevant as long as the entire surface moves. Two different turning points have been examined, one in the middle and one at the bottom (see figure 23), both turning points communicated effectively. Both the addition of ‘eyes’ and ‘nose’ were explored within the Looking scenario. However, the ‘eyes’ proved to be more beneficial as they have a stronger potential for communication, given the importance of eye-gaze in pedestrian interactions. Participants also reported feeling “seen” by the ADV, which positively affected their sense of safety and comfort. Additionally, the inclusion of ‘eyes’ is expected to be more readily accepted by participants, as the presence of a black stroke already conveyed the concept of ‘eyes’, whereas a nose or beak did not have the same impact. Even though it could be interesting to explore the Nose addition, I have chosen to focus on creating a sense of eyes because of the mentioned reasons.

In the following chapters the exploration will focus on the evaluation prototype which will contain either the small or the big Looking scenario. The summarised version of this conclusion can also be found in a visual representation on the following page.



Whether the turning point is in the middle or at the end doesn't matter. Both are tested in several scenarios.

The ears aren't apparent enough.

The looking movement is recognised by participants as a body-movement people use in traffic situations.

Whether a larger or smaller part of the body moves is irrelevant as long as the entire surface moves.

Very clear signal which communicates the desired intent and is visible from above.

A nose is not as effective as eyes and it was more confusing than helpful in communicating the intent.

In the NL people assume that the ADV will keep to the right side.

The robot is anthropomorphised a lot. The black stroke was enough to represent as eyes. *Participants feel safer when they have the feeling that the ADV 'sees' them.*

Wing and angle scenarios communicate that the ADV will take a turn, instead of weave.

Figure 23, overview of the conclusions of the test exploration chapter.

Prototype design criteria

To achieve an evaluation prototype that focusses on correctly communicating the intended intent through body language, it is important to include all insights from previous research and explorations. Therefore, in this chapter I will present design criteria for the evaluation prototype that encapsulate these insights. Additionally, the criteria will include general considerations for ADVs, extending beyond the research scope of this thesis.

- **The prototypes behaviour should be predictable for the participants.**

- **The prototype should intuitively communicate its intent, through body-language, to the participants.** By communicating the intent, the behaviour of the ADV will be more predictable for pedestrians.

- **The prototype should strive to resemble existing ADVs**, to ensure that the results are also applicable to existing ADVs and that the design proposal can more easily be implemented. This also includes resembling the speed of the existing ADVs.

- **The prototype should be dynamic and change body panels automatically.** The prototype has to be in motion to resemble the real ADV-pedestrian interaction. When the body panels were manually moved, it unintentionally directed the participants' attention towards the signal itself. However, it is important for the signal to be perceived and interpreted independently, without any external guiding factors.

- **The design should make it easier for pedestrians to anthropomorphise the prototype by including 'eyes' (in one way or another).** This enhances participants’ sense of being “seen” by the ADV, improving their sense of safety. The inclusion of ‘eyes’ in the design has shown to have a more positive impact compared to the scenarios involving the Nose or Ears. This can be attributed to the communicative role that eyes play in traffic and overall interaction situations, whereas noses and ears are not typically used as visually communicative tools.

My personal goal is to use anthropomorphism in my advantage and implement an aspect that resembles eyes without it literally looking like eyes.

- **The prototype contains a signal that is visible from an overhead position.** Certain scenarios in the test exploration were easily overlooked, while the Looking scenario in both small and big variations stood out. This is, among other things, attributed to the fact that the entire surface of the ADV moves. This makes it highly visible from an overhead position, which is a common perspective during pedestrian-ADV interactions, since the ADV drives below eye level.

- **The prototype should maintain a comfortable distance to the participants.**

- **The prototype should be able to execute the intent signal without direct human involvement.** The signal should be executed from a distance to avoid unintended guidance of the participants attention.

9. Evaluation

To create an evaluation prototype that communicates the correct intended intent, to be able to test whether the chosen signal movement works, the evaluation prototype is based on the design criteria of the previous section. However, additional decisions have to be made to be able to create a complete prototype design. Therefore, this chapter aims to discuss and explain these decisions, encompassing aspects such as incorporating "eyes", the modification of body panels, determination of the turning point and the selection between the Big and Small Looking scenarios.

Evaluation prototype

Analysis and changes

The test exploration concludes by providing an overview of all the prototyping insights gathered throughout the process. Based on this overview, several design criteria for the evaluation prototype can be extracted. However, there are still some decisions to be made, changes to be implemented, and further research to be conducted in order to complete the evaluation prototype design. These aspects will be discussed in the following sections, but a brief introduction is provided below.

Certain aspects have already been identified during the testing exploration. The known aspects which require changes are:

- Eyes: it was evident from the test exploration that people feel safer when they perceive that the ADV “sees” them. Therefore, the evaluation prototype will incorporate “eyes,” and further exploration will be conducted to refine their shape.

- Changing body panels: In previous prototypes, the body panels were manually changed, unintentionally guiding participants attention. To eliminate this it is crucial that the evaluation prototypes’ body panels change automatically.

- Speed & size: The current speed of the ADV prototype is considered too fast. This can be addressed by using a heavier material and making the prototype larger to resemble existing ADVs more accurately.

The known aspects that require more research are:

- Turning point: both a turning point in the middle and at the end have been tested and shown to effectively communicate the desired intent. A choice will have to be made based on feasibility, desirability and viability.

- Big & small Looking: both Looking scenarios successfully convey the desired intent. However, a decision needs to be made regarding which scenario to utilize based on feasibility, desirability, and viability. Additionally, the constraints related to the thickness of the looking part will be explored.

The following sections will focus on addressing the changes, decisions and additional research of these aspects, all of which will contribute to the design of the evaluation prototype.

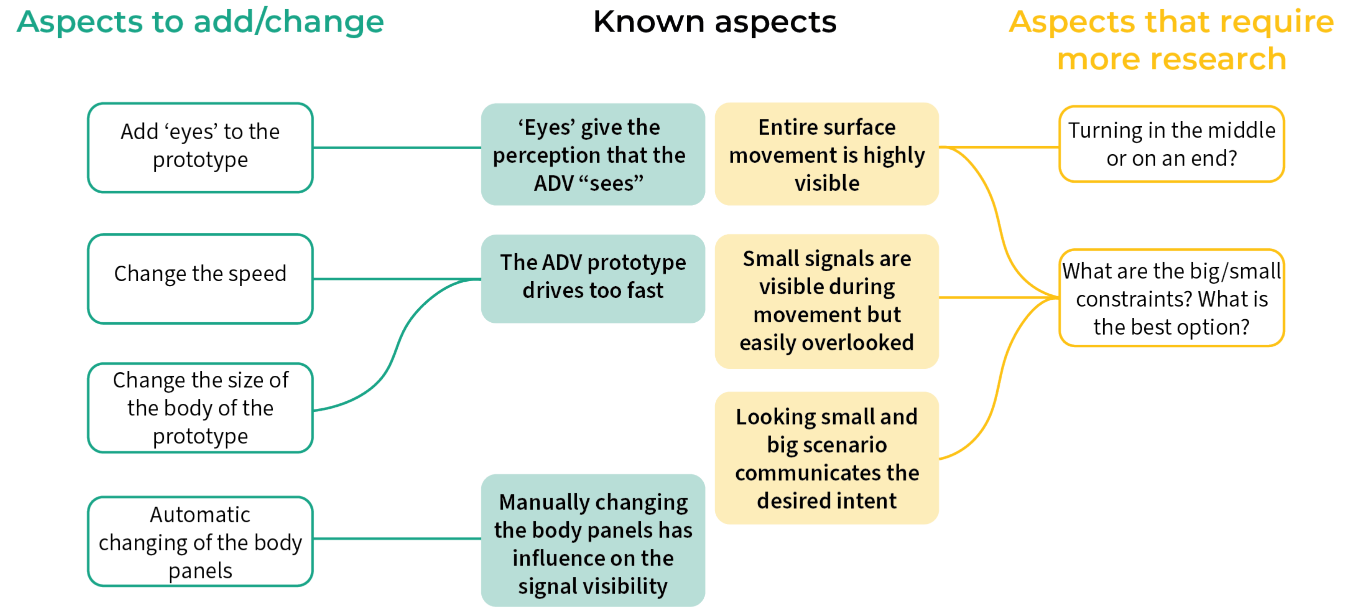


Figure 24, overview of which aspects need changing or additional research.

Eyes

The black stroke was first integrated during test day 2 of the test exploration. Participants reacted positively to this addition: they felt "seen" by the robot which increased their perception of safety. Similarly, we often find ourselves waiting to cross at a pedestrian crossing, assessing whether drivers have seen us. This careful anticipation comes from the understanding that when the driver did not see us, this can lead to potential dangerous traffic situations due to unresponsiveness. When the driver does see us, we trust that they will react accordingly to the situation, which in this case is that the driver will brake for the pedestrian crossing. Therefore, this feeling of being seen can be very helpful to enhance peoples sense of control and safety in multiple traffic situations.

Throughout the test exploration, participants consistently attributed human-like qualities to the prototype. This tendency to anthropomorphise causes participants to say "eyes" and "his face" when talking about the black stroke and the top part of the robot. Therefore, we can conclude that the black stroke is interpreted as eyes by the participants. Which causes this feeling of being "seen" by the robot, which gives people a more safe feeling in traffic since they now trust that the robot will react to them in that specific situation.

The current shape and visual representation of the black stroke is based on the design of existing ADVs. Nevertheless, there is still potential for improvement. Exploring different approaches to the representation of 'eyes' is an interesting aspect to look into.

Changing body panels

In the previous tests it became apparent that when the manual changing of body panels was visible to the participants that this guided their focus. To be able to know whether the Looking scenario is effectively communicating the intent it is important that the signal is visible without any unintended guidance. This is implemented by making the movement of the Looking scenario automatic via an Arduino, a servo-motor, and an IR-receiver. Pictures of the turning mechanism are presented in figure 25 below. A turntable, that works with a lazy Susan mechanism, is mounted on the top layer of the large box. The top box is mounted on top of the turntable, thus when the wheel turns the top part moves too. The servo-motor is mounted on the bottom of the top layer of the large box. The motor is connected with the turntable, thus when the servo-motor turns, the turntable turns and the top box turns too.

The servo-motor is connected to an InfraRed-receiver, and an Arduino board that works on a power-bank, which is all placed inside the larger box. The IR-receiver is programmed to work on the TV remote of my Sony television. When a specific button is pressed the servo-motor turns a certain degree to the left, waits for a few seconds, and then moves back to the original position. The Arduino code for the turning mechanism can be found in appendix C.

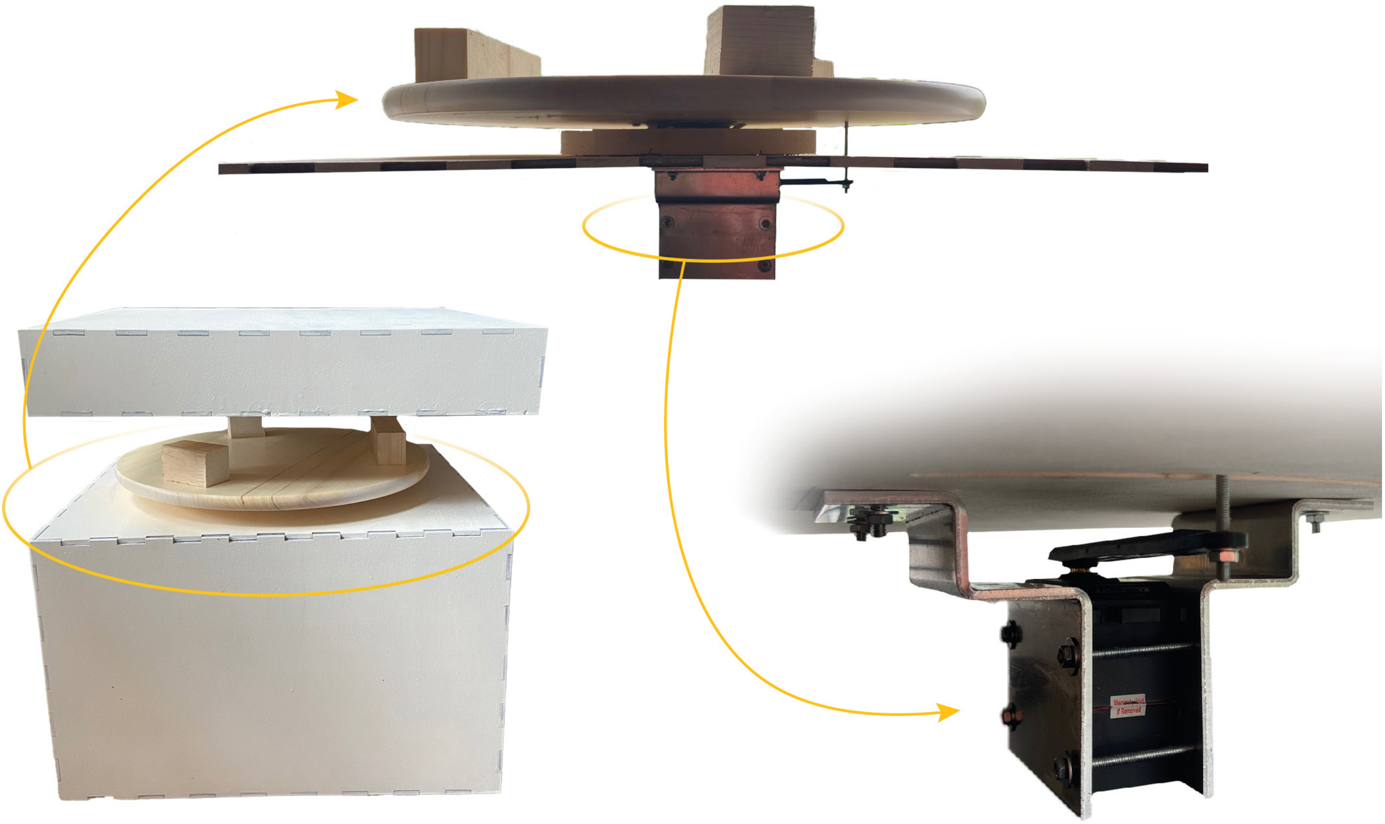


Figure 25, the turning mechanism of the evaluation prototype, from left to right: placement of the mechanism, side-view of the mechanism, the servo-motor below.

