CHALMERS
UNIVERSITY OF TECHNOLOGY

Development of an Intuitive Pedestrian Interaction System for Automated Vehicles

Bachelor of Science Thesis in the Thesis Degree Program Design and Product Developement

ALEXANDER KARLSSON & TIM HEDLUND

Department of Industrial- and Material Science
Division of Design & Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

Bachelor of Science Thesis

Development of an intuitive pedestrian interaction system for automated vehicles

ALEXANDER KARLSSON & TIM HEDLUND

SUPERVISOR: FJOLLË NOVAKAZI
EXAMINER: LARS-OLA BLIGÅRD

Department of Industrial- and Material Science
Division of Design & Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

Bachelor of Science Thesis IMSX20

Development of an intuitive pedestrian interaction system for automated vehicles
Bachelor of Science Thesis in the Thesis Degree Program Design and Product Developement

Chalmers University of Technology
SE-412 96 Gothenburg, Sweden
Phone +46(0) 31-772 1000
Cover photo: Alexander Karlsson & Tim Hedlund
Print: Repro Service Chalmers

Acknowledgements

We would like to extend our thanks to everyone who has helped with the thesis along the way. Thank you to Fjollë Novakazi, Azra Habibovic, Mikeal Ljung Aust and Lars-Ola Bligård, whose supervision and invaluable input always propelled the thesis in the right direction. We would also like to thank Veprox for providing a great work environment and the initial contact with Volvo Cars and RISE. Thanks to Bosse Larsson for getting the thesis off the ground and taking the first steps with the project. And lastly, thank you all the participants who took part in our evaluations and workshops.

Abstract

This thesis has examined the lack of communication between pedestrians and automated vehicles (AVs). As a result, a light-based interface with animated signals was developed as a proposed solution to this problem. The goal was to make the interface as intuitive as possible. The communication approach that was chosen for this thesis was communicating the AV intentions and actions to the pedestrians rather than giving them explicit directions. If there is to be an AV-pedestrian communication interface implemented, it would be very beneficial for users if it was standardized across all vehicle brands and models. If every brand develops an individual way of communication it might create confusing, disorienting and ultimately ineffective experience for the pedestrians. Previous research has presented contradictory findings in regard to the need of an AV-pedestrian communication interface. Therefore, it is important to further investigate the role of such an interface. Previous solutions to the problem have been analysed and negative and positive aspects of each have been identified. There are several approaches to AV-pedestrian communication with various levels of testing and effectiveness. The user system consisting of the categories user, objective, product and context was subsequently analysed before going into the ideation phase. The ideation generated five concepts that were evaluated with a focus group consisting of industry and research experts. Through evaluation analysis, the concepts were refined and narrowed down to three concepts. This time it was evaluated through interviews and surveys of 18 test participants similar to end users. Analysis from the result of this evaluation combined with a last iteration of the concepts generated one final concept. Future work needs to examine the use of sound signals and test the impact of varying parameters like placement, frequency, colour or timing.

Table of Contents

1. Introduction

With the introduction of automated vehicles (AVs), questions have been raised regarding how the vehicle should communicate with its surrounding. In the absence of a driver controlling the vehicle, driver-pedestrian interaction is lost and a substitute solution is needed if AVs are to be accepted by the general population. Therefore, one of the bigger challenges is to gain the trust of the people that will interact with the AVs. The successful communication of the AVs intent is a key factor in this process (Parasuraman & Riley, 1997).

The field of AVs has seen a high level of development regarding the performance and safety of the autonomous drive (AD). However, a field that still remains in an early stage of development is AV communication. How should the AV communicate to the driver that the vehicle is controlled by the AD? How should the AV alert the driver that it needs to take back control of the vehicle in a situation the AD cannot handle? How should the AV communicate with other road users, like pedestrians or cyclists? These are some of the questions car manufacturers and researchers have started to ask, whereas this thesis intends to propose a solution to the latter.

Recently, several different AV communication solutions with various levels of testing have been proposed (Habibovic et al., 2018; Lundgren et al. 2018, Merat et al., 2016). However, some conclude that the movement pattern of the AV is sufficient communication (Dey et al., 2017; Rothenbücher et al., 2016). These contradictory findings places importance on further investigation of the role of such communication. It would be beneficial for the users if there was a standardized interaction system based on universal signals, to eliminate the need to be familiar with every vehicle’s specific way of communicating. If a solution is to be standardized across all brands and models, it needs to fulfil certain specifications, and be subjected to rigorous testing. This creates a need of exploring different types of AV-pedestrian communication and determine the intuitiveness of these.

1.1 Aim and Research Question

The aim of this thesis is to develop design concepts that will meet the needed specifications for an interaction between vehicle and pedestrians and evaluate these. The research questions on which the thesis will be based are the following:

- RQ 0. How can elements and characteristics of an external AV interface be designed, to maximise the intuitiveness in regards to AV-pedestrian communication?
- RQ 1. How can the interface amplify or accentuate the AVs motion pattern and other modalities?
- RQ 2. Given the nature of the concepts, what is an appropriate way to verify them? RQ 3. Given the use context, what messages are needed?

This thesis will focus on the graphical and visual aspects of AV-pedestrian communication, through a light strip, or display, positioned in the pedestrian’s field of view. This concept of communication is inspired by the concept car from Volvo 360c and will be used as a reference.

The generated concepts will be applied on the existing model Volvo XC90 to ensure the application for production vehicles, and not only futuristic concept studies.

The thesis project is a part of a bigger project, where the goal is to see if online-testing (M-turk) can effectively be used for early phase evaluations, and how it compares to traditional testing (Amazon, n.d). M-turk is a crowdsourcing tool used to generate a lot of opinions and feedback through an online community. One of M-turk's major strengths is its diverse userbase which creates the possibility to carry out tests on people from many different geographic locations and form several cultures. However, this thesis will be limited to testing on people geographically located in Gothenburg Sweden since the M-turk phase takes place after the thesis work is completed.

The thesis will also be constrained to what is possible to test in an online survey. Particularly two-way communication and several-outcome situations are hard to replicate, among other things. Hence, the concepts will be limited to what is testable in M-turk.

1.2 Development Process

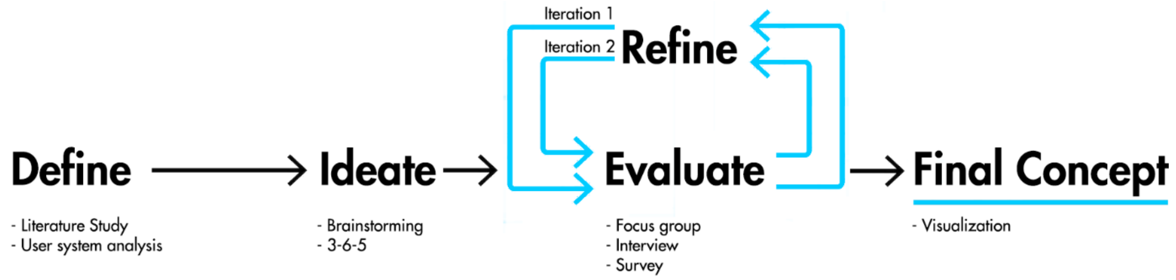


Figure 2: Design Process.

The overall process followed the characteristics of a design process (See figure 2). Initially, the project was empathized through different literature studies on previous projects. The next step of the project was to define the context and constraints of the project. This was accomplished together with the industry experts from Volvo Cars and RISE which had a great insight of legislative and executive requirements of the industry. This was very helpful when moving on to the ideation phase. Different concepts were generated through different workshops. Three ideation phases were carried out through sketches, 2D and 3D animations.

For each ideation, the concepts were tested through various evaluations using different methods such as interviews and focus groups. The purpose of the evaluations was to narrow down the selection of concepts and to get closer to a final concept. In addition, the results were used to guide the refinement of each selection leading into the next evaluation.

The evaluations consisted of mixed-methods adapted for each specific goal. The methods used were expert evaluation, focus group, interviewing and surveys. The types of test participants were also dependent on each evaluation. For instance, the focus group consisted of experts and the interviews consisted of participants more similar to the end-users. Each evaluation was later on analysed through methods such as the KJ method (Österlin, 2016). In other words, the ideation- and evaluation phase was performed in an iterative manner. The purpose of the final iteration was to verify the success factor of the final concept. The development process will in the following chapter be described in a chronological manner. The methods used will also be described and explained alongside the result they produced. More explicitly the result will be presented in chapter 3, which covers development, and chapter 4, which covers refinement and evaluation.

Alongside the refinement of concepts, the report was written. The purpose of writing the report early in the study was to prevent the outcome of memory loss of important details of different studies. This was also very helpful to adjust minor details and error together with the supervisor of this project. Once the report was almost finished, the presentation was prepared in order to present the outcome of the whole project (See figure 3).

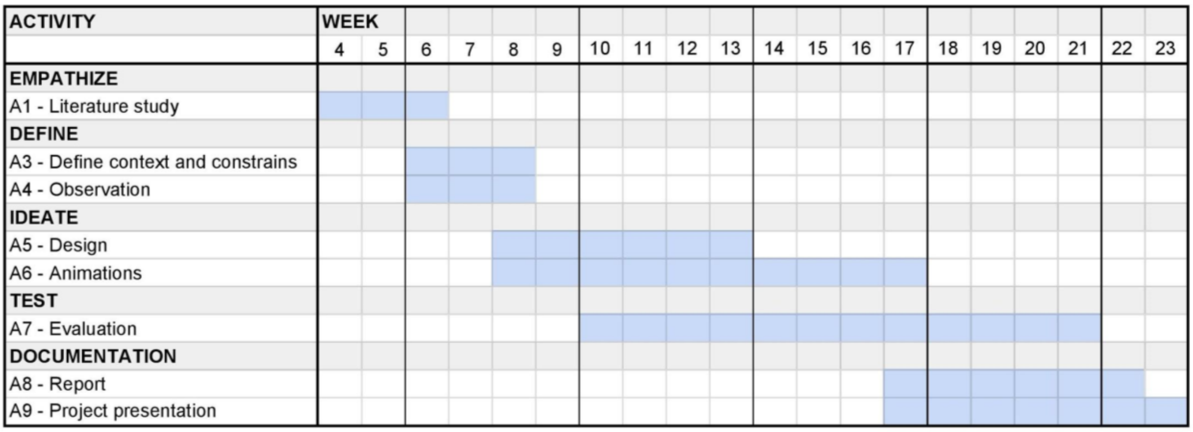


Figure 3: Milestones.

2. Background of Previous Studies

In this chapter background necessary to understand the following work is given. This mostly consists of previously done work in the same field and is meant to make sure the current situation regarding the state of the art AV technology is understood. Examining how others have approached this issue, as well as identifying the negative and positive aspects of these approaches laid the foundation for the following development. The background also served as inspiration for the idea generation and helped to ensure that the concepts are grounded and positioned in the right context.