Speed & size

Design criteria have been established to ensure that all the gathered insights of the test exploration are implemented in the evaluation prototype. One of these criteria focuses on strengthening the resemblance of the prototype to existing ADV designs, with the goal of enhancing its market compatibility of the Design proposal. Considering that the previous prototype did not sufficiently match the speed and size of existing ADVs, modifications need to be implemented to address these aspects.

The previously moving prototypes made use of a remote controlled car which was attached to the bottom. Six of the 12 participants that tested a moving prototype have mentioned that the prototype moves too fast. The remote controlled car has a fixed speed of 10km/h, while according to Starship Technologies' Customer Support, their robots have a maximum speed of 6.5km/h.

When looking at the difference in speed it would be preferable if the prototype would resemble the existing ADVs more, to get more accurate test results. To achieve this, wood was chosen as the material for the prototype. Wood has the advantage of being heavier than cardboard, which can help slow down the remote controlled car. However, it is not too heavy to cause balance issues with small errors. Another advantage of using wood is that it can be precisely cut using a laser cutter, allowing for an exact replication of the size and dimensions of existing ADVs. This ensures that the prototype closely resembles the real-world ADVs in terms of size and proportion.

Figure 26 provides an overview of the new and old size of the prototype, showcasing the progress made in aligning it with the dimensions of existing ADVs.

Turning point

The changing body panels for the Looking small have been tested on two different turning points: the middle and on the end/back. Both turning points effectively communicated the intent signal, thus the decision has to be based on alternative factors.

A crucial aspect in comparing the two turning points is the overall balance of the ADV. Insights from driving behaviour studies during the Research Phase revealed the ongoing challenge faced by current ADVs in maintaining stability. Multiple online videos show ADVs lying on their side, unable to get back up. Therefore, the intent signal should not worsen an already unstable factor.

When considering both turning points, the turning point on the outside would compromise the ADV's stability by altering the centre of gravity. On the other hand, utilizing the central turning point would maintain the centre of gravity in its original position. Additionally, when exploring the possibility of using the moving top section as the ADV's 'lid' (which opens to receive/give packages), the central moving point allows for wider coverage of the area below. This adaptation makes it less prone to criminal activities.

Considering these aspects, the middle turning point emerges as the most preferable choice.

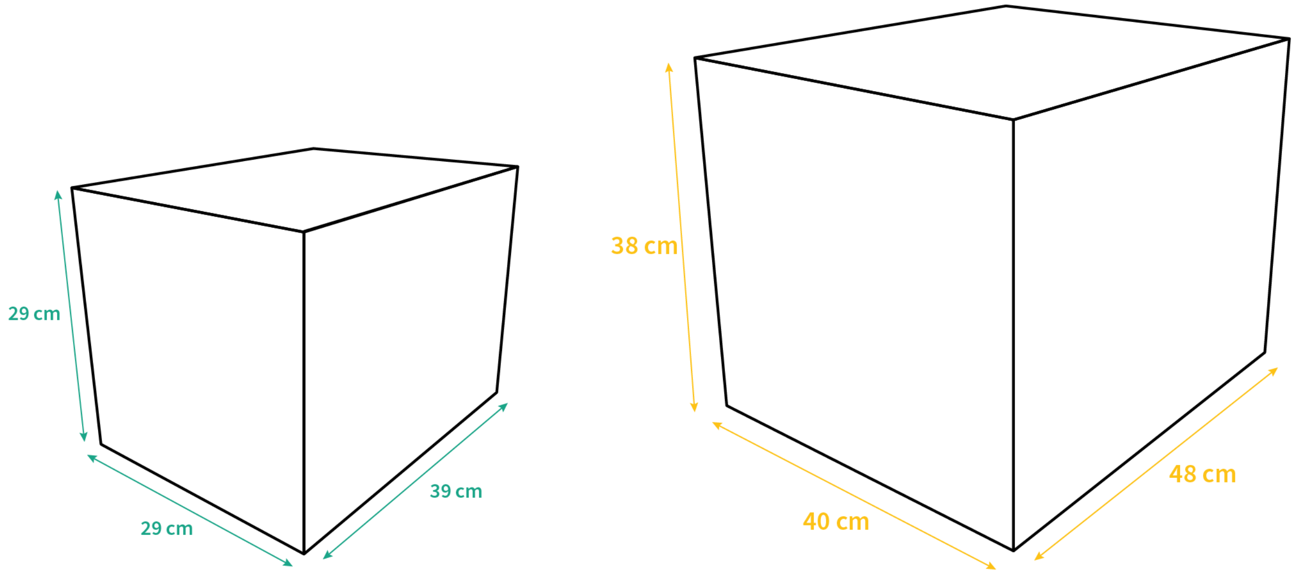


Figure 26, the different sizes of the ADV prototypes: on the left the cardboard prototype and on the right the wooden prototype.

Looking big & small scenarios

One of the primary design criteria is to ensure the intuitive communication of the correct intent. The Looking big and small scenarios have successfully achieved this goal. However, it is essential to consider other criteria before making a decision, such perception and electric efficiency.

During test day 4, a participant expressed a preference for the Looking small scenario, as it felt more agile compared to the Looking big scenario. To better understand this perception, we can delve into the 12 principles of animation, which originated from animators at Walt Disney Studios.

The 12 principles of animation

The 12 principles of animation were documented to help new animators achieve more realistic and visually interesting animations. One of these 12 principles is highlighted to answer the questions whether to choose the big or small Looking movement. This principle is Anticipation.

Anticipation: *Major action should be telegraphed such as reaching back before throwing an object (Schulz et al., 2019).*

Basically, animators make the figure execute an emphasized version of a movement which humans/animals also use in nature before executing the actual, bigger action. This is what is done in the design of the ADV as well. The Looking scenarios simulate the turning of the head or body towards the direction it wants to go in, which is an observed signal that pedestrians use in traffic situations. However, there is a difference between turning your head towards the desired direction and turning your body. When we turn our body, we are already partially engaged in the movement towards that direction, making it more difficult to stop abruptly. It is possible that people associate the turning of a larger part (Looking big) of the ADV with the turning of the entire body. Additionally, when looking at the Anticipation principle, a bigger anticipation movement means a bigger action movement.

This could both explain why the participant felt like the Looking big scenario was less agile than the Looking small scenario. It could be of influence that when moving a bigger part of the prototype it is going to be associated with a larger and less agile body movement. This does not mean that the ADV is not effectively communicating its intent. However, I expect that the less agile appearance of the ADV could have an impact on the seamless integration and the overall interaction in a pedestrian environment. This makes the Looking big scenario less desirable than the Looking small scenario.

Electric efficiency

Moreover, it is preferable for the ADV to minimize its power consumption while effectively communicating its intent. When turning a larger part of the ADV, it will require more power due to the increased weight. This is further influenced by the varying weight of the package carried by the ADV. Although the exact electricity needed for turning different-sized parts will not be calculated, it is assumed that the larger part, which includes the weight of the package, will necessitate more power to execute the movement compared to the smaller part.

Taking all these aspects into account, the Looking small scenario appears to be the more favourable choice for the evaluation prototype. Its perceived agility and energy efficiency make it an optimal choice for effectively communicating the ADV’s intent, while also ensuring a positive and comfortable experience for pedestrians and the ADV itself.

The evaluation prototype

The top part could be moved from a distance by using a IR-receiver and a remote which were connected to an Arduino and a servo motor.

Smaller looking scenario was perceived as more agile and is more energy efficient.

The size is larger than previous prototypes (40x48x38cm) and the material is *wood*.

Turning point in the middle was chosen since it provides overall more coverage for the layer below.

The prototype is heavier because of its material and size, therefore the prototype moves slower.

To make participants feel more safe the ‘eyes’ were incorporated.

Figure 27, a visual representation of the evaluation prototype including its decisions.

Evaluation test

The goal of the evaluation test is to examine whether the evaluation prototypes behaviour is more predictable for pedestrian, by effectively communicating the correct intent through body language. Therefore, the evaluation prototype (presented in figure 27) will be tested. This section will discuss the test set-up of the evaluation test, the prototyping scenarios, and the main insights including conclusions for future design guidelines.

Test set-up

The evaluation test is focussed on answering the following questions:

To what extent does communicating intent have influence on the perceived level of safety, trust and comfortability of participants?

How relevant do participants find communicating intent?

Is the intent communication correctly interpreted, visible and is it perceived as intuitive?

The test took place outside on a broad pavement. The prototype and the participant were facing each other at a starting position of around 10 meters apart. I explained to the participant that the prototype is an ADV and clarified its definition. The participant received information that we would enact two different scenarios, followed by a series of open-ended questions. The participant was asked to start walking, at which the prototype would start to move as well. From previous tests it was concluded that people automatically assume that the robot will keep to the right side, and communicating intent can be most beneficial in unclear and unexpected situations. Therefore, in both scenarios the prototype would weave around the participant on the left side, since this is an unexpected scenario. In one scenario there was no intent communication and in the other scenario the intent was communicated by the "looking small" scenario. Which scenario was played out first varied per participant.

After playing out both scenarios, participants were asked open-ended questions regarding both scenarios. In framing these questions I referred to them as 'scenario one' and 'scenario two', avoiding terms as 'with / without intent'. This approach aimed to avoid (unintended) steering the answers of the participants. Additionally, it was aimed to assess whether participants independently saw the difference between the two scenarios and understood what this difference meant.

Prototyping scenarios

The insights of the test exploration leaded to design criteria for the evaluation prototype. These criteria can be found on page 41 and the decisions that lead up to the prototype are explained in the previous sections. The images of the evaluation prototype can be found in figure 27 on the previous page. The evaluation prototype focusses on the Looking small scenario, in combination with an automatic turning mechanism and a black stroke of 'eyes'.

In both scenarios the prototype would weave around the participant towards the left side. In one scenario the prototype communicated its intent by turning the top part to the left, in the other scenario there was no intent communication. Both scenarios were tested with 8 different participants.

During the Research phase it became apparent that people struggle with feeling safe and comfortability with ADVs in traffic, and that they don't have a lot of trust in them yet. Therefore, safety, trust and comfortability are important aspects to take into account during the evaluation test, to test whether communicating intent can have a positive impact on these aspects. The questions regarding *safety, trust and comfortability* were relatively similar. Containing questions such as:

• How safe did you feel in both scenarios?

• Was there a difference in how safe you felt between the two scenarios? --> Why?

• Is there anything that could be changed to the prototype to make you feel more safe in the future?

For trust and comfortability the questions were the same but then regarding trust and comfort instead of safety.

Other important aspects to evaluate during this test are: *relevance, visibility, intuitiveness* and whether the signal is correctly *interpreted*. All these aspects refer back to the design scope:

Design a delivery robot that ***communicates*** its **intent** through **body language** to make its behaviour more <u>intuitively</u> ***predictable*** for pedestrians.

Main insights

To what extent does communicating intent have influence on the perceived level of safety, trust and comfortability of participants?

In general, participants experienced a sense of safety, comfortability and trust in the ADV during both scenarios. Nonetheless, when the ADV communicated its intent: 8/8 felt more safe, 7/8 felt more comfortable and 6/8 had more trust in the ADV and the traffic situation. The reasons participants gave for this increased sense of safety, trust and comfortability were related to: the ability to predict what the next move of the ADV was going to be; and the sense that the robot has seen them because its reacting to them.

Six participants mentioned that they were confused and unsure what was going to happen when there was no intent communicated. They mentioned that their confusion and doubts were taken away when the robot did communicate its intent. The mentioned reasons that caused this difference are similar to the reasons mentioned for the difference in safety, trust, and comfortability. Two participants mentioned it was because they were able to predict the direction of the robot, three participants mentioned that the robot was "looking around" which meant that it was turning in that direction, and one participant said that "it seemed like he was paying more attention to the situation, which made me feel less like I was about to be hit." Thus the feeling of being seen and being reacted to, in combination with the ability to predict gives participants not only more sense of safety, comfortability and trust, but also causes less confusion and doubts for other traffic participants.

How relevant do participants find communicating intent?

As previously indicated, participants felt more safe, comfortable and had more trust in the robot due to: their ability to predict its movements, and the responsive behaviour of the robot lead to the feeling of being recognised. This increased sense of safety, comfortability and trust contributed to the fact that all participants felt that communicating intent was a relevant and important difference.

> **“This indicates the direction of the robot, because there are some kind of eyes on the front, so I interpret that it is looking there, so it is going in that direction.”**
>
> *- Participant 5.5, answer to what the intent signal meant to them*

Is the intent communication correctly interpreted, visible and is it perceived as intuitive?

Among the group of eight participants, seven correctly identified the meaning of the movement of the top-half as indicating the robot's intended direction. An initial misinterpretation arose from one participant who initially associated the intent signal with a turn rather than a weave. However, after asking more detailed questions, this participant realigned their understanding to match the others. Each participant found the signal to be clearly visible and all of them immediately and intuitively understood the meaning of the signal.

Five participants commented that the intent movement resembled a head turning, or someone who is looking around. This aligns with the inspiration for the signal movement. One participant thought it resembled a body turning toward the desired direction, while another perceived it as a gesture of pointing at something. Despite the fact that not all participants agreed on the exact physical representation of the robot's signal, they all unanimously agreed on its intended meaning, which holds greater significance.

> **“I felt safer because I could predict where it was going, because he was looking to that side.”**
>
> *- Participant 5.5, answer to why they felt safer*

> **“I had more confidence because it is indicated what will happen. Otherwise I think he has not seen me and I have to step aside myself.”**
>
> *- Participant 5.6, response to why they found the intent signal a relevant difference*

> **“It felt very human to me as a person also looks where he is going, so it indicated to me which direction he was going.”**
>
> *- Participant 5.4, answer to what the intent signal meant to them*

Conclusion evaluation test

The evaluation test serves to validate whether the designed prototype aligns with the established design scope. The design scope of this thesis is:

Design a delivery robot that ***communicates*** its **intent** through **body language** to make its behaviour more intuitively ***predictable*** for pedestrians.

Among the participants, 7 out of 8 accurately interpreted the intent signal as indicating the desired direction. They unanimously agreed on the signal's visibility and intuitively understood its meaning, even before initiating the weave. Hence, it can be concluded that the prototype effectively, understandably, and intuitively communicated the desired intent.

The evaluation prototype communicated its intended direction by "looking" into the desired direction. Participants recognised this movement from previous traffic situations: a pedestrian looking around or turning its head. Therefore, it can be concluded that the prototype effectively made use of body language to communicate its intent.

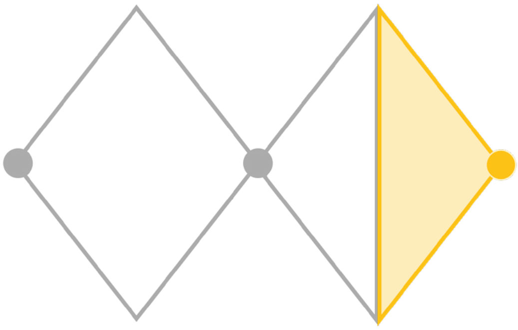
The Research phase revealed the challenges current ADVs face in establishing a sense of safety, comfort, and trust among pedestrians. However, the evaluation test indicated that the communication of intent resulted in participants feeling safer, more comfortable, and more trusting in the overall traffic interaction. This enhancement can be attributed to two key factors:

- Participants had the ability to instinctively and correctly predict the future movements of the robot;

- The robot reacted to the participants, which gave them the reassurance that the robot has seen them and thus won't hit them.

Communicating intent creates the ability to predict future movements and gives people reassurance of being acknowledged. These combined effects further amplified the feelings of safety, comfort, and trust. This stands in contrast to the insights from the Research phase literature. In chapter 5, Communication guidelines for ADVs, we learned that predictability in behaviour could be achieved through intent communication and that heightened trust and comfort could be achieved through communicating the vehicle's driving state. However, it appears that intent communication alone can achieve enhanced feelings of safety, trust *and* comfortability. This could likely be attributed to the fact that intent communication gives participants a sense of acknowledgement and being "seen", which creates an additional enhance in feelings of safety, trust and comfortability. Therefore, intent communication could be the only necessary means of communication to solve both the unpredictable behaviour and the feelings of discomfort and distrust.

In conclusion, the evaluation test confirmed that the prototype aligned with the design scope: effectively utilizing body language to communicate its intent correctly and intuitively. This led to improved predictability, acknowledgement, and ultimately, an enhanced sense of safety, comfortability, and trust in the behaviour of ADVs. Furthermore, the evaluation test provided prove that solely intent communication could potentially be enough to solve both the unpredictable behaviour, as the feelings of distrust and discomfort that pedestrians feel towards ADVs. The sense of acknowledgment and the perception of being noticed are intertwined with these results, and delving deeper into this subject through further research would be intriguing.



Design proposal

The design proposal resembles the last stage of the Double Diamond Design Process. This phase contains a conducted timing study, the three design guidelines on which the design concept is based, and the concept that includes the designed intent signal from the evaluation test. This phase concludes the thesis with a discussion and conclusion on the overall work of this project.

10. Design proposal

To achieve a design concept that enables ADVs to portrait more predictable behaviour towards pedestrians, one last iteration is needed over the evaluation prototype. Therefore, in this chapter the timing of the movement is examined by a user study, design guidelines are presented that encapsulate the insights of this thesis in a more broadly applicable way, and a concept sketch is presented to give an idea of how the examined intent signal could be implemented in an ADV design. This concept is based on the established design guidelines, in combination with the knowledge gained throughout the research journey.

Timing of movements

To effectively implement the design proposal, it is crucial to determine the timing of intent communication and understand the constraints of people's perception based on the distance between them and the ADV. These factors play a significant role in optimising the design for seamless interaction and effective communication in traffic. Hence, a study was designed to investigate the timing and distance factors in determining the optimal communication distance. The study was structured as follows:

Study set-up

The study consists of three different scenarios and it aims to find the comfortable distance at which ADVs and pedestrians can co-exist. This study contains five participants.

In scenario #1 the participant and the ADV would be facing each other at a distance of 250cm. The participant would stay put and the ADV would slowly approach them. The participant had to state when they would start to feel uncomfortable and when they would want the ADV to stop and don't come any closer (referred to as the 'no-go zone'). Both distances would be measured using a measuring tape.

In scenario #2 the same questions were asked and the participant would stay put while the ADV would slowly approach the participant. The only thing that was different is that at the 250cm the ADV would communicate its intent through the Looking small scenario. Again both distances were measured: when they started to feel uncomfortable and when they wanted the ADV to stop.

In scenario #3 the ADV and the participant are standing side to side. The ADV is placed on four different distances from the participant: 10cm, 20cm, 30cm, and 40cm. For every distance the participant had to elaborate on how they felt and whether the ADV was too close, scoring it from 1-3 (with 1 being too close, 2 being okay if the space is limited, and 3 being good). After testing the four distances, the participants had to stand at a distance at which they felt 100% comfortable.

Results

The results from scenarios #1 and #2 revealed that participants felt more comfortable with the ADV approaching closer when it communicated its intent compared to when it did not. The average distance at which participants started to feel uncomfortable without intent communication was 138cm (σ = 43,2). When the ADV did communicate its intent, participants felt uncomfortable at an average distance of 116cm (σ = 26,8). This indicates that the ADV can approach approximately 22cm on average closer when it effectively communicates its intent. Interestingly, the no-go zone distance remained relatively consistent between scenario #1 and #2 per participant. Therefore, when considering all participants and both scenarios, the average stop distance was found to be 72cm (σ = 24,3). A visual representation of these results can be found on the next page in figure 29.

Due to the significant variation in the standard deviation of the average distance among all participants, it was decided to divide them into two distinct clusters. Cluster 1, consisting of two participants, expressed discomfort when the ADV approached too close. Without intent communication, their uncomfortable distance averaged at 185cm (σ = 7.07), while with intent communication, it decreased to 145cm (σ = 7.07), resulting in a 40cm difference. Additionally, their no-go zone began at an average distance of 98cm (σ = 8.53).

Cluster 2, consisting of three participants, displayed a higher tolerance for the ADV approaching closer. Without intent communication, their uncomfortable distance averaged at 107cm (σ = 5.77), and with intent communication, it decreased slightly to 96cm (σ = 2.89). Cluster 2's no-go zone commenced at 53cm (σ = 5.16). For a visual summary of the findings of cluster 1 & 2, please refer to figure 30 and 31 on the following page.

Scenario #3 examined participants' perception of distance when the ADV was positioned on the side rather than the front. Participants rated their comfort levels on a scale of 1-3, with specific distances assigned to each rating: 10cm = 1; 20cm = 1,2; 30cm = 2,2; and 40cm = 3.

The results indicated that distances below 20cm were generally considered a no-go zone, with only one participant mentioning potential acceptance in narrow pavement situations. From 30cm onward, participants were comfortable if no additional space was available, and from 40cm onward, they found the distance appropriate for passing situations. Interestingly, when participants were asked to stand at the most comfortable distance assuming an infinitely wide pavement, they consistently chose a range of 60-70cm (average: 64cm, σ = 4.18). This average aligns with the grand mean of objective interpersonal distance for comfort as supported by personal space literature (Gifford, 1983).

A visual representation of the comfort range between participants and the ADV on the side can be found in figure 28.

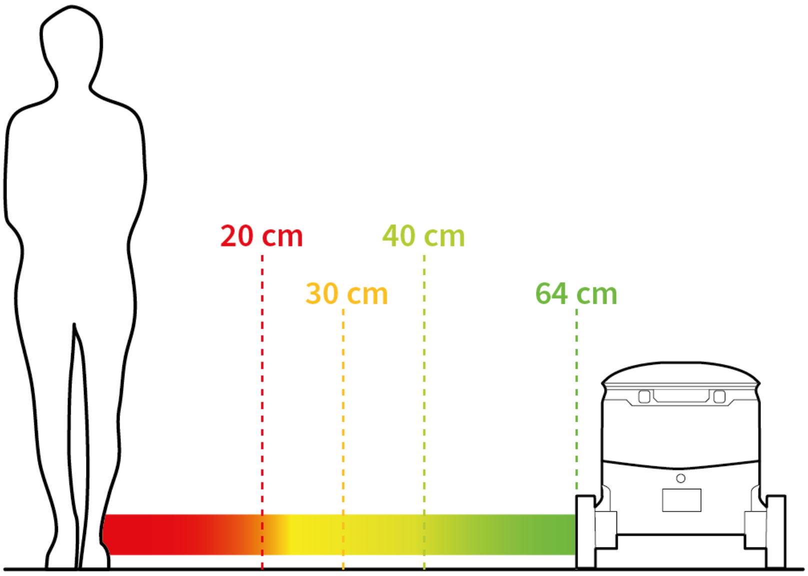


Figure 28, overview of the results of scenario #3

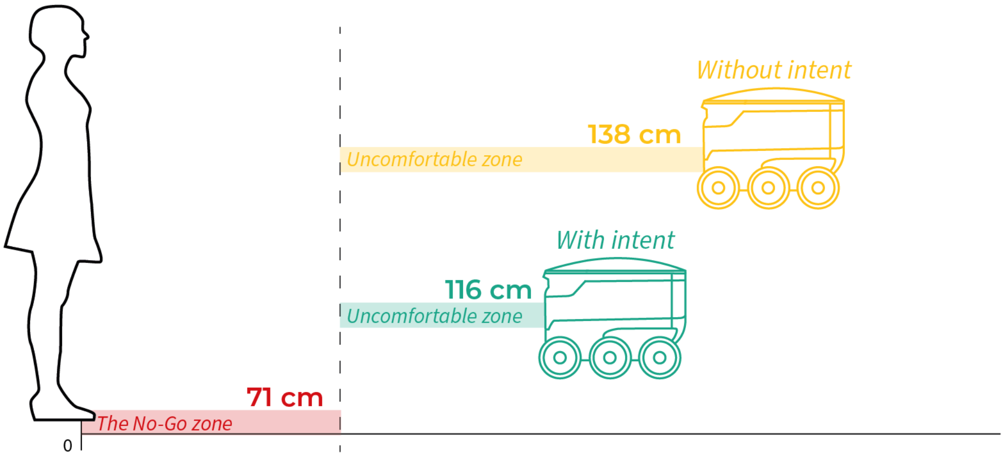


Figure 29, overview of the ***average results of all participants*** *of scenario #1 (without intent) and scenario #2 (with intent).*