State of the Art

The area of AV-pedestrian communication has seen a lot of activity in the recent years. Several car manufacturers and researchers have suggested solutions to the problem of AV-pedestrian communication using various approaches. Therefore, an important step for the thesis is to position itself in relation to the other solutions. Firstly, the previous work on subject can be divided in whether or not it concludes that an AV-pedestrian interaction system is needed. Some simply imply that the motion patterns of AVs are sufficient communication (Dey et al., 2017; Rothenbücher et al., 2016). Others conclude that interactions may be affected by the absence of communication with drivers and needs additional communication features (Habibovic et al., 2018; Lundgren et al. 2018, Merat et al., 2016). Given these contradictory findings, it is important to investigate the role of such features.

Mercedes has developed a concept which projects a zebra crossing onto the ground (Mercedes-Benz, 2017) to communicate with pedestrians. A problem with this concept however, is that it depends on very favourable light conditions. In daylight, where most interactions take place, the projection will barely be visible. Future technology might negate this problem, but it is beneficial if AV-pedestrian interaction can be solved with existing technologies. Another aspect of this concept is that it is only functional when the car is stationary. Communicating to pedestrians that the AV is stationary and is waiting for them to cross might be somewhat useful. However, communicating different AV states like yielding or accelerating might more urgently require a form of communication. It is preferable if a concept can communicate information regarding several of the AVs states.

Furthermore, another problem the Mercedes concept and other similar concepts creates, is they might invoke a certain ambiguity regarding if they are suggesting that the pedestrian can or should cross. It is illegal in several countries for a driver to wave to a pedestrian implying that they should cross, precisely because the driver cannot guarantee that it is safe to cross (STR, 2018; Department for Transport, 2015). This logic can also be applied to AVs which then means that no concept should be able perceived as an invitation or an instruction to cross. A potentially dangerous situation is created if the pedestrian assumes that the signal means that it is safe to cross when that is not the case.

Lyft is a company which located in the US which works with the development of shared transportation. In 2017, they presented their first concept of a self-driving car to communicate with the pedestrians (McNeil J., 2019). The concept simply relies on showcasing a text messages on a display through the windows. On the first sight it might seem intuitive and simple, but as in this project, the goal is to approach the problem in a different way. The idea of having a text showcasing it to the pedestrian has been proven on previous studies not to be very effective. As for the legislative aspects on this topic, telling the pedestrian what to do is illegal by law. Other difficulties that arises with text messages is the language barrier. If the goal is to create a universal concept applicable anywhere around the world, relying on different language would be very difficult and not very intuitive. Other car makers that have been relying on the idea of showcasing text messages are EQ fortwo (Diamler, 2019) and Nissan with their concept called IDS (Nissan Motor Co., Ltd.; 2015).

There is no denying that pedestrian are the most vulnerable casualties in the traffic. In Sweden, about 50 pedestrians die every year which usually occurs at night time during winter (STR, 2018). This represents about 17 % of all the deaths caused in the Swedish traffic roads, which in average ends up around 300 casualties every year (Statistika Centralbyrån, 2009; Historisk statistik för Sverige). As for this project, the main focus is to observe the pedestrian behaviour at a zebra crossing. According to the article Psychology-Based Research on Unsafe Behaviour by Pedestrians When Crossing the Street, some of the major reasons for pedestrians to cross a road unsafe is because of the reason that everyone else is crossing the road unsafe and that the red light is taking too long (Ding, Wang S., Zhang and Wang Q., 2014). By creating a system that interacts between pedestrians and AVs, pedestrians will be able to cross the road more effectively. By doing this, the fatal pedestrian casualties might decrease in the traffic, as the society might be one step closer towards the Vision Zero which has been aimed for in Sweden since 1997 (Goodyear S., 2014).

AVIP is a concept developed by Azra Habibovic et al. that takes on an approach based on communicating the intent of the AV (2018). The AVs intent includes yielding, waiting/resting and departing. When the AV slows down and intends to yield to the pedestrian, a light bar at the top of the windshield show an animation that communicates the AV intent. This avoids the issue of not being able to explicitly tell the pedestrian what to do. Instead the pedestrian is simply able to use the information regarding the AVs intent to inform its own choice of action. As the AV prepares to depart from the zebra crossing an animation is displayed allowing other pedestrians to anticipate this action. It was also concluded that the animation used for when the car was stationary was not noticed by the majority of pedestrians and confused the few pedestrians that did notice it. It was believed that the signal for this state of the AV was not as important and that using too many signals will only confuse pedestrians. Furthermore, it might be hard to read this interface if a pedestrian or a bicyclist is further from the zebra crossing and is observing the front of the car at an angle greater than 45 degrees.

Volvo has developed an AV concept called 360c with a graphic interface display along the whole exterior of the vehicle. The concept uses light pulses and flashes to indicate its intention and various actions. While this concept avoids problems that have been identified with other solutions, it does face some challenges with regulation. It is unclear whether having light signals on every side of the car will be allowed. Lastly, it is possible to question if light signals on every side is needed to achieve sufficient communication.

3. Development of Light Concepts

This chapters covers the analysis of the use scenario which sets the boundaries for the subsequent idea generation. The methodology behind the idea generation as well as the results it created are also described in this chapter. In other words, this chapter covers the development of all the necessary prerequisites for initial evaluation and a first iteration.

3.1 Defining the Use Scenario

The scenario revolves around the AV-pedestrian interaction that takes place around zebra crossings. Before the ideation it is important to identify aspects of the specific scenario which will become constraints or goals. These aspects fit under the categories user, context, product and objective (See figure 4). Some of these aspects were identified before the initial ideation and some later on in the thesis after evaluation.

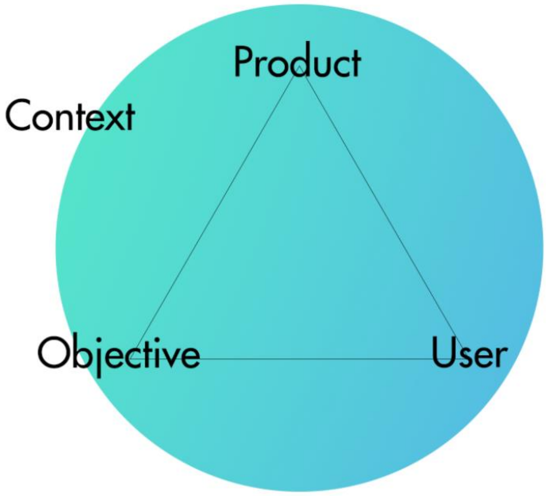


Figure 4: Use scenario.

3.1.1 Defining the Objective

The objective is the goal, task or intended purpose of the product. In this case it is to communicate a message from the AV to the pedestrian. As mentioned, this is supposed to increase the trust in automated technology and enhance the user experience. The information that will be contained in this communication is the AVs current status, as well as what the AV is going to do next. For the intent of the study, it is assumed that the AV will always stop at zebra crossings. Figure 5 shows the actions within the scenario, from the AVs point of view

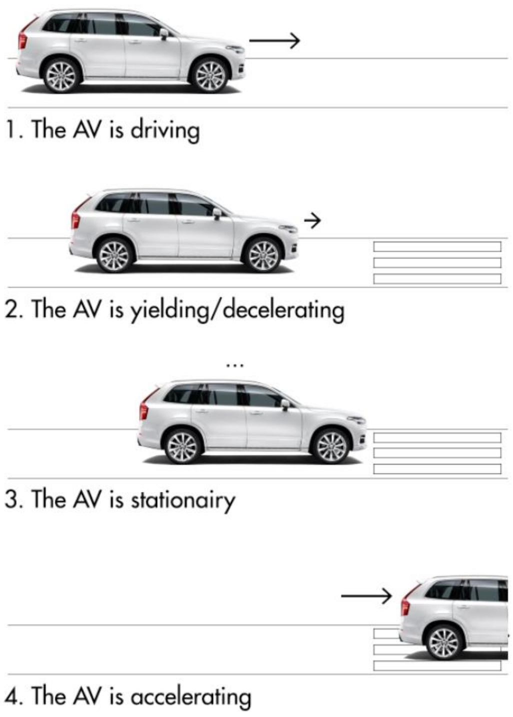


Figure 5: Considered AV actions.

The AV needs to communicate the above described intentions. The pedestrian can then take part of this information and use it to inform its own choice of action. Pedestrians already use a vehicles' "body language" or behaviour and seek eye contact with the driver to inform their actions. As mentioned, this thesis intends to fill the absence of certain communication to bring AV-pedestrian communication up to the standard of traditional communication. However, it is also possible that an additional level of communication might surpass the existing form of communication in effectiveness. Additionally, there is an opportunity for the pedestrian to better anticipate what the AV is going to do before this action is taken. Therefore, another objective is to accentuate or amplify the AVs motion/action or anticipated motion/action. This formed the basis for RQ1. Lastly, in accordance with RQ0, this needs to be achieved in the most intuitive and understandable way possible.

The general messages that needs to be communicated by the concepts are the following: "I'm in AV-mode", I'm yielding", "I'm waiting", "I'm about to start driving" and "I'm departing" (See figure 6). These messages are constrained to AV driving, meaning they will not appear if the AV is manually driven. What is considered to be a complete concept within this thesis is a solution which can directly or indirectly communicate all of these messages.

"I'm AV-mode" ensures the pedestrian that the vehicle is driven by a computer program and does not need to be alarmed if the person in the driver seat is not paying attention to the road. For instance, the person in the driver seat might be reading a newspaper, looking at their phone or just in another direction, which might cause concern with the pedestrian who is looking for confirmation that they have been seen.

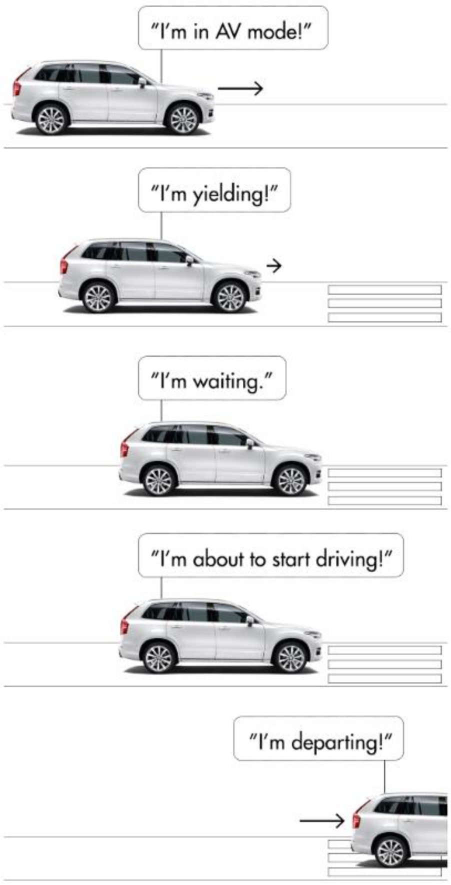


Figure 6: Required AV messages.

“I’m about to yield” communicates that the AV will give way to the pedestrian. The AV has the ability to guarantee that it will stop. It is a simple matter of the program calculating the stopping distance. However, as mentioned it cannot guarantee that it is safe for the pedestrian to pass. Again, this is the reasoning for why it is better to communicate that the AV is yielding rather than inviting the pedestrian to cross. Pedestrians can benefit from this message if it is successfully communicated, since they will in some situations be able to cross the street earlier with the assurance that the AV will yield. If the AV does not have time to stop and a pedestrian seems to intend to cross the road, a traditional signal like the car horn can be used.

“I’m waiting” is a message the found to be superfluous, by the AVIP project which was examined in the literature study. Most of the participants in the study did not notice the signal, and those who did got confused by it, or could not interpret it. However, while a pedestrian crossing the zebra crossing might not look towards the AV for more information but a second pedestrian approaching slightly further away might, in the AVIP studies only one test participant acted as a pedestrian at a time, and it is possible that this aspect was missed.

Lastly, “I’m about to accelerate” and “I’m departing” serves as slight warning that the AV will depart from the zebra crossing. This is important information for pedestrians approaching the zebra crossing. An important aspect for every message but especially this one is that they need to be reversible. If the circumstances of the situation change and the AV needs to change its intention the messages communicated needs to be reversed. For example if the AV has decided to depart and communicates the “I’m about to accelerate” message, but a pedestrian suddenly decides to cross the street, the message needs to communicate its opposite or be reversed. This is a very important aspect, since it is when the AVs communication is influenced by external behaviour that it becomes a two-way interaction.

3.1.2 Defining the User

The user in this scenario will be the pedestrian since the passenger in the AV is not affected by the communication that is examined. The concept's requirements will vary greatly, depending on how much experience with AVs the pedestrians are assumed to have. If AVs will be implemented, the user's experience will consist of few or a very large number of encounters. Considering this, the very first encounter is a very small fraction of the whole user experience. Therefore, the pedestrian in this scenario is assumed to be semi-familiar with AVs in order to make sure that the concepts are not sub-optimized to the first encounter. Semi-familiar is defined by the project as pedestrians that are aware of AVs and know they exist in traffic. However, AVs are in this situation not fully implemented and the users are not quite sure if they are in favour of, or against AVs. There exists some friction in the relation between them and the users are not yet fully decided if they can trust the AVs. This scenario is modelled after how the situation might look in the early implementation period of AVs which will probably be in the next 3 to 5 years.

User behaviour can be sporadic and hard to interpret as seen through. It is also not uncommon for the user to change its mind about what action to take. A user that is approaching a zebra crossing might just decide not to cross and walk somewhere else. Sometimes users can perform illegal actions like crossing the road where it is not permitted. The AD and by extension the AVs communication needs to able to handle these situations created by the users' behaviour. As mentioned earlier this creates the condition of "reversible" communication, which means that the AV will need to communicate that it has changed its plan of action or intention.

3.1.3 Defining the Context

The conditions that the concepts must follow will be derived from an as realistic as possible context. For example, in a real context the number of pedestrians can range from 1 to 20, and this needs to be taken into account. A concept that only works with 1 pedestrian or oppositely only with 20 pedestrians is not useful. When considering multiple pedestrians, more complex situations can arise. For example, an AV comes to a zebra crossing and encounters a pedestrian on the right. When the pedestrian is passing, another pedestrian arrives at the curb. If the AV has at this point started communication that it will start to accelerate, there needs to be a way to reverse this communication if the AV has to change its course of action due to unforeseen events. Therefore, a big emphasis will be put on the concepts' performance in regards to the conditions generated by a realistic context.

It is important to consider when the signals are needed and should be active. Since the signal are meant to communicate with pedestrians they should only be active when a pedestrian is present. However, the concepts that were tested and developed approached this question quite differently. An important question was for example, what the signals should communicate when the AV was stationary. The effectiveness of the different approaches was tested indirectly through their performance in the evaluation.

The emergency level of the situation was also analysed. Since it is assumed that the AV will always stop for pedestrians when it is possible, the risk involved is not very high. The message that the AV is communicating is only its intention and action, which is not a threat to the pedestrian. Considering this, the communication itself needs to reflect a lower level of urgency. However, it is important to note that confusion or misinterpreted communication can potentially be dangerous. For instance, if pedestrians interpret the AVs communication as a guarantee that it is safe for them to cross when this is not the case, the risk goes up considerably. This places a further importance on the clarity of the communication.

The urban environment is considered critical due to its multitude of traficants and complex traffic situations. Therefore, the geographical location of the concept will be set in the downtown area of Gothenburg, Sweden. In other words, the concept will in a sense be benchmarked in relation to an urban environment which is considered to be the most critical. However, the concepts still need to work in rural environments. In Sweden there are no zebra crossings without traffic lights on roads with a speed limit exceeding 60 km/h (STR, 2018). Therefore, it is assumed that all considered interactions are below the speed 60 km/h. Furthermore, the cultural and traffic norms in China are for example very different compared to the Swedish. Considering a bigger area with bigger differences in cultural and traffic norms is very important to this issue but is out of the scope of this thesis.

Daylight is the least favourable time condition in regards to a graphic or light based display. AVs and vehicles in general need to be usable at all times of the day. Therefore, functionality in daylight is a concept constraint.

3.1.4 Defining the Product

The product is in this case a horizontal light strip with full RGB and 2D animation capabilities. This modality was chosen in the early stages of ideation. The reason behind the choice was partly feedback from the bigger project, this thesis was a part of, and conclusions from the literature study. The following development circled around what the light strip should show rather than how or through what modality it should be shown. However, using multiple modalities is beneficial, but out of the scope of this thesis.

In line with RQ0, the biggest goal in regards to the product which is to be ideated, is that it must be as intuitive and easily understandable. The generated concepts must also minimize the use of memory, as this improves how easily things are learned (Jordan, 1998).

Another aim is for the generated concepts to be implementable independent of brand or model. Hence, the goal is to create a universal concept. The reasoning behind this is that it will save users effort if they do not have to familiarize themselves with every car manufacturer's particular way of solving this problem. It is questionable if it is even possible to make a sufficiently effective solution to this problem, if it is not universally implemented. This places additional weight on constraints like not basing any concepts on brand specific features or a brands specific aesthetic. Lastly keeping the cost of implementation down is another factor that is important for creating a universal concept.

During the idea generation, concepts using abstract signals like dynamics or symbols were favoured. These might initially be harder to understand, but if the concepts are selected and optimized based on intuitiveness, this issue is minimized. Abstract signals are more based on the cognitive processes of the users rather than learned “knowledge in the brain”, which might vary in different parts of the world (Jordan, 1998). For instance, using text to communicate instantly creates the problem of different languages. This makes abstract signals favourable when developing something that is supposed to be universal.

A big factor that has taken much consideration is placement. From a user-centric point of view it needs to be placed somewhere in the users’ point of view. Preferably somewhere close to where the pedestrian would direct their eyes to establish eye contact with the, in this case absent, driver. However, the placement issue becomes more complex when considering practical aspects like regulation or manufacturing possibilities. According to one of the technical advisors from industry, who supported during the thesis, the concepts could not come closer than 100 mm to the blinkers of the AV. Additionally, some placements become too complex from a manufacturing point of view. For example, placing a concept on the AVs doors require electrical supply that is not currently located at that specific spot. Placing the concepts too low on the AV might also become an issue in environments where a lot of snow or dirt builds up on vehicles.

3.2 Idea Generation

The initial idea generation was carried out using various idea methods and took place over a span of several meetings and workshops (See figure 7). The goal was to generate a large number of ideas with a wide range of solution approaches. After this the ideas that were perceived to have the most potential were selected to advance to the next stage which was the first evaluation. The focus was on different ways of communicating using a light strip. The position of the lights would be placed on the whole side of the vehicle, from the headlight to the tail light. The generated concepts that were subsequently evaluated are presented in this chapter.

Figure 7: Ideation workshop.

3.2.1 Ideation Methods and Concepts

In order to serve as an inspiration during the ideation phase, workshops, mood- and imageboards were used. The imageboard consisted of similar solutions to the same problem.

The mood board tried to capture the feeling of different forms of communication and display these in an inspirational format.

3-6-5 is a method used to focus on the quantity rather than the quality of the concepts (Österlin, 2016). By creating 3 concepts in 5 minutes, the concepts are rotated around the table (usually among 6 people) for further development. Some ideas might be interpreted differently than the original which in some cases can be a good thing for generating more concepts. This method requires an open-minded approach for every concept presented. All ideas are written down and are evaluated for further evaluations. Even the craziest idea might turn into something handy later on.

Some of the ideas generated are inspired by the associations of other existing concepts such as the seatbelt signal of an airplane, or the loading bar of an online website etc. (Stickdorn et al., 2018). By creating associated concepts associated to the situation of the AV, the signal might be a lot stronger. It might also make it easier for users to interpret the meaning and purpose of the concept.

Biomimicry is an approach to ideation that mimics nature's solution to certain problem. Often it is used for sustainability problems (Benyus, 2009). However, in the case of this thesis it was used to draw inspiration from body movement communication in the animal kingdom. For example, animals can use body language to communicate to intimidate or communicate danger. Biomimicry was also used in a more abstract way where the general movement of objects was studied. This could for example answer a question like how can a light pulse be animated to imply that it has weight?

Users use what is called mental models to understand how a complex systems, machines or products work (Nielsen, 2010). For example, a user might not know exactly how a washing machine works but still has an idea in their head about the inner workings of the machine. In this thesis it was relevant to consider the pedestrians view of how an AV works. For example, this became very clear in the later evaluations where test participants frequently interpreted the light signals as some sort of sensor. They most likely made this association since a big part of the users' mental model of how an AV works is sensors.

3.2.2 Knight Rider

Knight Rider was inspired by the loading bar which usually appears when loading a web browser with poor connection. While discussing this concept, it was concluded that the concept loosely resembled the car from the famous television show, called Knight Rider. Instead of having the light bouncing back and forth like at Knight Rider vehicle, the goal was to have the light move backwards to give the AV a sense of speed (see figure 8). The light pulses appear when the AV is yielding and accelerating and disappear at rest. To communicate that the AV is active, a turquoise light appears stationary at the front of the light strip.

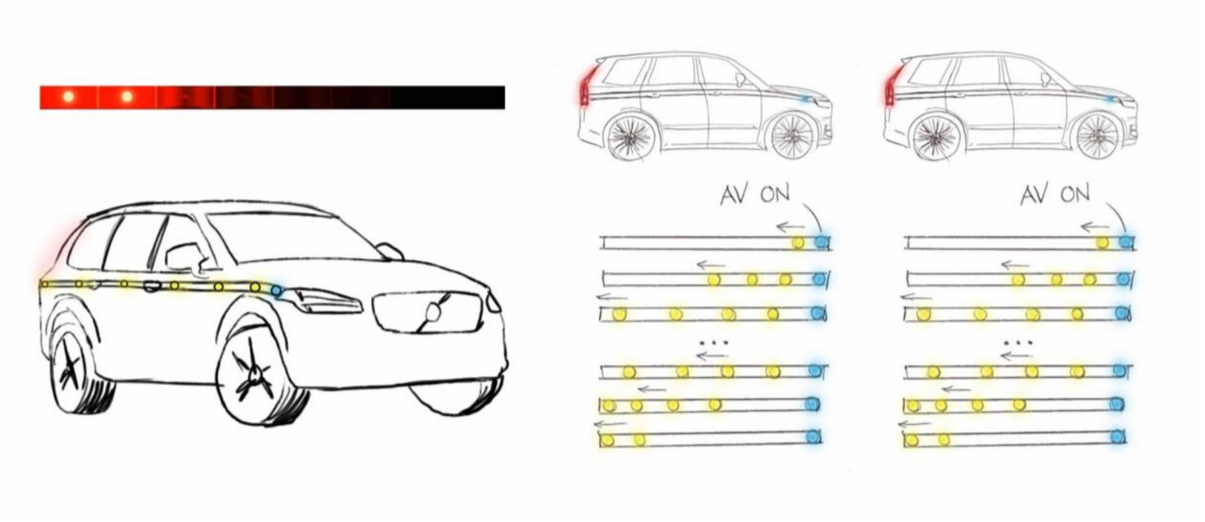


Figure 8: Knight rider idea sketch.