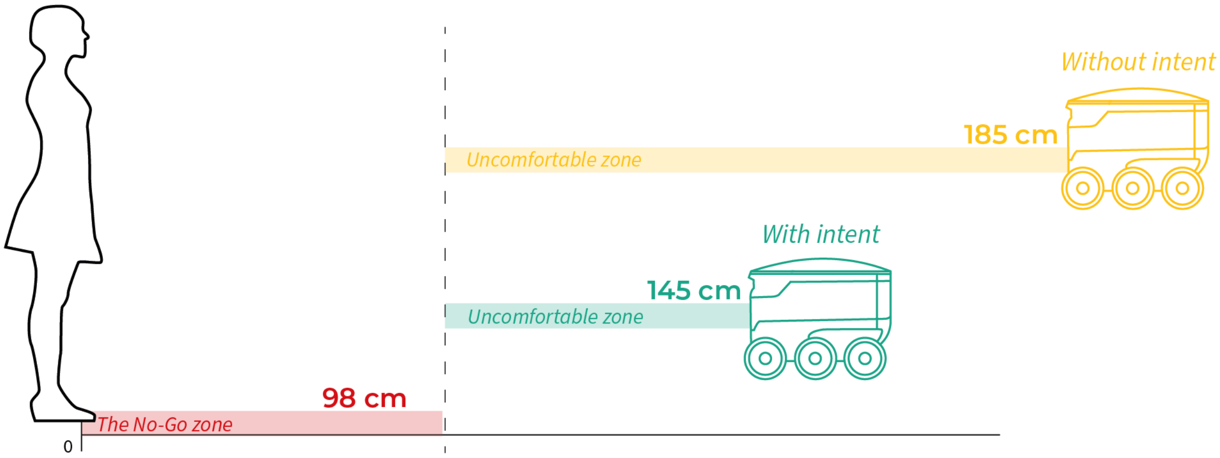


Figure 30, overview of the ***average results of cluster 1*** *of scenario #1 (without intent) and scenario #2 (with intent).*

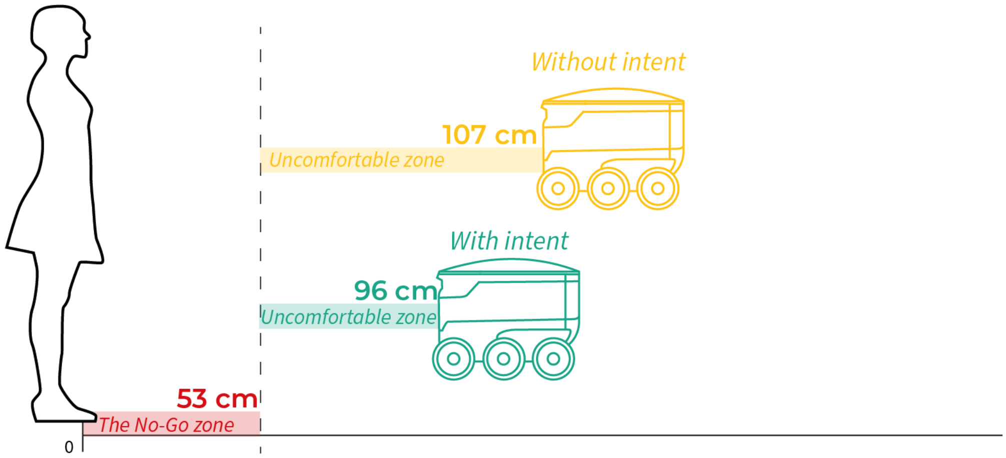


Figure 31, overview of the ***average results of cluster 2*** *of scenario #1 (without intent) and scenario #2 (with intent).*

Insights from Timing study

The timing of movements study provided valuable insights into participants' comfort levels and preferences regarding distances with the ADV. Additionally it gave insights into the difference intent communication can have on the comfort-levels of people.

From scenario #1 and #2, it was observed that participants felt more comfortable when the ADV communicated its intent, allowing the vehicle to approach approximately 20cm closer on average compared to scenarios without intent communication. However, the no-go zone remained relatively the same. It can be concluded that people will feel comfortable for a longer time when the ADV communicates its intent, but the intent communication does not have impact on the no-go zone of people. On average this zone is around 72cm when the ADV and the participant are in a face-to-face orientation.

In scenario #3 this no-go zone was explored further, but now the participant and the ADV were side-to-side. Distances below 20cm were generally considered a no-go zone, while distances from 30cm onward were acceptable if no additional space was available. Interestingly, participants consistently chose a range of 60-70cm as the most comfortable distance assuming an infinitely wide pavement, aligning with the grand mean (65,7 cm) of objective interpersonal distance for comfort as supported by personal space literature (Gifford, 1983).

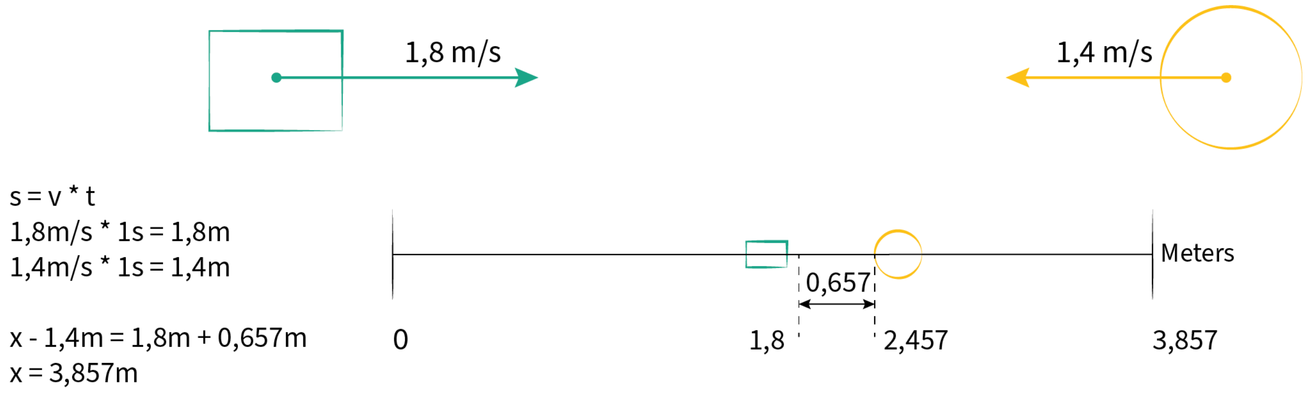
These findings suggest that effective intent communication and appropriate distances are crucial factors in enhancing participant comfort and trust in ADV interactions. The results can be utilized to determine the timing and distance at which the ADV should communicate its intent and initiate weaving movements.

Established timing of movements

The results and insights obtained from the timing study highlight the significant impact of distance on pedestrian comfort during ADV interactions. It is crucial to determine the appropriate timing for the ADV to initiate its weave movement before the distance becomes too small and individuals start feeling uncomfortable. Furthermore, determining the optimal timing to communicate the intent is crucial for effective ADV-pedestrian interactions. By understanding when to convey the intent most effectively, the ADV can ensure clear and intuitive communication with pedestrians, enhancing their understanding and trust in the ADV's actions (Domeyer et al., 2020; Kruse et al., 2014; Petersen & DeLucia, 2022; Risto et al., 2017, as cited in Keesmaat, 2020). The following calculations are based on a dynamic situation in which both the pedestrians as the ADV move towards each other and where there is enough space for the pedestrian and the ADV to co-exist.

Participants mentioned that from 40cm on they are good with the ADV passing them on the side. The frontal distance lies between 45cm - 110cm with the five participants. Therefore the grand mean of objective interpersonal distance for comfort will be used, which is 65,7cm (Gifford, 1983). Thus the range in between the ADV can come is 40 cm - 65,7 cm.

It takes the ADV prototype approximately 1 second to weave from a frontal position into a not colliding position. The Starship robot moves at 6,5 km/h (=1,8 m/s) (Starship Technologies, n.d.) and the average walking speed of people is 4-5 km/h (Fletcher & Wilson, 2022), which is rounded up for safety reasons: 5km/h (=1,4 m/s). With this information the distance at which the ADV should start the weave action can be calculated and is at 3,857 meter, the calculation can be found in figure 32.



s = v * t
1,8m/s * 1s = 1,8m
1,4m/s * 1s = 1,4m

x - 1,4m = 1,8m + 0,657m
x = 3,857m

Figure 32, calculation of the distance at which the ADV should initiate the weave movement.

It is important to note that the calculated distance is based on a simplified scenario where both the ADV and pedestrians maintain the same speed and direction. In reality, the ADV may need to slow down while initiating the weave movement, and when the participant and the ADV are positioned side by side, the distance can be decreased to as close as 40cm. Therefore it is assumed that the distance at which the ADV should start the weave is in reality shorter than the calculated 3,857 meters. The objective of this thesis is that the ADV correctly and intuitively communicates its intent to make its behaviour more predictable- and the interaction more comfortable for pedestrians. Therefore it is not necessary to pinpoint the exact moment the ADV should initiate the weave, but an estimated range will be sufficient. Based on the calculated distance of 3,857m, the estimated range for initiating the weave movement is set between 3,5m and 4m.

Calculating the timing of the intent movement is a bit more complex. An experiment was conducted in an attempt to identify the distances at which pedestrians communicate their intent. However, the results were inconclusive, suggesting that the timing is influenced by various factors and relies mainly on pedestrian intuition. Therefore an estimation will be made considering the timing of the intent movement.

For optimal communication, the intent movement should commence before the distance between the ADV and pedestrians reaches the range of 3,5 and 4m. Additionally, it is estimated that the intent should be visible for a minimum of one second before initiating the weave movement. Considering the average speed of pedestrians and ADVs, within one second, the pedestrian and the ADV would have covered approximately 3,2m in distance. Hence, the estimated communication distance for the intent should be around 7m (≈ 4m + 3,2m) to ensure sufficient visibility and comprehension of the intent signal.

Design Guidelines

To ensure that the research and findings of this thesis are more broadly applicable in the field of mobility and beyond, three overarching design guidelines are established. These guidelines are formulated to ensure their broad applicability, offering an abstract yet enriched representation of the valuable insights gained through the research journey. The three guidelines are based on interpretation, visibility and relevance. Each guideline starts with the knowledge and insights it is based upon and it ends with recommendations for future research within the scope of that specific design guideline.

Interpretation

In the conclusion of the test exploration phase (can be found on pages 38-40), anthropomorphism was discussed to play an important role in the ability to let an object simulate a human-like gesture. Participants observed a cardboard box which was moved in certain ways to simulate human-behaviour. Participants would refer to the cardboard box as a "he" and mentioned attributes such as "eyes" and "face". Therefore, anthropomorphism can help to signal an intent if that gesture or movement of the object reminds participants of existing gestures or movements that carry the intended meaning of the intent.

Important to note is that in the test exploration conclusion it also became apparent that when the Nose and Ears scenarios communicated the intent that eyes normally do, it didn't have the same positive effect. This was attributed to the fact that ears and noses don't carry the same significant communication role, in body-language, as eyes do. Therefore, it is important to note that using a different body part than humans do, to communicate the same intent, does not always have the same effect. Hence, it is important to simulate the body movement with a body part that suffices the function and position of communicating the intent.

From the test exploration it also became apparent that anthropomorphism can have an unintended negative effect. Participants thought that the Angle and Wing scenarios meant that the robot was going to make a turn, because these signals reminded them of existing movements that carried a different intent than planned. Therefore, it is important to be aware of the possibly different meanings certain gestures already carry in specific cultures.

In chapter 9, Evaluation, it is discussed whether the Looking big or small scenario was preferred. In this section the 12 principles of animation are presented, with one in particular: Anticipation. This principle relies on exaggerating existing movements of humans in cartoons, by having the figure execute an emphasized version of the movement before moving into the bigger action. Hence, when a bigger anticipation movement is executed, you can expect a bigger action movement. Therefore, there was a difference established between the Looking small and big scenarios. The Looking big scenario resembled more the turn of a body into a certain direction, which would explain why one participant felt that the Looking big scenario was less agile. The Looking small scenario on the other hand resembled more the turning of a head in the desired direction. Therefore, it is not only important to know whether a specific movement already has a meaning in a different context, but it is also important to consider the timing and flow of that specific moving part.

Anthropomorphism, the insights form the test exploration, and the anticipation principle of animation all lead to the following design guideline which is based on interpretation.

The **interpretation** design guideline is as follows:

The flow and timing of moving specific body-parts that humans use to signal intent can be used to signal that same intent in other situations.

• Suggesting that the position and function of those body parts suffice.

• Beware of similar but different signals as they may trigger ambiguities, for example: head turns to signal intended heading; body turns to initiate the heading.

This guideline could benefit from further research in the following areas:

• Expanding the scope of identifying relevant human signals. While this thesis has explored certain human signals through observation studies (figure 15 on page 19), a more comprehensive analysis could be conducted.

• The exact flow and timing of moving specific body-parts should be established through iterative experimentation and refinement.

Visibility

It is important for the intent signal to be clearly visible for the pedestrians. Therefore, there is a design guideline which encompasses the insights gathered in the area of visibility. During test day 3 in the test exploration, the Ears scenario appeared to be not visible enough. Participants did not notice the Ears intent signal when they were surprised by the robots encounter. A colour contrast was added to the Ears to help with the visibility of the signal. The colour contrast had a positive impact on the visibility. Additionally, when the Ears scenario was retested in test day 4, the movement of the Ears had an even better impact on the visibility of the intent signal.

Another aspect to consider is the sight-lines during an interaction. Given that the ADV's position is below the average eye level of adults, pedestrians must look downwards to observe the ADV. Therefore, the sight-line will be at the top and the upper-part of the front of the ADV. This also became apparent out of the tests since participants mentioned that the Looking big and small scenarios were most clear because they were very visible from an overhead position. Sight-lines are important to take into account because, if you want to communicate something important it should be right at the sight-line so people can not easily miss it.

In addition to size, colour, movement, and sight-lines, the overall design and contrasts contribute to highlighting certain aspects of a design as well. This leads to the **visibility** design guideline:

Use contrast in size, colour, and (particularly) shape-change, within sight-lines, to make moving parts more noticeable. As a condition for their movements to be legible.

- Small robots have the most visible sight line to their top.

This guideline could benefit from further research in the following area:

- Formgiving. Currently the research of this thesis has not been focussing on how the formgiving of the overall design could enhance the signal communication. It would be interesting to see whether i.e. certain shapes could have a positive effect on intent communication or on the overall pedestrian-ADV interaction.

Relevance

The last design guideline is focused on achieving a concept that is relevant to the current pedestrian-ADV interaction. During the pedestrian observation studies of chapter 4, Pedestrian behaviour, pedestrians were observed from an overhead position in a busy pedestrian-traffic environment. It became clear that pedestrians start communicating their intended direction already early on. Furthermore, I found that the intent signals became more and more apparent when the distance between the two pedestrians decreased. Therefore, I assume that when the distance between pedestrians in a heads-on conflict becomes smaller, the discomfort rises and a decision has to be made who is going to yield. This is precisely where intent communication proves invaluable.

As discussed in the evaluation test conclusions (which can be found on page 49), intent communication increases the feeling of safety, trust and comfortability. These enhancements are a direct result of participants' ability to anticipate on the robots actions, because they were able to predict its future moves. Additionally, the robot's responsiveness to the presence of the participants gave them the feeling of acknowledgement, which contributed to the enhancement of the feelings of safety, trust and comfortability. Therefore, when traffic participants are on a collision course, it can provide helpful to communicate the intent when both parties start to question which next moves to take. Furthermore, communicating intent will help with providing a more safe, trust worthy and comfortable traffic interaction between both traffic participants.

In the previous chapter the timing study conducted has been discussed. The timing study highlights the difference that communicating intent can have on pedestrian's trust in a safe and comfortable passing while they do not move. It also highlighted that when people start to feel uncomfortable differs. However, every participant allowed the robot to come closer when it was communicating its intent. Therefore, by communicating intent, you increase the trust that the other traffic participants have in a safe and comfortable passing.

The insights of the observational pedestrian studies, the evaluation test, and the timing study all contribute to the relevance of communicating intent. Which leads to the **Relevance** design guideline:

The weave intent should be communicated when people start considering who should weave during a heads-on conflict. This is to avoid harm and to increase their trust in a safe and comfortable passing while they're not weaving themselves.

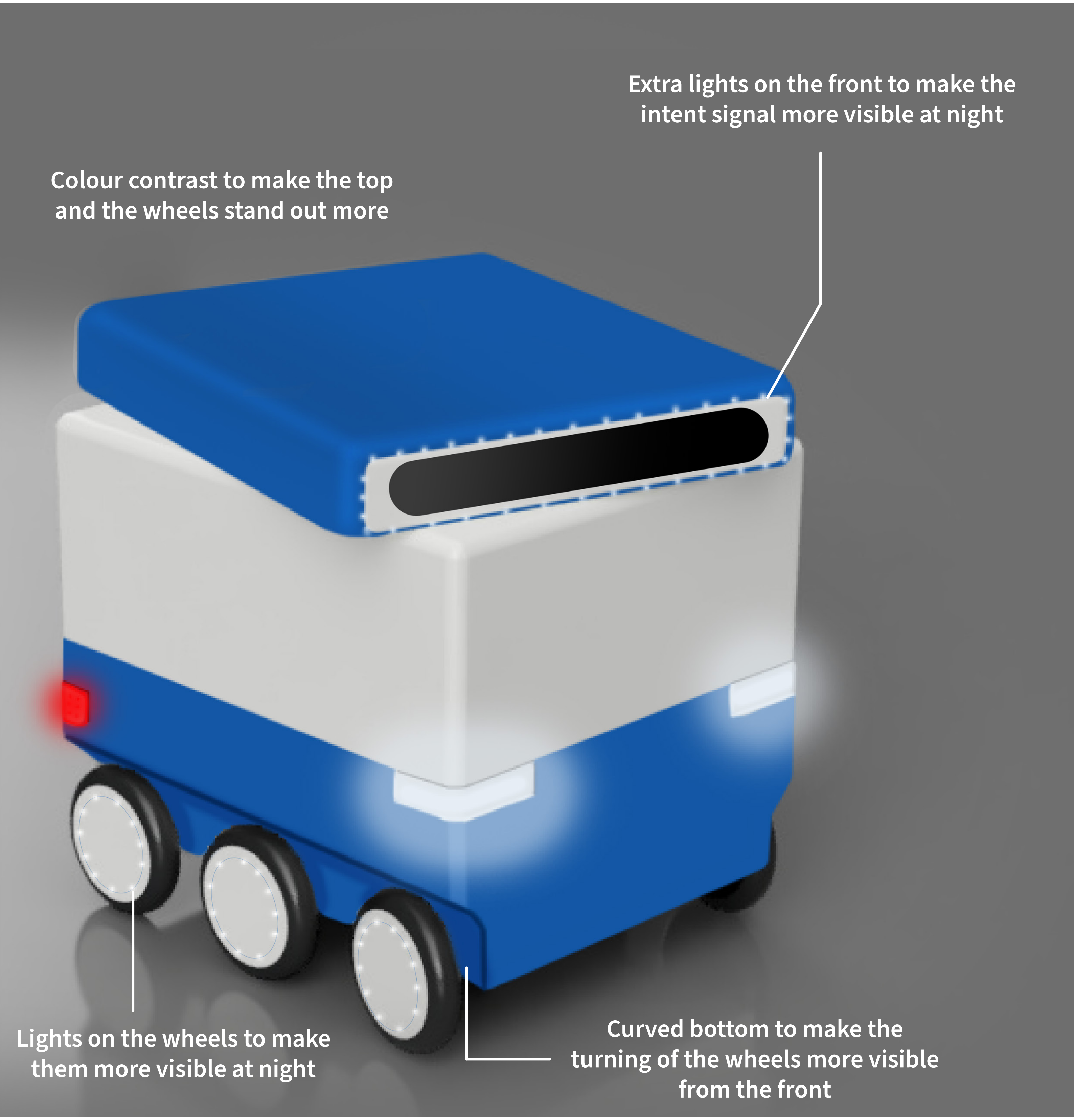
- If there is the possibility to weave early on, signalling the weave might not be necessary.

This guideline could benefit from further research in the following areas:

- Whether signalling might not be needed when weaving early on has to be tested, currently this is an assumption based on the pedestrian observational research.

- There are individual differences in when people feel the need for the ADV to weave, as shown in the timing study. Additional research is needed to determine the exact 'when' to weave, with a more extensive group of participants.

Design concept

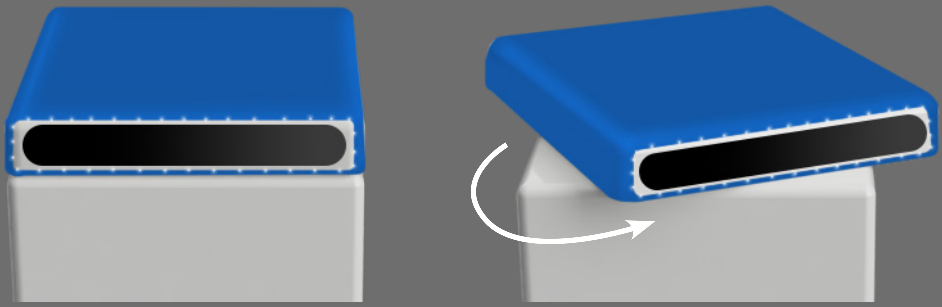


Extra lights on the front to make the intent signal more visible at night

Colour contrast to make the top and the wheels stand out more

Lights on the wheels to make them more visible at night

Curved bottom to make the turning of the wheels more visible from the front



The top indicates the intended driving direction of the ADV

This top is also the lid that opens up

Open the robot on the back to receive the package

Rounded and curved overall shape to give the robot a more friendly appearance

To achieve a more safe and comfortable traffic interaction between ADVs and pedestrians, the focus of this thesis has been about designing predictable behaviour for ADVs. This chapter discusses the concept of the ADV design that displays predictable behaviour through intent communication. The concept is based on the literature, test exploration and evaluation insights gathered throughout this thesis. The design concept has been presented on the previous two pages and the following sections will discuss the details of certain design decisions, such as the overall formgiving, the intent signal, and the shape of the eyes.

Overall formgiving

The design concept is a visual representation of how an ADV could look like while incorporating the tested intent signal. For the design of the ADV it was important that the intent signal was clearly visible. A colour contrast was added to enhance the visibility of the top. Blue was chosen as colour because when considering colours in cultural expression, blue stands for: truth, dignity, power, coolness, and melancholy (Wegman & Said, 2011). Furthermore, tech companies often use blue and white in their designs or logos (e.g. Twitter, Facebook, Samsung, PayPal) making the colour blue resemble technology as well. White was chosen as a good contrast colour for the blue while also keeping the overall design clean and calm.

The overall formgiving of the robot resembles the existing robots such as the Starship Technology robot, the Kiwibot and the Amazon Scout, and I decided to give the ADV three wheels. These decisions were based on a survey about the appearance of ADVs done by De Groot (2019). The Starship Technologies robot was preferred most on overall appearance and robots with less than three wheels were overall rated lower. This was due to the fact that the robots with two wheels reminded participants of remote controlled toy cars, which are often associated with reckless driving behaviour. Therefore, the design of the concept resembles the size and overall formgiving of the Starship Technologies robot and has three wheels. The measurements of the concept can be found in figure 33.