3.2.3 Centreline

Centreline took its inspiration from the vertical lines that appear in the middle of a road with several lanes. The idea was to invoke an association from other traffic signals. It was theorized that this would help pedestrians identify that the signal contained traffic information. As the car approaches the zebra crossing, light bars appear on the light board, shifting forward, in the direction of the car's movement (see figure 9). As it slows down towards the zebra crossing, the light pulses would shrink horizontally until they are no longer visible when the AV arrives at the zebra crossing. If the car is about to start, light bars appear once again to indicate its state of action. This concept indicates that AD is active through implicating that when the signals are active the AV is as well. Therefore, no specific "AV on" signal was used.

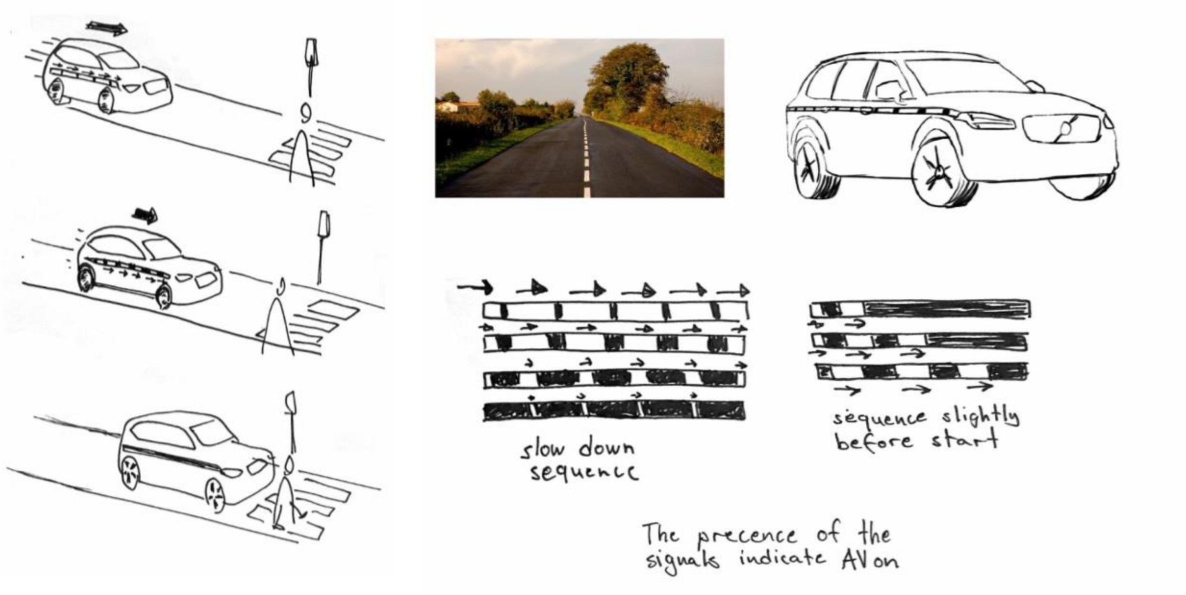


Figure 9: Centreline idea sketch.

3.2.4 Reflection

This concept was inspired by the reflection caused by various lights that are reflected on the exterior of the vehicle. These reflections appear to be stationary in relation to the ground, since the light sources that create them are as well. However, in relation to the vehicle itself, they appear to be moving backwards. If the light bar produces pulses that move backwards across the AV in the same speed as the AV moves forward, an illusion of pulses that are stationary in relation to the environment is created (see figure 10). The reason behind was that the illusion might help pedestrians perceive the speed of the AV with the additional reference point created by pulses that appear to be stationary.

As the car approaches the zebra crossing, the light pulses slow down as the AV slows down. Simultaneously, they increase in size while moving backwards until they cover the whole surface of the light strip. This was done in order to add a second level of dynamic change, which was expected to increase the rate at which pedestrians notice this change. Before the car accelerates again, the lights flash twice with the second flash being slightly longer. This was inspired by the airplane signal, which can be heard when the seatbelt is needed. This was intended to create an association to the plane departing and invoke a feeling of departure. This concept indicates “AV on” through projecting a face onto the windshield to give a feeling of eye contact or intelligence.

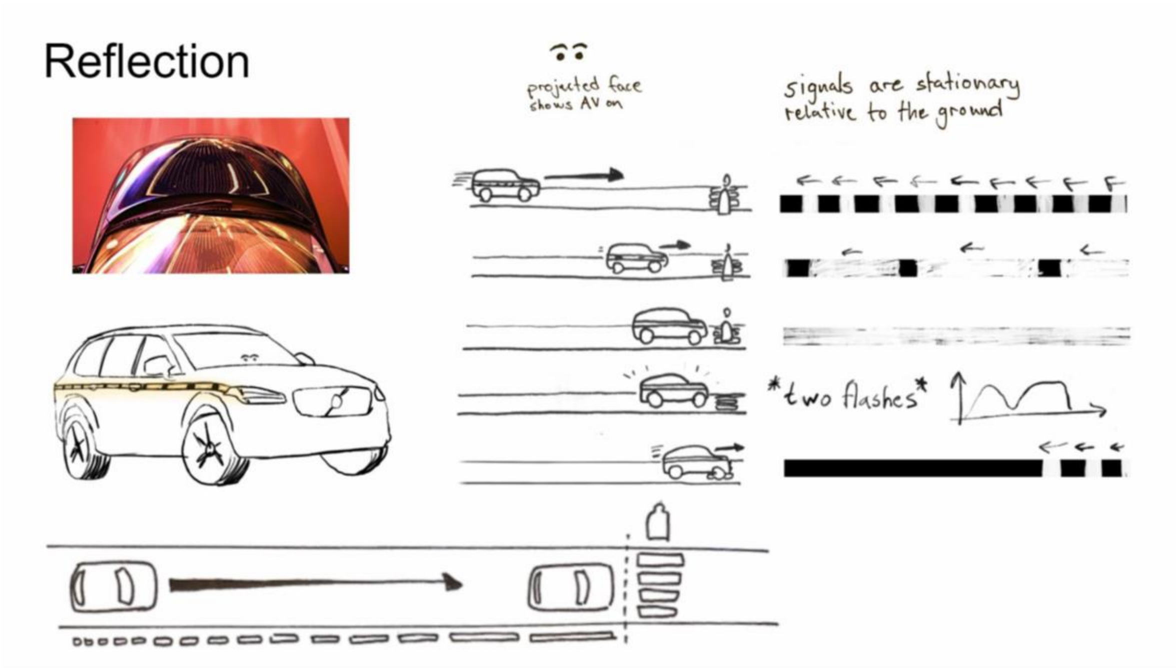


Figure 10: Reflection idea sketch.

3.2.5 Northern Lights

This concept was inspired by Northern Lights to invoke a calm and ambient feeling. As the car approaches the intersection with pedestrians, blurry lights faintly appear on the whole light strip with a slight movement in all directions (see figure 11). The goal was to replicate the movement of the northern lights, which has a flickering calm movement as it appears in the sky. The lights are at their brightest when the AV is stationary. The lights keep on moving until it is about to accelerate which is indicated by turning the blurry lights into clear light bars that then shoot forward as the AV departs. The use of contrasts between ambient and orderly patterns is an unexplored solution in this particular area.

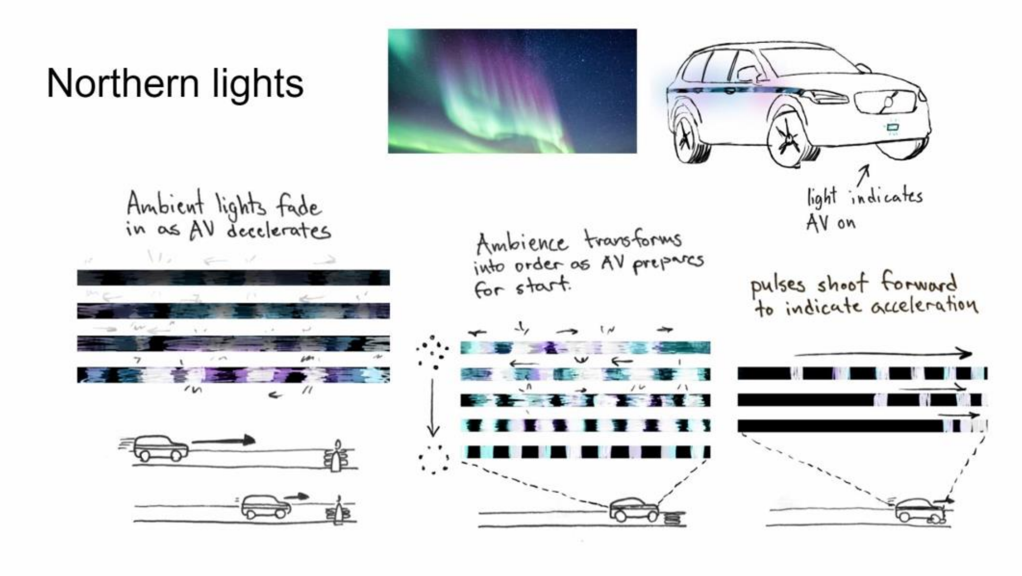


Figure 11: Northern lights idea sketch.

3.2.6 Hourglass

This concept was inspired by an hourglass which collects sand as time passes by. As the car decelerates, light bars move forward and fill up the light board once it approaches the intersection (see figure 12). At rest, the whole light board is lit up until the AV decides to accelerate, which is when the light bar starts to shrink outwards towards the front. When the light has entirely disappeared the AV accelerates.

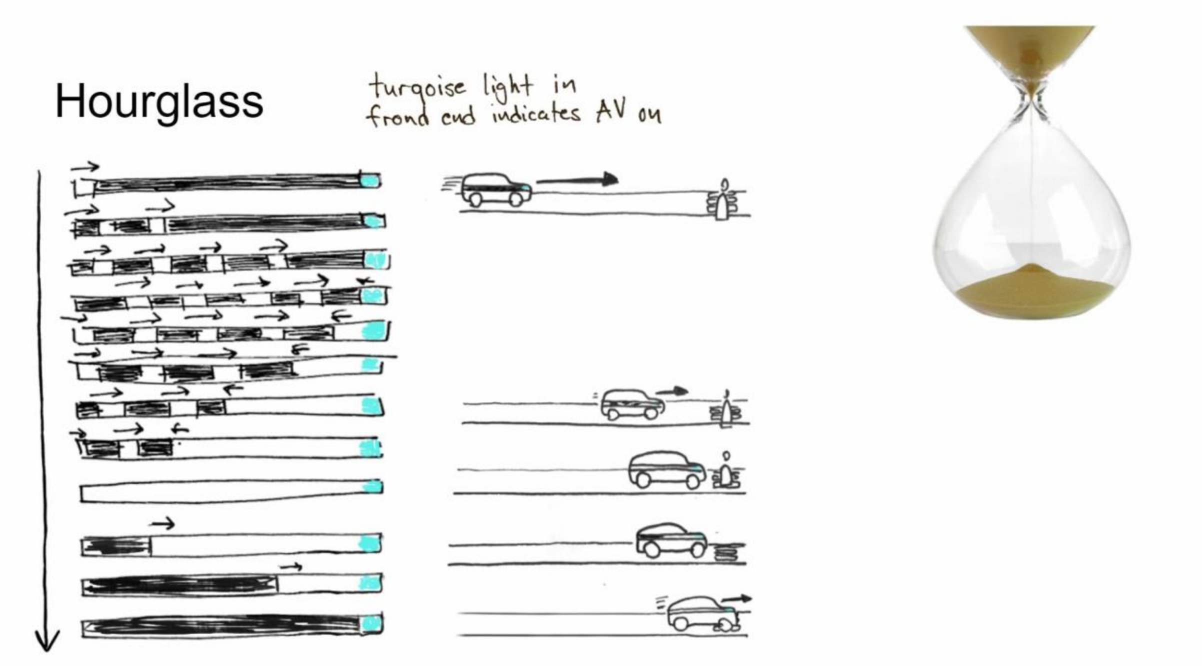


Figure 12: Hourglass idea sketch.

3.2.7 Discussion of development

As mentioned these five concepts headed in to a first iteration. As a product of the ideation methods used the concepts were only visualized in low-fidelity 2D-sketches. As will become apparent in the next chapter, interpreting these visualisation as moving animations when they are stationary sketches might prove to be hard. However, the ideas behind the concepts and their intended purpose and detail was all based heavily of the results of the user system analysis. In addition, all the previously done at this part of the thesis shaped these initial concepts. In other words, they are a step in the right direction in accordance with the purpose of the thesis. The first evaluation and iteration will further propel it towards end result.

4. Refinement and Evaluation

This chapter contains evaluation of the concepts and the process of narrowing them down to a final concept. The information from each evaluation needed analysis and this process is also described below. Finally, there is a discussion of the result.

4.1 Focus Group

The first evaluation consisted of a focus group with seven experts, one moderator and a recorder. The experts were from the development fields safety, automotive research, and automotive lighting. The focus group was introduced with a basic explanation of the goal and purpose of the project. Then, the five concepts were presented with simple sketches and animation charts. Between each concept there was a discussion led by the moderator. The focus was on the users' perception of the concepts and how understandable they were. In this early stage technical details were not prioritized. However, the discussion still gravitated towards these aspects. This is most likely explained by the participants' background in the industry where these aspects are highly prioritized. Figure 14 shows the guidelines used as the basis for the discussion.

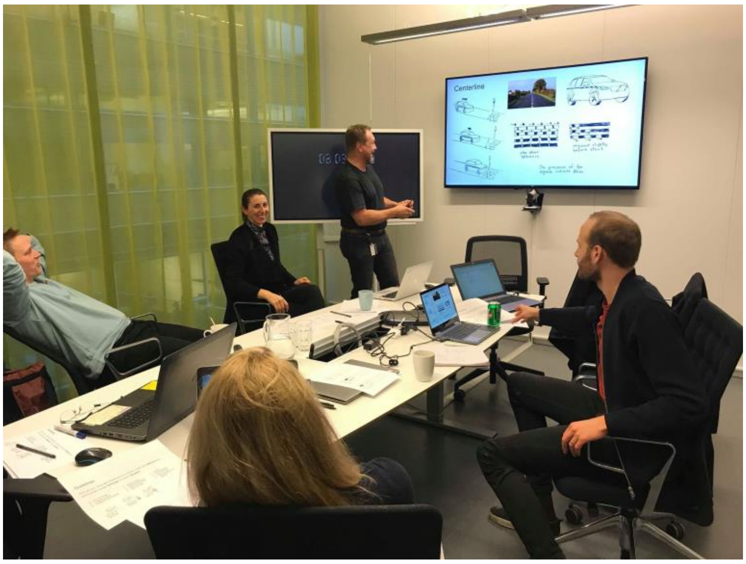


Figure 13: Expert focus group.

The results from the focus group were subsequently analysed using the KJ-method and sorted into themes. The results spurred the selection of concepts to refine and develop further. Besides providing specific and detailed feedback, the focus group gauged the general acceptance and qualitative understanding of each concept. This insight was used in combination with the KJ-analysis to determine which concepts to proceed with and what to improve.

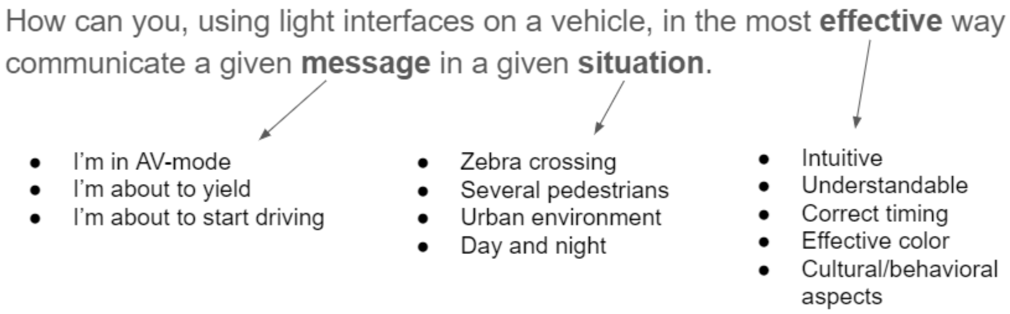


Figure 14: Focus group guidelines.

4.1.1 KJ Analysis of Focus Group

The KJ-method is a way to sort the discussions into themes. The emerging themes from the focus group were the following; Industry aspects, placement, interaction, AV on/off, behavior, colour, dynamics and frequency (see figure 15). In general, the comments from the experts in the focus group consisted of many interesting insights regarding technical and legislative aspects. What was mentioned, was that it is important that the pedestrian feels completely safe crossing the zebra crossing when encountering an AV, and that it is less important for the concepts to have a high aesthetic level. The learning curve for the concepts would strongly depend on the complexity of the concepts. Since the goal is to make the concept as intuitive as possible, the plan is to keep the learning curve as low as possible. In the end, what really matters is how the pedestrians actually interpret the light signal.

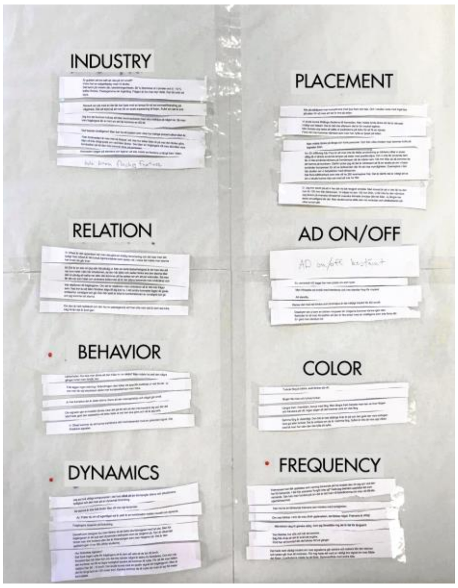


Figure 15: Focus group KJ-analysis.

Another essential comment, which was collected from the focus group, was to think about the best scenario regarding the pedestrian and the environment. For instance, it was mentioned that it is critical for the light signal not to be placed too far down on the AV because of the dirt that could occur depending on the weather. It was also suggested that the light board should be placed on the back and the front of the AV while making the animation as consistent as possible. As for the interaction between the AV and pedestrian, it was said that it is important to focus on the AV's behaviour rather than the relation between the pedestrian and the AV. With that being said, it is essential for the AV to show its intention by making the light system as predictable as possible. The two most crucial factors regarding the light system were claimed to depend on the two following aspects. Firstly, to display a strong dynamic change in the motion of the light system. Secondly to convey a sense of clarity which could be done by enhancing the signal with a sound system.

According to one of the experts in the focus group, the direction of the light system was considered less important. It was also added by one expert that the change in motion far away at high velocity would not be noticed by the pedestrian. At a closer distance, motion of the animation might be more relevant. As for the frequency, 4Hz were recommended to catch someone's attention. Any faster than this the lights would be perceived as aggressive and might be interpreted as a hazard light. Too slow and it would make the pedestrian impatient to cross the street and the crossing will be completely depended on the light signal only.

Further, it was discussed that the frequency of the animation should slow down in accordance with the speed of the car. The two flash signals, which indicate the intention to accelerate were considered good, but it was added that it should be reversible in case of another pedestrian crossing the street. It appears that the focus group agreed on using the colour turquoise for the light system. White, purple and pink also seemed to work well. The only legal constraint was to not have the colour red on the front or the side of the AV. The choice of colour was not highly prioritised, but rather that the animation should work well, regardless of the colour. The last thing that was mentioned in the focus group was the "I'm in AV-mode" signal. One participant proposed having a universal logo for all AVs, while someone else said that having this signal might give the pedestrian a false sense of security, assuming the AV may be smarter than it looks.

An important insight from conducting the focus group was the difficulty of portraying a moving animation in still pictures. The attempt to represent dynamics through sequences to the participants did not work very well, causing the focus group to be mostly confused by it. It became clear that for the following evaluations to be effective they had to include moving animations.

4.2 First Iteration

In the first iteration, the initial concepts were narrowed down and combined into three concepts: reflection, knight rider and northern lights. This was done through careful consideration of the information generated from the analysis of the focus group discussion, with the help of the KJ analysis. Since it had become clear that stationary representation of animations was not sufficient, it was decided that the next round of concepts was to be animated in 2D. The program After effects, which is an animation software suited for graphic animation, was used for this purpose. It was also decided that 3D animations would be too high fidelity for the stage of the development the concepts were in. The lower level of visualization also made it easier to make changes, which there were expected to be a lot of, since several iterations were planned.

The sketches from the first iteration were used as guidelines for the new tweaked concepts. The environment was set to take place in an urban city, with positioning of the lights stretching from the bonnet to the side of the car (see figure 16). The animation was a perpendicular view of an AV driving down an urban road. The AV identifies a pedestrian waiting at a zebra crossing further down the road. The AV then stops at the zebra crossing and lets the pedestrian pass. After the pedestrian has crossed the zebra crossing the AV starts to accelerate and drives out of the frame of the animation. Lastly, the three different concepts were imposed on the animation creating three different videos. See appendix 2 for links to all three animations.