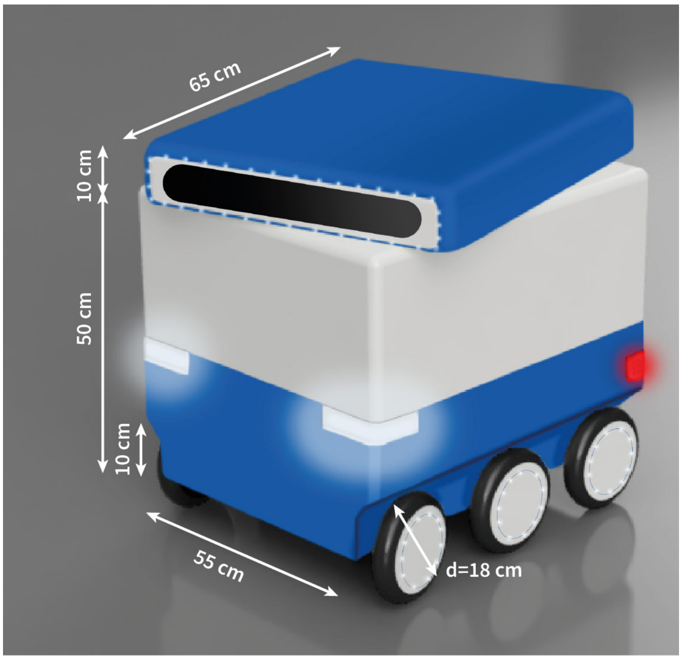


Figure 33, the measurements of the ADV concept.

People have a tendency to associate forms and shapes of robots with other objects they know and categorise these in their head. Therefore, it might be interesting to understand how this influences the perception of ADVs. De Groot (2019) has examined this and he found that for the function of the delivery robots people prefer rectangular shapes over very round shape. This can be attributed to the fact that packages and delivery vans, even the DHL bike all resemble these rectangular shapes as well. Therefore, the shape of the overall design of the ADV concept stays close to this familiar rectangular shape related to packaging parcels.

The colour contrast is not only applied to the top part of the robot but also to the bottom. The reason for this is to make the wheels of the robot stand out as well. During the first test day of the test exploration, it became apparent that people feel very confident in predicting the direction of the robot, when they're able to see the direction of the wheels. Therefore, the colour contrast is applied to make the wheels stand out more. However, this is not the only technique that is enforced to make the wheel more apparent. There are blue reflective circles placed on the side of the wheels which are covered with little white lights, to ensure the visibility of the wheels in the dark. Additionally, the shape of the bottom of the robot is curved on the side (see figure 34), this ensures a higher visibility of the turning of the wheels from a colliding view.

The overall formgiving of the robot is based on the visibility design guideline.

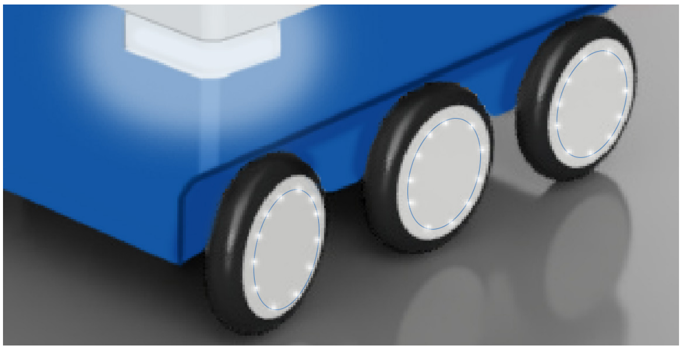


Figure 34, zoomed-in image of the bottom part of the robot.

Intent signal

Multiple different intent signals were tested during the test exploration and in the Evaluation chapter (chapter 9) it was decided to focus on the Looking small intent signal. The Looking small scenario has been incorporated into the concept. The top part of the robot turns and 'looks' into the direction it would like to go into next. This 'looking' movement is a smooth movement from centre to left/right, once it is positioned all the way to the left/right it will stay here for 1 full second, before moving back. The turning towards the left side is visualised in figure 35 below. Once the top starts moving back, the wheels will turn into the desired direction and the ADV will start to weave. Five participants mentioned in the evaluation test that the design could be even more safe or trustworthy with additional lights. The main reasoning behind that was to ensure the visibility of the intent movement at night. Therefore, little white lights are incorporated around the front of the top, around the black screen. There is the possibility to give lights a more prominent role in ADV design, by giving them e.g. more important functions. However, the focus of this thesis was to communicate intent through the use of body-language, specifically by shape changing body parts. Therefore, do the lights in this concept only serve a supportive role, to make the intent signal more visible during the day and especially at night.

The package is located in the body of the robot and the top layer of the body seals the package off from the outside world. This top part also contains a turn table in the middle which makes the top part able to spin around. The top part is mounted on this turn table (see figure 36 for a visual representation of the placement of the turn table). When the ADV reaches the customer, and the customer unlocks the ADV with their phone, the top layer of the body will unlock (this is a lock-system that a lot of ADVs currently use). Consequently, the user has the option to access the robot at the back, as illustrated in figure 37. A grip hole at the back is made to make it easier to grab the bottom of the top layer to open the ADV.

The design of the intent signal is based on the interpretation, visibility, and relevance design guidelines.

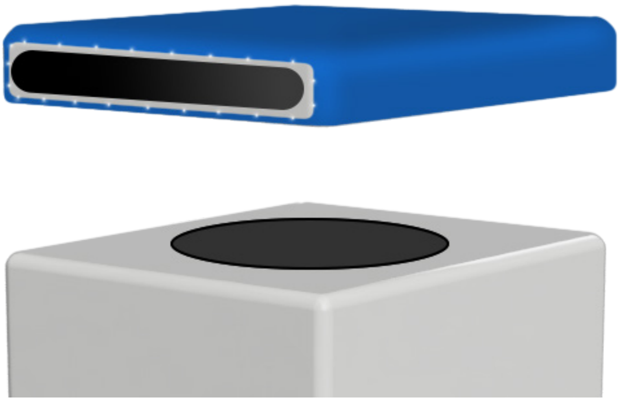


Figure 36, visual representation of the placement of the turn table.

Figure 37, how the robot can be opened up from the backside.

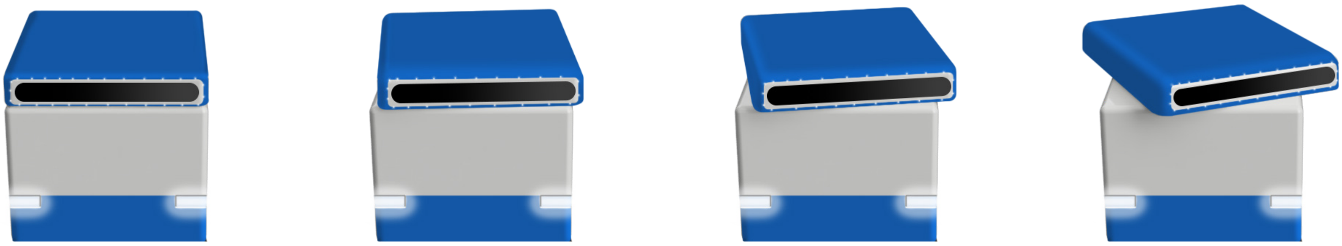


Figure 35, the turn movement of the intent signal step by step.

The Eyes

The design concept contains the same shape of 'eyes' as the evaluation prototype. However, other eye shapes have been explored. In figure 38 multiple different eye options are displayed.

The white lining around the chosen screen makes the eyes stand out even more due to the colour contrast. The contrast between white and black is bigger than between black and blue. Therefore, I have chosen to leave the part around the screen white. Furthermore, the shape is rounded to make it appear friendly and approachable. Some ADVs display actual eyes on the front, which makes them appear very friendly and approachable. However, the downside to this is that they become too approachable. For example, the DeliRo has eyes and the Japan News (2023) mentioned that children love playing with the robot. This can cause traffic hazards and can make it difficult for the robot to do its job. Therefore, I have chosen to stay away from displaying eyes on the screen. It became apparent from the test exploration that only a black stroke resembles 'eyes' enough to make people anthropomorphise the robot. Therefore, only a black screen will be enough to make the top part look like a turning head that is looking around into its intended driving direction.

The shape is inspired by the shape of the black screens of existing ADVs such as the Starship technologies robot and the Amazon Scout. However, these robots have the black screen curved around the side and this concept has the screen solely at the front. The reason for this is that the eyes of humans are also placed on the front of our faces, thus to make the screen resemble eyes that look around it would make sense to place them at roughly the same position as humans. Following the design guideline of interpretation.

Concept conclusion

The concept introduced in this chapter is based on the three design guidelines that were established based on the literature, studies and explorations that have been conducted throughout this project. The design concept is centred around the intent signal which is refined through the test exploration phase. The concept presented serves as a visual representation of how the intent signal might seamlessly integrate into an ADV's design. Importantly, this designed intent signal has the potential to be adaptable to various design shapes beyond the one presented. However, the intent signal has been tested in the embodiment of a rectangular shape. Therefore, further research is needed to determine whether this intent signal conveys the same message when it is integrated into different design shapes.

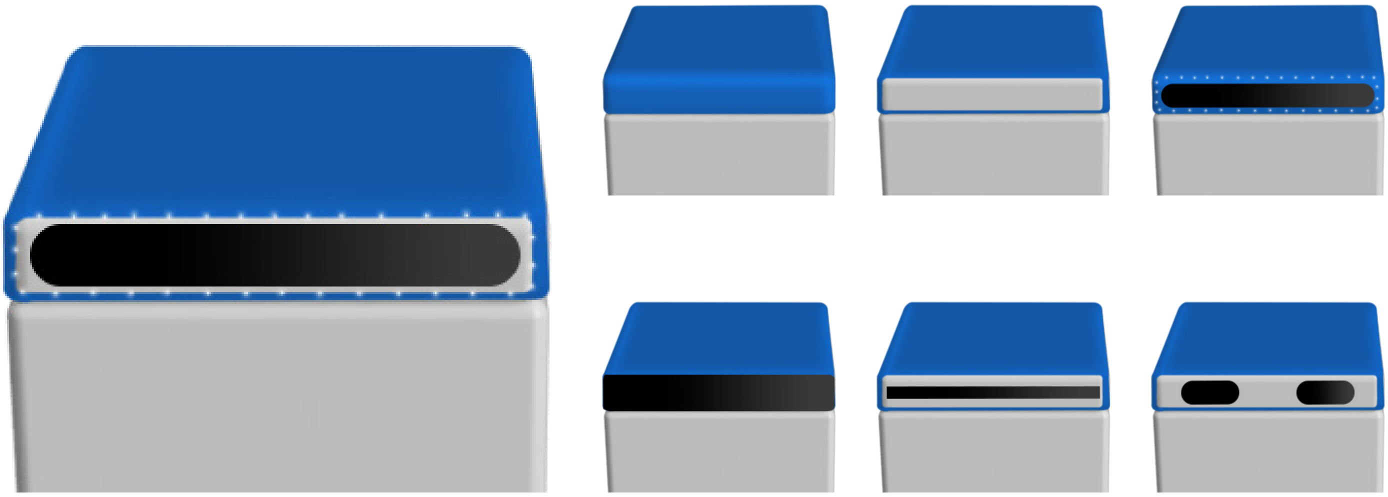


Figure 38, multiple different screen options, the bigger image on the left is the chosen option.

11. Discussion

The following sections reflect on the overall project and try to summarise the main insights in combination with critically examining the objectives. This is followed by limitations of the study and recommendations for future research. Over the course of this graduation project an intent signal was designed for an autonomous delivery vehicle to make its behaviour more predictable for pedestrians. The design scope was stated as follows:

Design a delivery robot that *communicates* its intent through body language to make its behaviour more intuitively *predictable* for pedestrians.

The following sections will discuss aspects of the design scope, containing the main insights and a critically reflection on whether this aspect has been achieved throughout the research and exploration of this project.

Communicating intent & predictable behaviour

Literature showed that to achieve predictable behaviour you need to clearly communicate your intent (Domeyer et al., 2020; Helbing & Molnar, 1995; Petersen & DeLucia, 2022). The evaluation test proved that by communicating the intent, participants felt that they were able to predict the future movements of the ADV. Furthermore, the results from the evaluation test showed that by communicating intent the feelings of safety, trust and comfortability also enhanced. This is in contrast with the literature, which stated that trust and comfortability could be reached through communicating the driving state (Lee & Kolodge, 2020, as cited in Domeyer, 2020; Skinner & Spira, 2003).

The evaluation test highlighted that intent communication not only facilitates predicting the robot's behaviour but also fosters a sense of acknowledgment from the robot towards the participants. This acknowledgement stems from the robot's reaction to the existence and presence of the participant by communicating its intent. This reaction gives participants the perception that the robot has noticed them. Therefore, the participants believe that the likelihood of getting hit by the ADV is reduced compared to situations in which they are unsure whether or not the robot has detected them. Hence, this perception of detection contributes to increased feelings of safety, trust and comfortability.

The increased feelings of safety, trust and comfortability by the perception of detection are not necessary connected to intent communication. These feelings are provoked because the robot is reacting to the participants. I believe that another reaction could possibly provoke the same outcomes. However, the positive outcome is that communicating intent is enough reaction to lead to these positive effects.