4.2.1 Reflection

This concept went through a major change compared to its first generation, since it combines aspects from several other concepts. Continuous pulsating light bars were added to show when the car is in automated mode (see figure 16). At the zebra crossing, the light pulses still stretch out but do not fill the entire light board. The pulses freeze in place as the AV is fully stationary. The two flashes before departure were also removed, instead the frozen light pulses continue to move backward as the AV accelerates.

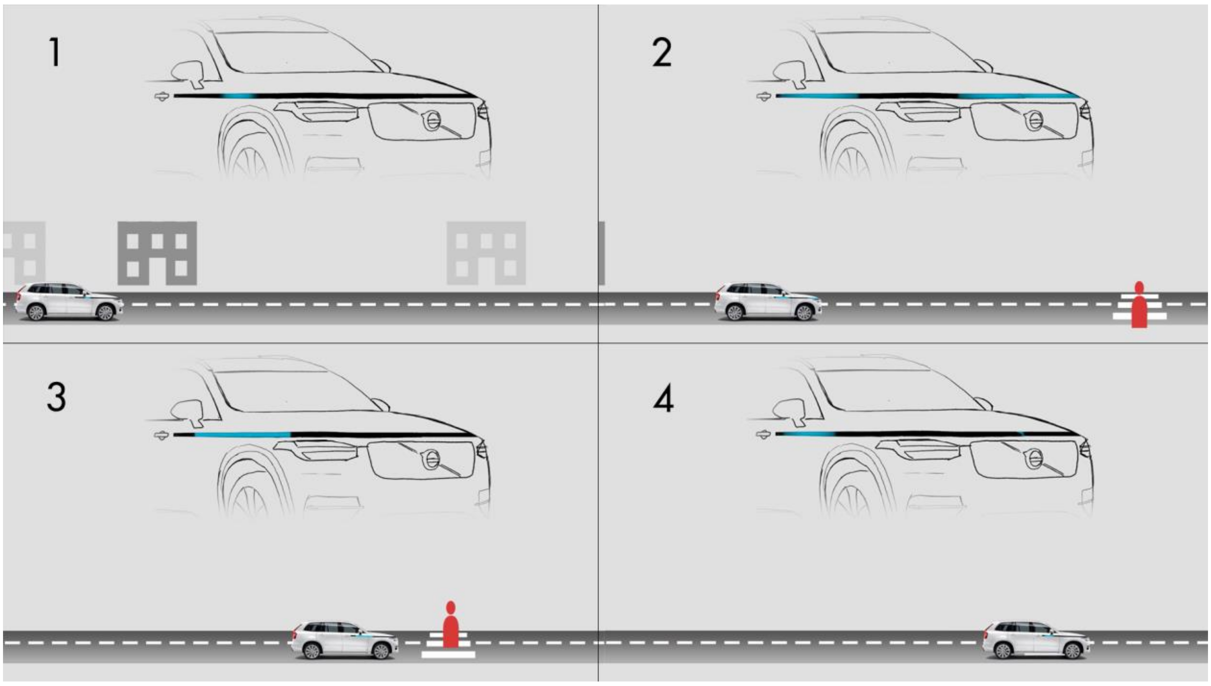


Figure 16: Screenshots from Reflection animation.

4.2.2 Knight Rider

This concept stayed mostly the same as the corresponding initial concept. However, some small details were changed. The light balls got stretched out in the middle to make it more visible, and the motion of the light balls shifted forward instead of backwards when decelerating (see figure 17). When accelerating, the light movement went backwards just like the concept from the first iteration. Another additional feature that was added into this animation was the decreased speed of the light movement as it approaches the zebra crossing. This gives the car a sense of speed for the pedestrian.

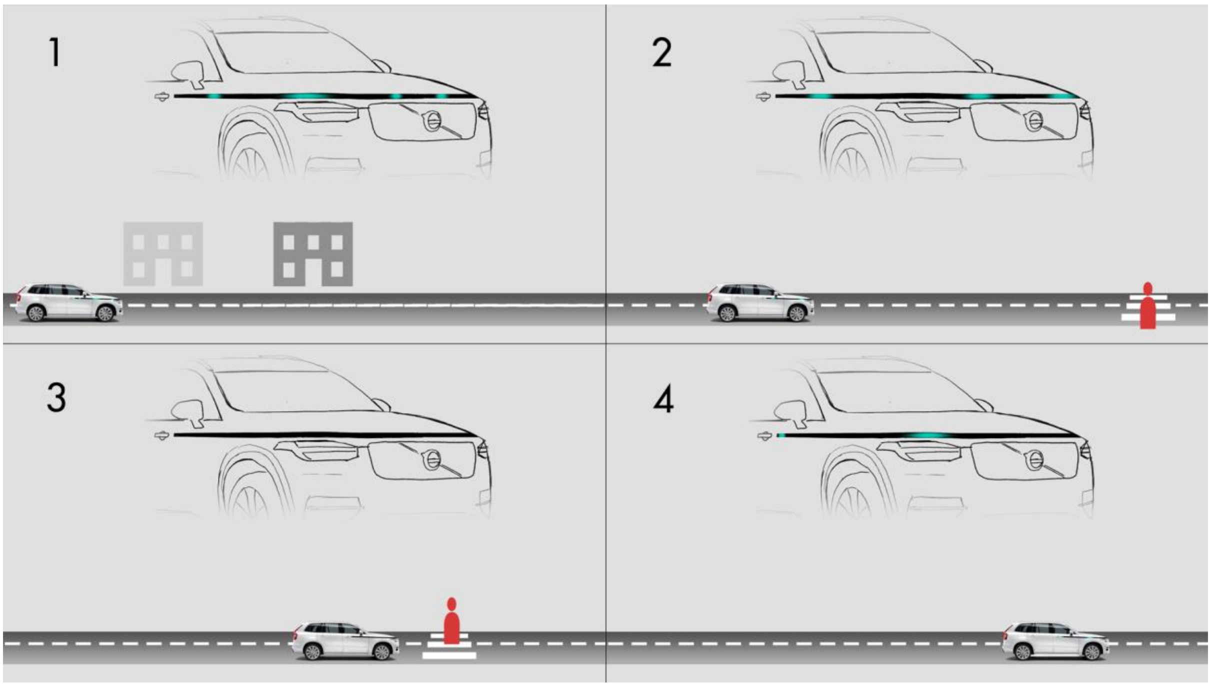


Figure 17: Screenshots from Knight rider animation.

4.2.3 Northern Lights

The Northern Lights did not go through many changes. All the features from the first iteration were added into this animation, and nothing additional was added to communicate with the pedestrian. The only detail that was changed was the colour of the light bars that got collected from purple, blue and turquoise to only being turquoise when it's about to accelerate (see figure 18).

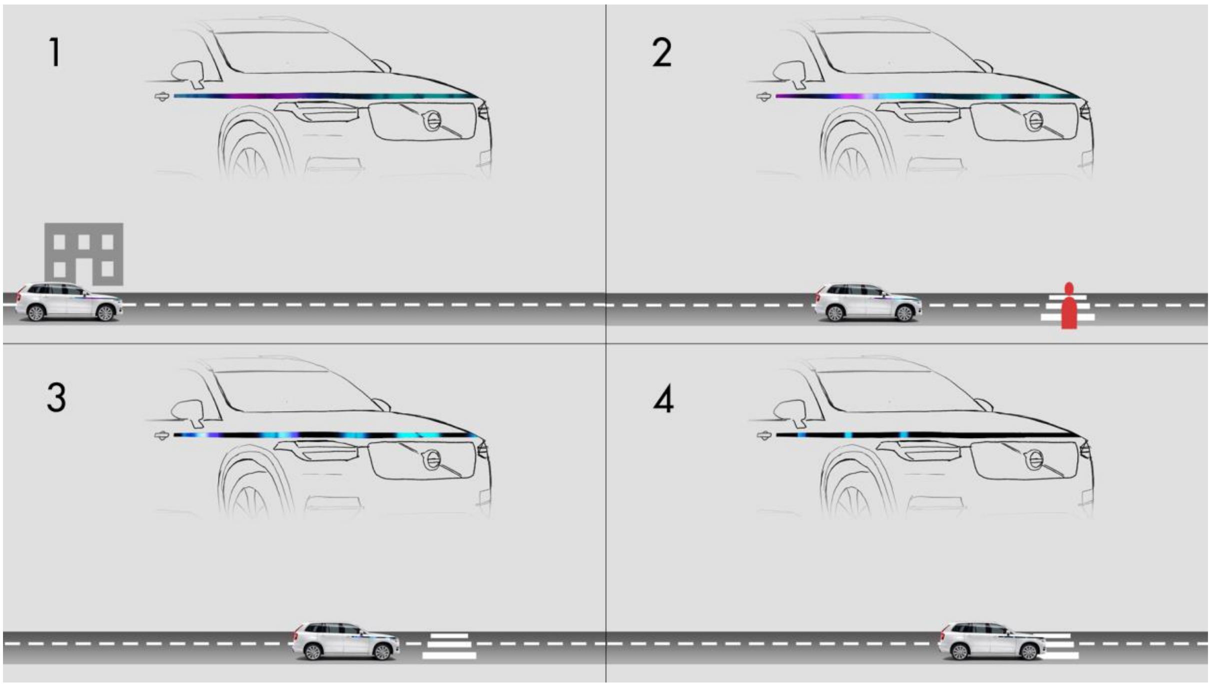


Figure 18: Screenshots from Northern lights animation.

4.3 Interviews and Survey

To narrow down the concepts to one or two final concepts, an evaluation consisting of interviews and a small survey was carried out. The 18 participants were selected based on demographic similarity to possible end-users. The demographic factors that were identified as important were gender and age. As well as how much experience, if any, they had driving and how often they navigate city traffic as pedestrians. Lastly their familiarity with AVs and driver assistance systems was examined. Nobody under age 18 participated since the way children's interpretation of traffic signals differs in that it is more based on learning rather than understanding (Charisi et al., 2017). After this a survey that contained questions about all the above-mentioned factors was filled out by the participants.

The participants were shown a 2D animation of an AV with active lights approaching a zebra crossing, where a pedestrian was standing. At that frame, the animation was paused. The participants were then, among other questions, asked what they thought the AVs intentions were, without having seen the outcome of the animation. After this, the whole video was shown revealing the AV letting the pedestrian pass and then continuing to drive. The participants were allowed to unlimited replays of the video. The amount of playbacks were noted and used in the analysis later on. The interviewing questions were based on the system usability scale which is designed to quickly evaluate the usability of a system or product (Brooke, 1996). It slightly adapted for the purposes of the thesis. The interview questions were meant to examine how and to which degree the participants understood the concepts. It was revealed at the start of the test that the car is in fact self-driving, but the lights were not mentioned. Discovering the lights and interpreting their purpose was entirely left to the participants. This was in accordance with the goal to find out which of the concepts is easiest to understand. Furthermore, the participants were asked in what ways the concepts could be misinterpreted and how they could be improved. See appendix 1 for the full interview guide. Each participant was only shown two of the three concepts and in a randomized order. This was done in order to minimize the learning factor which would favour the concepts shown last, if they were all sequentially presented. Another beneficial aspect was to not overwhelm the participants with too much information. Optimally each participant would have only seen one concepts. However, due to the limited resources of the thesis, showing two concepts was deemed as sufficiently minimizing the learning effect.

4.3.1 KJ Analysis of Interviews and Survey

A KJ-analysis was once more chosen as the most appropriate method. As the comments from the participants were more specifically directed at each separate concept this time, three sub analyses were made. Each analysis contained its own themes, some unique and some similar to the other concepts. The analysis was first regarded as three separate analyses and then finally merged to one analysis where more general conclusions were made.

Reflection

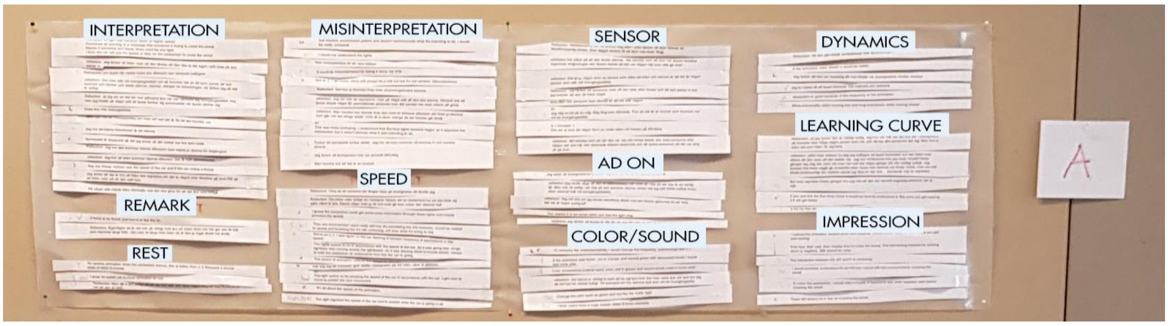


Figure 19: KJ-analysis of Reflection.

This concept was received well by the majority of participants but was controversial to some. Most participants were able to correlate the animation with the decreasing speed of the AV. This is one of the biggest goals of the lights, since it enables the pedestrians to “read” the AVs intention and use this information to determine its own action. A majority of participants also interpreted this concept as some sort of sensor and an indication that the car was self-driven. While it is better to interpret it as the AV is communicating intent, it is still positive to interpret it as a sensor which might increase trust. Even though only a small number of the participants seemed to dislike this concept, it still was considerably more controversial than the other two concepts. When asked about why they disliked it they gave answers like “it was confusing” or “I did not understand what it was doing at all” even if they earlier in the test interpreted it correctly. One explanation for this might have been that there were too many levels of change, resulting in overwhelming impressions. Perhaps it was because of the fact that the signals occurred before a pedestrian was spotted and this confused the participants when trying to decipher what the light meant. Or it was simply something about how it was animated that was hard for the TPs to put their finger on. What can be said for certain is that the concept gave some a feeling of confusion.

It is still important to mention that a big portion had a positive reaction to the concept. The reason behind this is most likely the clear and straightforward correlation between the speed of the animation and the speed of the car, which some participants mentioned outright. Being able to make this connection would lead pedestrians to directly understand the purpose of the lights as well as make it possible for them to process the information communicated.

Knight Rider

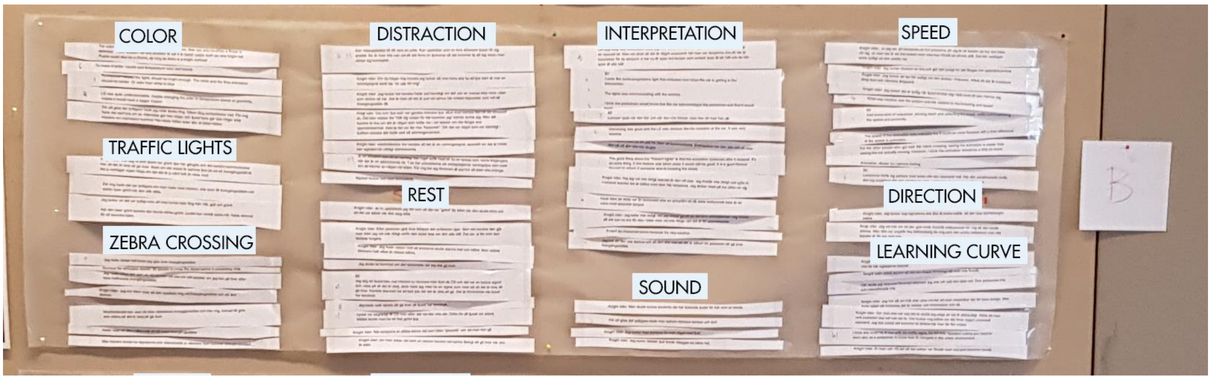


Figure 20: KJ-analysis of Knight rider.

Among all the concepts, the Knight Rider seems to be better received than the other concepts, according to the comments from the test persons. Some people got a negative impression, but it was concluded that it did not receive as much negative feedback as Reflection and Northern Lights. Some people thought the movement was too aggressive which could correlate with some kind of hazard light or a police car, but some people also mentioned it needed a bolder difference between the initial movement and the final movement. However, the decreased speed of the animation in relation to the speed of the car was highly appreciated, since most people found it helpful to tell if the pedestrian could cross the street. Some people thought it was better to have the animation go the other way when decelerating, even though the direction of the light might not affect the awareness of the lights. At rest, the light signal did not show any animation, which was threatening for some people. It was concluded that most people felt the need of a confirmation for crossing the street before the car completely stopped by the zebra crossing. The majority of the people found it easy to learn and were relatively positive to the new light system.

Nevertheless, the overall feeling of this concept seems to have gotten the most positive feedback from the participants, mainly because of the consistency, simplicity and its movement in relation to speed. The concept also seemed to have the lowest learning curve, since it had less playbacks compared to the other concepts.

Northern Lights

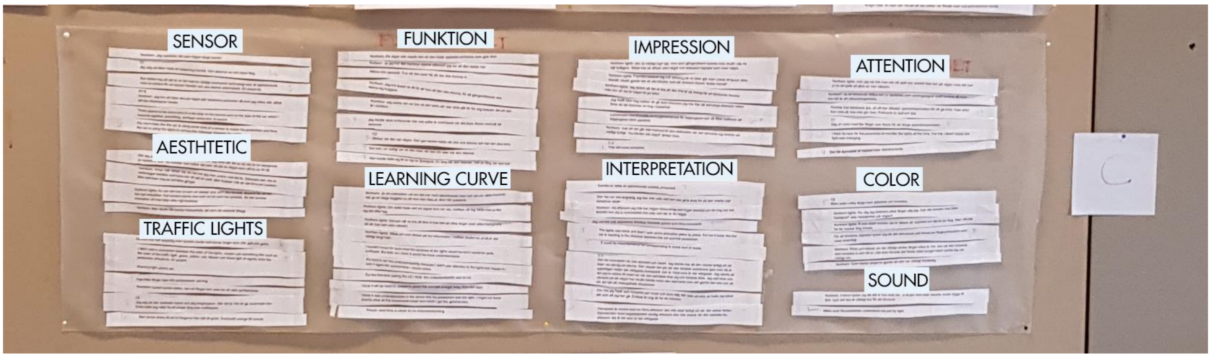


Figure 21: KJ-analysis of Northern lights.

The most apparent reaction to the Northern Lights was that the whole concept was in relation to the other two concepts, diffuse and hard to grasp. Considerably less people were able to correlate the dynamics of the animation with the decreasing speed of the car. However, most test persons were able to identify the concept as a signal with the purpose of communicating something. Most of them upon seeing the first part of the video interpreted it as some kind of sensor that indicated that the car was intelligent. Even though the concept was too diffuse it succeeded in conveying a calming feeling with its animation. Given the goal to ensure the pedestrian of the cars' intention to stop, this is advantageous. This is also preferable when compared to Knight Rider, which was perceived as "hysterical". The feeling of complexity, which some persons described, also served a purpose in conveying some form of intelligence. People are more likely to trust something intelligent and communicative (Wang, 2016). Furthermore, some participants mentioned that the fact that the concept looked, in their words, "cool" could lead to pedestrians interpreting it as having a solely aesthetic function. This problem conflicts with the car manufacturers and the consumers' desire for an aesthetic product. The solution is to identify the correct balance between aesthetic and function. In this case northern lights might lean too much towards the aesthetic side. Although, a few participants mentioned some positive aspects, e.g. an aesthetically pleasing signal could increase the desire to learn its function. Some test persons also said that the concept gave them a positive feeling or impression.

The biggest theme for this concept was “learning curve”. All concepts had this theme, but it was considerably larger on Northern Lights. When the test participants had figured out that purpose of the lights during the videos, or had an idea from watching a concept previously, many of them mentioned that a person's first encounter with the AV might be confusing. Some pointed out that it would be too confusing for people to learn. Yet perhaps a slightly bigger portion were more positive and thought there would not be any problem after someone had explained it to them. However, it was clear that the learning curve would most likely be steeper in comparison to the other concepts.

4.3.2 Discussion of Results

As mentioned in the previous section, there were still general conclusions to be made looking at the shared results of the three sub analyses. For instance, all concepts had about the same amount of comments that mentioned the risk of misinterpreting the vehicle as an emergency vehicle. However, the risk of this misinterpretation is judged to be fairly low, especially at small or medium distances to the vehicle. In addition, the animation, appearance, placement and intensity of these kinds of lights is entirely different. One explanation of this comment appearing on all three concepts is that the participants did not have a particularly strong opinion on the question “How can this be misinterpreted?”. Still, most participants still felt that they needed to give an answer, which resulted in that they simply said the first thing that came to mind. This also aligned with the interviewer’s impressions at the individual interviews. Some measures can still be taken to avoid this misinterpretation. When the colour turquoise is used it needs to lean closer a green-blue hue rather than a blue and red hue. This will help to slightly distinguish it more from police lights which is what the participants mostly referred to. On all concepts the test persons made approximately the same comments about traffic colours. Upon getting the question “How can this light be improved?” most participants mentioned having the lights work like the red, yellow and green street lights. This is not possible for reasons gone over earlier in the report. However, some other interesting ideas were brought up like using temperature colour depending on the proximity, which is basically the idea of changing the colour from warm to cold colour such as orange to blue or vice versa. Overall, the question of colour seemed to be important to a majority of test participants which interestingly contradicts the expert’s opinion gathered from the Focus Group. Another frequent insight was the need for the addition of sound signals. This project has however placed sound outside its boundaries. Although, the result clearly indicates that this is an important aspect in the situation and should therefore be looked further into in future developments. Finally, a lot of insights regarding the various animations at the rest-state were gathered. Reflection freezes its animation at rest, Knight Rider simply had no animation and Northern Lights had a continued animation at rest. Out of all these three, Knight Rider got a considerable amount of negative feedback. There was an indication that the participants started to associate the presence of the signals with the operational status of the AV. Some mentioned that the lights indicated that the car was “intelligent”. When it is clear that the lights are a channel for the AV to communicate, an expectation for communication is also created. This in turn creates a concern if there is no animation which made some test persons suspect that something is wrong with the AV, or that it was inactive for some reason.