Chapter 3, ADV interactions, discusses the problems which current ADVs are facing. The most significant interaction problems were related to unpredictable behaviour and distrust, which both lead to an unsafe and uncomfortable ADV-pedestrian traffic interaction. The results of the evaluation test highlight the increase of feelings of safety, comfort, and trust of participants during the ADV-pedestrian interaction. Therefore, it can be concluded that the intent communication leads to more predictable behaviour and that intent communication is a possible means to solve both interaction problems.

Additionally, I would like to add two general insights that can contribute to a more safe and comfortable ADV-pedestrian interaction. Literature and the observational studies on pedestrian behaviour showed that Dutch people generally keep to the right side and will expect others to do so as well. Therefore, it would be preferable if the ADV would follow these cultural 'rules' in traffic for passing and overtaking situations. Figure 12 shows how these situations are embedded in the Netherlands, but be aware that this differs per culture. The second insight is that the wheels of the robot communicate its immediate direction. Therefore, does the direction of the wheels give a lot of useful information and will it be preferable if this turning is clearly visible for traffic participants. This is partly already implemented in the design of the concept, however I find this insight too rich to not explicitly mention it in combination with its impact on predictable behaviour.

Body language & intuitively understandable

The reason for focussing on body language was based on the pedestrian observational studies. I created an understanding of the environment in which the ADVs would take place (pedestrian rich environments), and I analysed the key-players in this environment (InCoPs/pedestrians). I mapped different human signals and gestures that people use to communicate the desired direction. This map of human signals and gestures is not complete, but it provided enough information to start the test exploration with.

By basing the intent signals that the ADV would communicate on human signals, I wanted to achieve a signal that was intuitively understandable since it could be interpreted from past traffic experiences. During the test exploration it became apparent which signals were intuitively understandable and communicated the desired intent. The Looking big & small scenarios provided to be the best choice for the evaluation prototype. The Looking scenario was intuitively understandable because it reminded people of a person who is turning his head- or looking into the desired direction. Anthropomorphism played a role in the effectiveness of this scenario. By turning only the top part and including a stroke to resemble eyes, people perceived the top part as an actual head with eyes, even though it did not physically resemble a head with eyes.

The evaluation prototype undeniably used body language to convey its intent and all participants of the evaluation test mentioned that they intuitively understood what the intent signal meant. Therefore, the designed intent signal is intuitively and effectively communicating the correct intent to pedestrians.

Designed intent communication signal

The literature and studies conducted during the Research phase lead to the identified interaction problems. The means chosen to solve these problems was communication, with the focus on intent communication through body language. Multiple different prototypes were tested during the test exploration and the most promising scenario was implemented into the evaluation prototype. The knowledge, insights and exploration of these steps lead to the design concept presented in this thesis. The concept will be discussed in the terms of desirability, feasibility and viability.

Desirability: The problems of current ADVs that were identified were primary interaction problems. Pedestrians were unable to predict the behaviour of the ADV. This became a safety concern since traffic decisions are mainly based on anticipation, and when you are unable to predict you can not anticipate. Furthermore, was there a strong distrust in ADVs which resulted in an uncomfortable feeling for pedestrians during an ADV-pedestrian interaction. Pedestrians won't have a say in whether they want to share the pavement with ADVs, because the government will decide this for them. Not only users of the ADVs will encounter them, all InCoPs will be affected by the implementation of ADVs. Therefore, it is very important to ensure a safe and comfortable embedding of these ADVs in pedestrian environments.

The design of the ADV presented in this thesis contributes to a safe and comfortable embedding. By clearly communicating its intent through body language, participants felt more safe, more comfortable, and had more trust in the ADV and in the overall traffic interaction. Hence, this design can contribute to a safer and more comfortable embedding of ADVs in traffic, thereby fulfilling a desirability of not only users of the product, but all InCoPs that will be confronted with the implementation of ADVs.

Feasibility: The system of opening the ADV does not have to change when implementing this intent signal. An additional top part could be mounted on top of the original robot, whilst implementing a turntable in between. Since only the top part will be moving, it will not need much power, keeping the robot energy efficient. The concept is a visual representation of how the intent signal could be implemented into an ADV design. However, the intent signal is the core of the design and could be implemented on many different e.g. shapes and sizes.

Viability: The intent signal is based on the research and exploration done throughout this project. The design guidelines resemble very rich insights that could be broadly applied in the field of design, even beyond the mobility sector. The design concept is based on these guidelines and it provides a solution for the problems current ADVs are struggling with. The turning top is based on human-like gestures of intent communication. Therefore, it is a universally recognizable form of communication.

Limitations

Participant demographics

Multiple different tests have been conducted during the course of this thesis. With the exceptions of the observational studies, all the other studies had test participants from a similar age, cultural and educational background. I can imagine that elderly pedestrians react differently to an ADV than young adults do. The participants in the test were roughly around the ages 18-26, Dutch and highly educated. The timing study already highlighted that pedestrians will have individual preferences considering when the ADV should weave and how much distance it should keep at all times. Therefore, testing the design again with a bigger and more diverse group of participants could yield more nuanced insights into optimal timing and understanding for pedestrian-ADV interactions.

Speed of the ADV

The speed of existing ADVs is generally cut-off at around 6km/h. The remote controlled car, that was used to make the prototypes in the test exploration and the evaluation test move, had a fixed driving speed of 10km/h. Especially during the test exploration, participants commented that the driving speed of the ADV was too fast and intimidating. In the evaluation test the weight of the prototype slowed the remote controlled car down, making it resemble the existing ADVs more. However, I was still unable to change the speed, because it was slower but still fixed. During the timing study I needed to be able to stop the ADV at the moment people started to feel uncomfortable and this provided to be a challenge considering the speed of the remote controlled car. To work around this, I pressed the velocity button really fast and short, instead of holding it down. This resulted in the prototype to move forward with short shocks of speed. This could have caused people to feel uncomfortable sooner, since the robot moved very aggressively and unpredictably. Therefore, having a prototype that is able to adapt its speed is preferable to be able to test different scenarios. Literature also shows that by slowing down, you also convey a message to the traffic participants around you and because of the fixed speed and the absence of a break option, I was not able to test these aspects.

Expansion to complex traffic scenarios

The scope of this thesis was to examine a heads-on conflict situation between one pedestrian and one ADV, in which the ADV had to clearly communicate if it was going to weave towards the right or left side of the pedestrian. All the tests in the test exploration and the evaluation test were focussed on this scenario. However, when ADVs will drive on the pavement they will find themselves in more difficult traffic situations with more traffic participants. Expanding the scope of the intent communication by testing it in more complex traffic scenarios is essential for a comprehensive understanding of the concept's effectiveness.

Test set-ups

Over the course of this project, multiple user tests were conducted. It proved to be more difficult than expected to conduct the tests the exact same way for different participants. On multiple occasions the prototype would malfunction in one of the following ways: the prototype would fall on its side, and the prototype started to weave too late which resulted in hitting the participants. The impact of such a hit was very small, since it was made of cardboard. However, the participants behaved more cautious when interaction with the prototype after the hit, which affects the results. This late weaving was a combination of human error and malfunctioning in the response-time of the remote controlled car.

These malfunctions caused small differences in the set-up of user tests, which could have impacted the results. Hence, it would have been more ideal if all the various tests had been standardized for each participant, ensuring consistency and minimizing potential variations in results.

Recommendations

Design Guideline recommendations

In the Design guidelines chapter the design guidelines are presented and each of the guidelines came with certain recommendations for future research. Starting with the Interpretation design guideline:

One of the recommendations of this guideline included a broader mapping of human signals. This thesis has explored certain human signals though observational studies. However, it is recommended to broaden the scope and conduct a more comprehensive analysis. Mapping out a range of human signals that can be used for effective communication between ADVs and pedestrians, such as: body language, gestures, expressions and even auditory cues.

Another recommendation that is linked with this guideline is the exact determination of the flow and timing of moving specific body-parts. Optimising this would enhance the naturalness and comprehensibility of the intent communication and possibly make it even more intuitive. This exact flow and timing can be established through iterative experimentation and refinement. An attempt has been done in this thesis to determine the timing of the intent signal, by recording when people started to feel uncomfortable. However, this study proved that participants have an individual preference for this. Therefore, to determine this exact timing of the intent movement more studies need to be conducted with a broader and more diverse group of participants.

The Visibility design guideline states that more research has to be done on the exact formgiving of the robot design. The research of this thesis was not focussed on the formgiving of the robot, but on how the design could visibly signal the desired direction of the robot. It would be interesting to see whether e.g. certain shapes could have a positive impact on the visibility of the intent communication, by investigating the impact a physical design can have on e.g. how an ADV is perceived. In the evaluation test participants mentioned that they would feel more safe and comfortable if the robot would look less aggressive, which was related to the squared shape (sharp corners) of the robot. By understanding how the robot's appearance influences communication effectiveness, you can contribute to designing more ADVs that are perceived more safe, trustworthy, and that pedestrians feel more comfortable with.

The Relevance design guideline stated two recommendations. The first recommendation is based on an assumption. The assumption is that when two participants are in a colliding path, and one of the participants moves out of the way at a very early stage, they don't need to communicate their intent to weave. This assumption is coming from the fact that it seems that intent communication is important at the moment people start to wonder who will move out of the way. When one participant already moves out of the way very early on, the other participant might not have wondered yet who was going to move. And based on that scenario, the participant who weaves does not have to communicate its intent. However, this is based on an assumption. Therefore, to be able to confirm this statement, this still has to be tested in future research.

The other recommendation that emerged from the Relevance guideline is focussed on the exact timing of the weave. The recommendation of Interpretation already mentioned the importance of timing and flow of the signal movement, but this is focussed on the exact timing of the weaving. In the timing study an attempt was made to give a distance range in which the ADV should start to move. A no-go zone was determined but it remained difficult to pinpoint the distances since these were based on individual preferences. Therefore, an additional study is needed to determine the exact timing of the weave.

Lights and displays

The focus of this thesis was on communicating intent through body language, in particularly the shape changing of certain body parts. Lights have not been in the scope of this thesis, which was mainly due to a study from Dey et al. (2020). In this study 70 different eHMI (external Human Machine Interfaces) systems were analysed and 69% of these eHMIs were using lights and displays. Since lights was one of the most used means to communicate information in eHMIs, it pushed me to follow a different path. However, the fact that so many eHMIs do use lights and displays also means that they could prove to be an interesting addition to an ADV eHMI communication system. For the design concept I decided to implemented lights as a supportive addition to the designed intent signal, with the main function being visibility at night. However, I believe that lights can play a more significant role in ADV designs and I would encourage others explore the possibilities of merging the insights from this study with lighting design.

Furthermore, I deliberately stayed away from creating human like facial expressions on the screen of the ADV. Even though I had my reasons, I do believe that there are possibilities for the display screen that can be explored. However, be aware of the fact that it can make a robot too approachable.

12. Conclusion

This project has delved into an alternative way to sustain the growing last mile delivery market, by using Autonomous Delivery Vehicles (ADVs). The focus of this thesis was on designing predictable behaviour for ADVs by making them communicate their intent through the use of body language. Hereby addressing the challenges which current ADVs face, such as displaying unpredictable behaviour and conveying feelings such as distrust and discomfort with pedestrians. Through literature research, observational studies, and an extensive exploration of various scenarios, movement patterns, and visual cues, this project has examined the complexities of intent communication.

In conclusion, this project successfully identified interaction problems of current ADVs, researched the most promising means to tackle the interaction problems, discovered intent signals used by pedestrians in traffic, and implemented these signals into the embodiment of an ADV. The designed intent signal was based on a human movement, namely a turning head-, someone looking into the desired walking direction. By basing the intent signal on a human-like movement, participants were able to recognise the movement from past experiences, making the intent signal intuitively understandable. The evaluation test showed promising results, by communicating the intent signal the behaviour of the ADV was more predictable for the participants, leading to increased feelings of safety, trust and comfortability. Furthermore, the intent signal evoked a feeling of acknowledgement, because the reaction of the ADV to the situation gave participants the perception that they were detected by the robot. This perception of detection also lead to increased feelings of safety, trust and comfortability.

While the evaluation test showed great promise in solving the interaction problems, it is recognised that further research, evaluation, and collaboration are necessary to fully understand the effectiveness, feasibility, and safety of the proposed intervention. The limitations and recommendations provide valuable directions for future research and serve as a foundation for implementing intent communication in the mobility sector.

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Appendix

A. Confidence score

This section is related to the first test day of the test exploration phase. It contains the table of the confidence scores of all the tested scenarios.

Test day 1

Test set-up

The first test day aims to answer the following question:

What types of body panel changes can be designed to intuitively communicate the robot's intended direction (left or right) around a pedestrian?

This is explored by making a prototype that resembles an ADV and by changing the orientation of the different body panels, to communicate a desired direction.

In this test the participant stands face-to-face and directly in front of the prototype (referred to as the ADV). To test whether the participant correctly understands the intended direction that the ADV is communicating, the participants are asked whether the ADV is going to pass them left or right. To avoid the possibility of random guessing, participants were also asked to indicate their level of confidence regarding the determined direction the ADV was intending to go in. They were asked to rate their confidence on a scale of 1-5, with 1 being not confident and 5 being very confident.

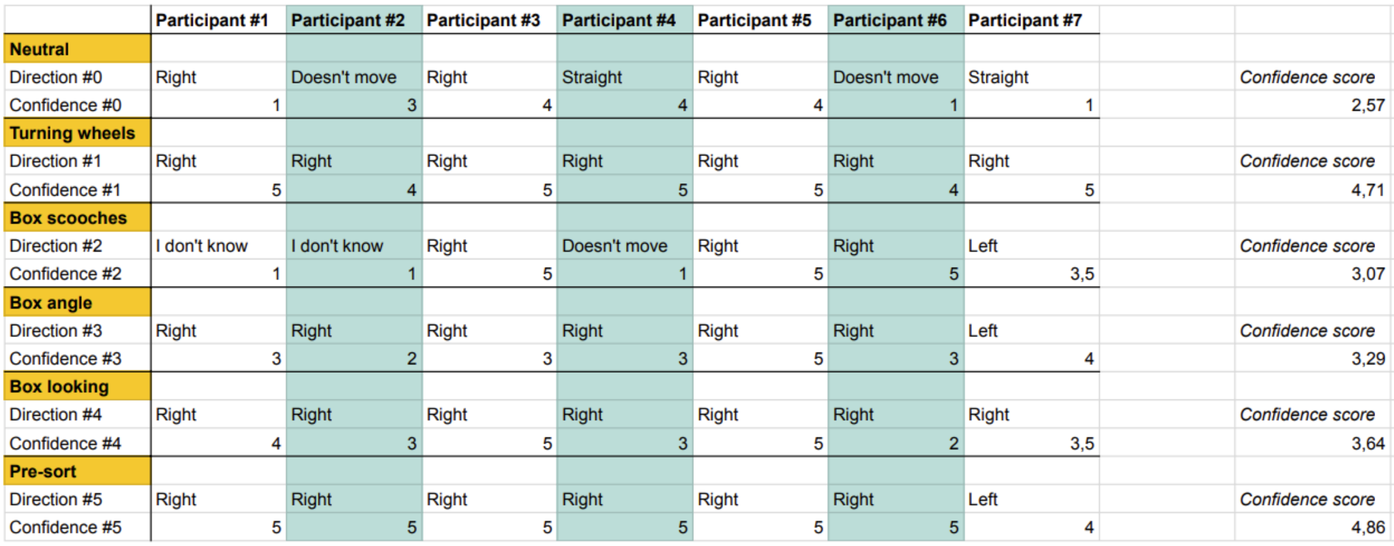
Main insights

Three out of the seven participants indicated that the ADV would pass them on the right side in the Neutral scenario. Two of them were even confident (scored a 4 on a scale of 5) about this indication. This demonstrates how deep rooted the right-hand rule is in the Dutch culture, so much that we even expect robots to adhere to this rule.

All seven participants could correctly predict the intended direction of the ADV for the scenarios: Turning wheels, Angle, Looking and Pre-sort. This shows that the scenario Shove isn't displaying a clear intent signal and will therefore not be subjected to further testing.

Six participants gave the Pre-sort scenario a 5/5 confidence score (average of 4.86 confidence score) and five participants gave the turning wheels scenario a 5/5 (average of 4.71 confidence score). Consequently, participants exhibit the highest level of confidence in perceiving the intended direction of the ADV when they observe actual wheel movements towards that direction. The best scenario that doesn't display wheel movement is the Looking scenario (average of 3,64 confidence score).

In the table below the confidence scores are listed for every prototyping scenario, including their average confidence score. As shown in the table below, people had the most confidence in the pre-sort scenario and in the turning wheels scenario.



	Participant #1	Participant #2	Participant #3	Participant #4	Participant #5	Participant #6	Participant #7		
Neutral									
Direction #0	Right	Doesn't move	Right	Straight	Right	Doesn't move	Straight		*Confidence score*
Confidence #0	1	3	4	4	4	1	1		2,57
Turning wheels									
Direction #1	Right	Right	Right	Right	Right	Right	Right		*Confidence score*
Confidence #1	5	4	5	5	5	4	5		4,71
Box scooches									
Direction #2	I don't know	I don't know	Right	Doesn't move	Right	Right	Left		*Confidence score*
Confidence #2	1	1	5	1	5	5	3,5		3,07
Box angle									
Direction #3	Right	Right	Right	Right	Right	Right	Left		*Confidence score*
Confidence #3	3	2	3	3	5	3	4		3,29
Box looking									
Direction #4	Right	Right	Right	Right	Right	Right	Right		*Confidence score*
Confidence #4	4	3	5	3	5	2	3,5		3,64
Pre-sort									
Direction #5	Right	Right	Right	Right	Right	Right	Left		*Confidence score*
Confidence #5	5	5	5	5	5	5	4		4,86

B. SUS questionnaire

This section is related to the second test day of the test exploration phase. This test was based on the SUS-questionnaire and this section contains the exact questions that were asked to the participants and the overall results. The data is presented in the table below and the results are visualised in the graph.

The following questions were part of the SUS questionnaire and were filled in for every scenario:

Please rate the following questions from 1 (strongly disagree) to 5 (strongly agree).

1. I was able to predict the direction of the ADV. 1-2-3-4-5
2. I found the movement easy to understand. 1-2-3-4-5
3. The intended direction of the ADV was intuitively understandable 1-2-3-4-5
4. I would imagine that most people will learn to understand this movement very quickly. 1-2-3-4-5
5. I felt very confident in this traffic situation. 1-2-3-4-5
6. I need to learn a lot of things to be able to understand the movements of the ADV. 1-2-3-4-5
7. I found the movement unnecessary complex. 1-2-3-4-5

Test day 2

Test set-up

The second test aims to answer the question:

How effectively and intuitively are the changing body panels perceived when the ADV is moving?

In order to assess the intuitiveness of the prototype, both the prototype and the participant were moving, creating a time-limited scenario that required quick and intuitive reactions and perceptions of the signals. Due to this time constraint, participants could only rely on their intuitive reactions, providing insights into the effectiveness of the changing body panels in communicating the intended behaviour.

This was executed by letting the participant walk from one side of the room towards the other, and the ADV would drive in the opposite direction towards the participant. The ADV would 'weave' around the participant in the direction of its communicated intent (with the exception of the Neutral scenario). In the context of this thesis, the term 'weave' refers to the ADV's movement of driving around the participant in a curved and smooth manner. In the first test day it became apparent that people automatically assume that the robot will keep to the right side, as this is seen as normal, therefore the ADV communicated a left direction in all scenarios.

After the ADV and the participant would pass each other, the participants had to fill in a questionnaire. The body panels are changed in between the scenarios whilst the participants filled in this questionnaire, and after completion there were additional open questions.

The questionnaire was based on the System Usability Scale (SUS) with adapted questions to fit the testing context. The SUS questionnaire and the results can be found on the following page, although it should be mentioned that the number of participants limits its validity as conclusive evidence.

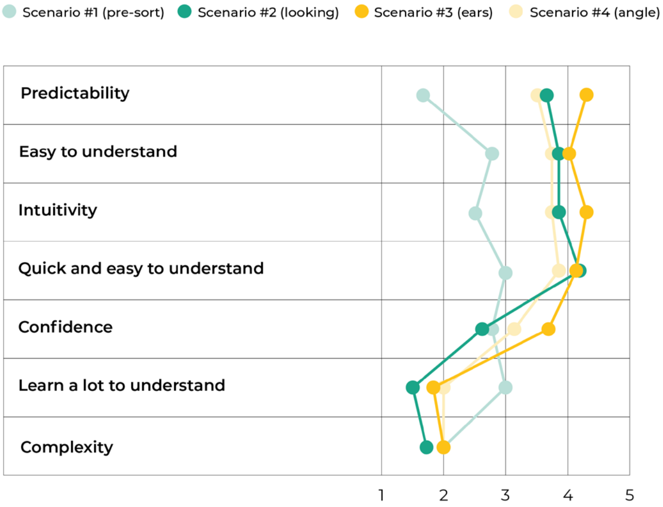
Main insights

The signals were rated on: predictability, ability to understand the motion quick and easy, intuitiveness, confidence in the traffic interaction, and on how complex the movement was. Overall the Ears scenario scores best on these categories, a full overview of the asked questions and the scores of the different scenarios can be found in appendix B. However, it is worth noting that the three scenarios (Looking, Ears, and Angle) received positive ratings in comparison to the Neutral and Pre-sort scenarios. Additionally, the Looking, Ears, and Angle scenarios received similar ratings overall, but the Angle scenario was a bit confusing for 3 participants. They mentioned that they expected that the ADV would exhibit a larger movement, which is possibly influenced by the dynamic nature of vehicles, i.e. motorcycles often lean or angle themselves during sharp turns to maintain balance. It is interesting to test this hypothesis in the coming test.

It is important to emphasize that all three scenarios mentioned above have a positive impact on all the tested categories compared to the no-intent communication scenarios (Neutral and Pre-sort). This shows that by communicating the intent, the predictability of the behaviour of the ADV enhances and people feel overall more comfortable during ADV interactions.

		Second place	***Best scenario***	***Close third***			
	Scenario 1 (neutral)	**Scenario 2 (looking)**	**Scenario 3 (ears)**	**Scenario 4 (angle)**	**Scenario 5 (pre-sort)**		
Predictability	1,5	3,666666667	4,333333333	3,5	1,666666667		High
Easy to understand	1,666666667	3,833333333	4	3,666666667	2,833333333		High
Intuitivity		3,833333333	4,333333333	3,666666667	2,5		High
Quick and easy learning curve		4,166666667	4,166666667	3,833333333	3		High
Confidence	1,5	2,666666667	3,666666667	3,166666667	2,833333333		High
Learn a lot to understand	3	1,5	1,833333333	2	3		Low
Complexity		1,833333333	2	2	2		Low

The table above contains the average of answers for every scenario of six individuals. On the right side of the table it is stated whether it is preferable to have high or low outcomes for that specific attribute. The Ears scenario has the best overall score, but does not have the best score on every single category. The Looking scenario has better scores than the Ears scenario on 'Quick and easy to understand', 'have to learn a lot to understand' and 'complexity'. The data of the table is visualised in the graph on the right. The scenarios are represented by different colours, and the desired outcome is a high score on the first five questions and a low score on the last two. Upon analysing the visual, it is evident that the Ears scenario performs the best overall, although the Looking scenario excels in certain aspects. It is remarkable that the Looking scenario scores better on all the categories that are related to how much prior knowledge is needed to understand the movement.



C. Arduino code

The evaluation prototype contains an Arduino to make the top part move from a distance. The code that is written to make this happen can be found in this section.

The Arduino code used in the evaluation prototype to be able to turn the intent signal from a distance is provided below.

The code contains a servo-motor and an IR-receiver that is operated with the TV remote from my Sony television.

```
#include <IRremote.h>
#include <Servo.h>

const int IR_RECEIVER_PIN = 2;
IRrecv irrecv(IR_RECEIVER_PIN);
decode_results results;

Servo myservo;
const int servoPin = 6;
long waitTime = 1000;
long isHome = true;
long whenMoved = 0;

// The IR code is the code of the button of my TV remote
const unsigned long desiredIRCode = 0xCD0;

void setup() {
  Serial.begin(9600);
  irrecv.enableIRIn(); // Start the IR receiver
  pinMode(servoPin, OUTPUT);
  myservo.attach(servoPin);
  myservo.write(52);
}

void loop() {
  if (isHome) {
    // check for IR code
    if (irrecv.decode(&results)) {
      if (results.value == desiredIRCode) {
        // IR code received; move servo and ignore button
        for (int pos = 52; pos >= 5; pos--) {
          myservo.write(pos);
          delay(15); // Increase the delay value for slower forward movement
        }
        isHome = false;
        whenMoved = millis();
      }
      irrecv.resume(); // Receive the next value
    }
  } else {
    // servo is not home; see if it's time to go home
    if (millis() - whenMoved > waitTime) {
      // move servo home
      for (int pos = 5; pos <= 52; pos++) {
        myservo.write(pos);
        delay(15);
      }
      isHome = true;
    }
  }
}
```