Based on previous work it initially was deemed that animations at rest were not a high priority. The reason was that Azra Habibovic et al. had shown that most people do not notice these "resting" animations, when they are crossing the road (2018). However, pedestrians that are not crossing yet, but are approaching the zebra crossing where the car is waiting, are still considered part of the interaction. Information about the cars state and intention is still important to these pedestrians. Therefore, the need of an animation at "rest" is confirmed.

4.4 Second Iteration of Concepts

The second iteration mainly focused on the development of Knight Rider by combining features from the other concepts. The reason why Knight Rider was picked as the main concept was simply because of the small amount of misunderstanding comments compared to Reflection, which for many felt illogical, while Northern Lights felt too esthetical. Even though Knight Rider had a few issues, it was rather minor details which could be changed very quickly. One of the few issues Knight Rider had was the frequency of the lights which appeared to move too fast, giving it a hysterical impression. The frequency of the lights was therefore decreased to a maximum rate of 4 Hz. This was in accordance with the expert from the focus group which assumed that a higher intensity would be perceived as a warning or a danger.

When yielding, the rate of the signals goes from 4 - 0 Hz shortly before the AV completely stops. The direction of the light is also changed to a backward motion like Reflection. As mentioned before, this issue is less important from a cognitive point of view, however, the idea of having the light seem stationary in relation to the car felt like an important feature to keep to maximize simplicity. Another issue that was raised during the second evaluation was the concept not showing any animation at rest. The solution for this problem was therefore to make the signal freeze at zero velocity just like Reflection.

Furthermore, the change in animation speed in relation to the AVs speed was made as clear as possible, since this was the most positive insight from the evaluation. One important aspect that was frequently brought up on the second evaluation was the desire to have the lights shifting like the traffic lights. Even though it is legislatively unacceptable to use the lights like the traffic lights on the car, the thought of using the colour as an additional feature to catch the users attention was considered when creating the final concept. Instead of having the light shift using the traffic lights, a colour gradient was added shifting from white to turquoise depending on the proximity of the zebra crossing, just like the Northern Lights. Since this is an additional feature added to this concept, the functionality of this concept is not depended on the colour change completely. Even though this is an idea that has been untested, there is a strong believe that this will work since it was brought up plenty of times on all the concepts during the second evaluation. See Figure 22 for a visualisation of a suggested placement of the light strip. It could potentially also be placed higher up on the roof or at the top of the windshield spanning to the intersection of the two side doors.

Figure 22: light strip placement visualisation. Authors’ own figure.

The signal for when the concept is about to start is slightly different compared to initial animations in 2D. When the concept is about to depart, the car pulsates twice before moving backwards in relation to the cars movement in a rate from 0 Hz to 4 Hz. This message when the AV needs more of an alerting character since there is mild potential danger. At this point pedestrians need to be alerted that they cannot cross the road. The further the car gets from the zebra crossing, the whiter the lightbar gets, shifting from turquoise to white until it disappears completely. This pulsating signal of the light bar before departure comes from the initial thought of having the light signal communicate clearly with the pedestrian. It was also mentioned in the second evaluation that it was not appreciated when the car didn’t show anything at rest and that it would be good to insert a signal that was reversible if there is a scenario of another pedestrian crossing the street when the first pedestrian finished crossing the street. If this were to happen, the signal would go back to its initial state of “freeze mode” meaning that the AV is at rest. There is a strong belief that the pulsating signal is necessary to clarify its intention of something happening, almost like a pre-signal before the main-signal of departure, which catches the pedestrians attention.

4.4.1 Execution of the final concept

As for the 3D animation, the motion of the Volvo car and the urban city was created using Alias Autostudio while the signals on top of the display was created using Adobe After Effects. The method for mapping out the signals on top of a moving object simply relied on a method called rotoscoping. It is a very common method used when animating with After Effects and relies on layer masks which moves in relation to the motion on the animation for each frame of the video. Below in figure 23-26 are rendered images of the Volvo car and the 3D city environment. There is also a close up view on the display and zebra crossing.

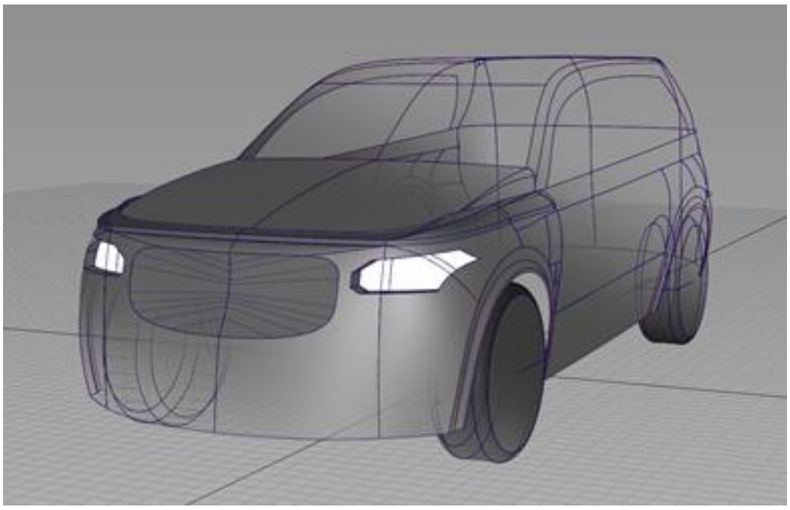


Figure 23: 3D model of Volvo car.

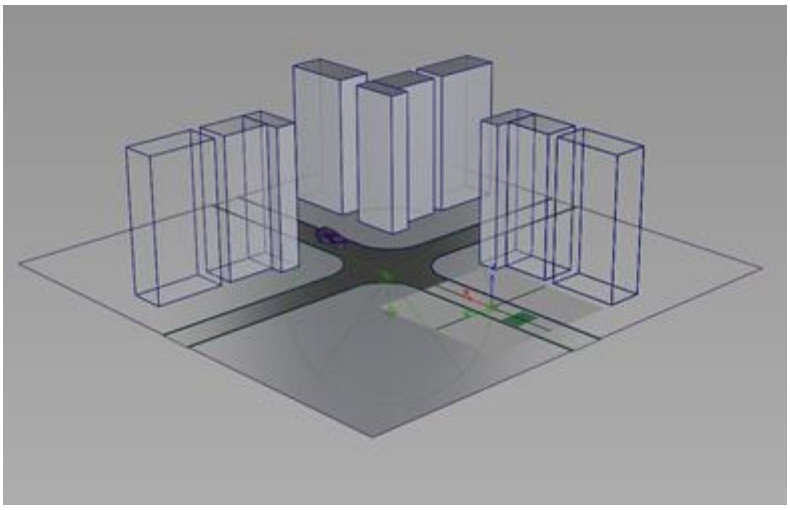


Figure 24: 3D City environment.

Figure 25: Close Up View of Display.

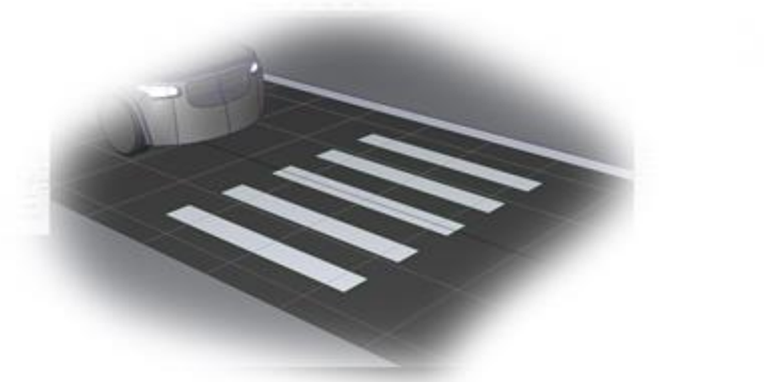


Figure 26: Close Up View of Zebra Crossing.

Below in figure 27 and 28 are screenshots from the animations of yielding and departing. In the first animation, the car is observed as the one crossing the street. In the second animation the perspective is from another pedestrian who is approaching the zebra crossing while the AV has decided to depart. See appendix 3 for links to the full animations.

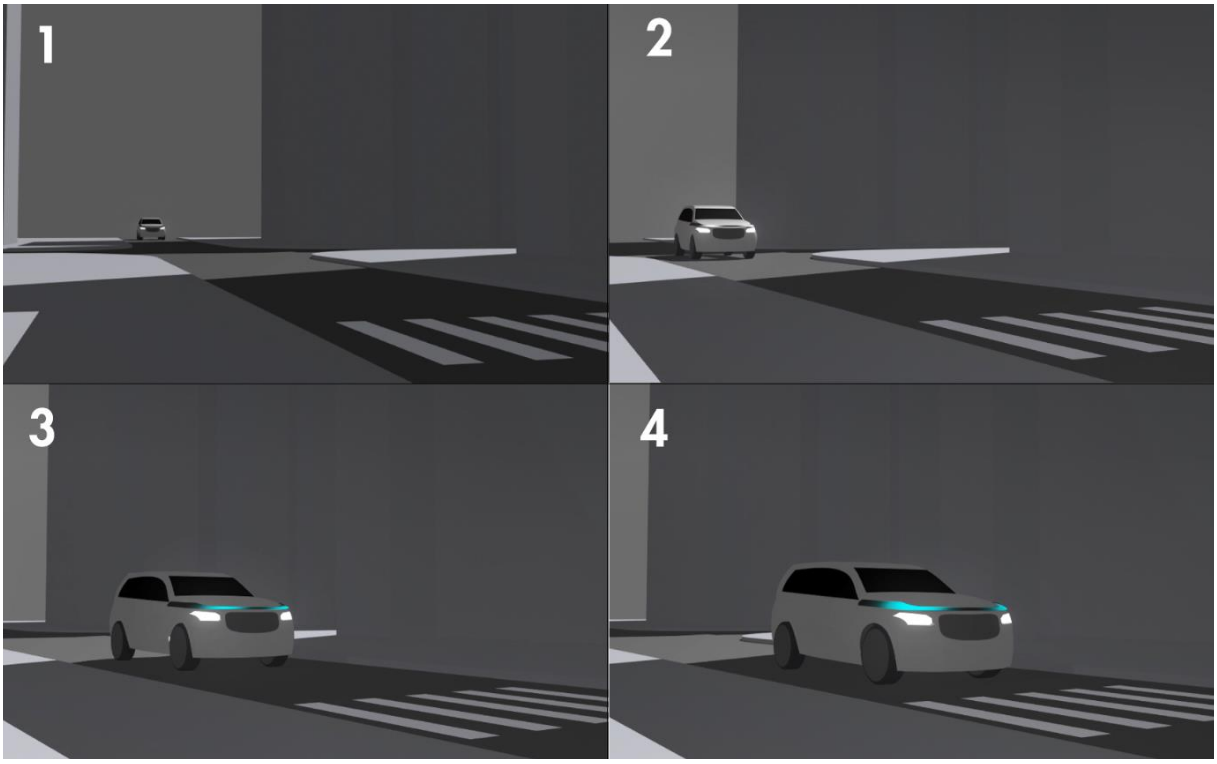


Figure 27: Yielding.

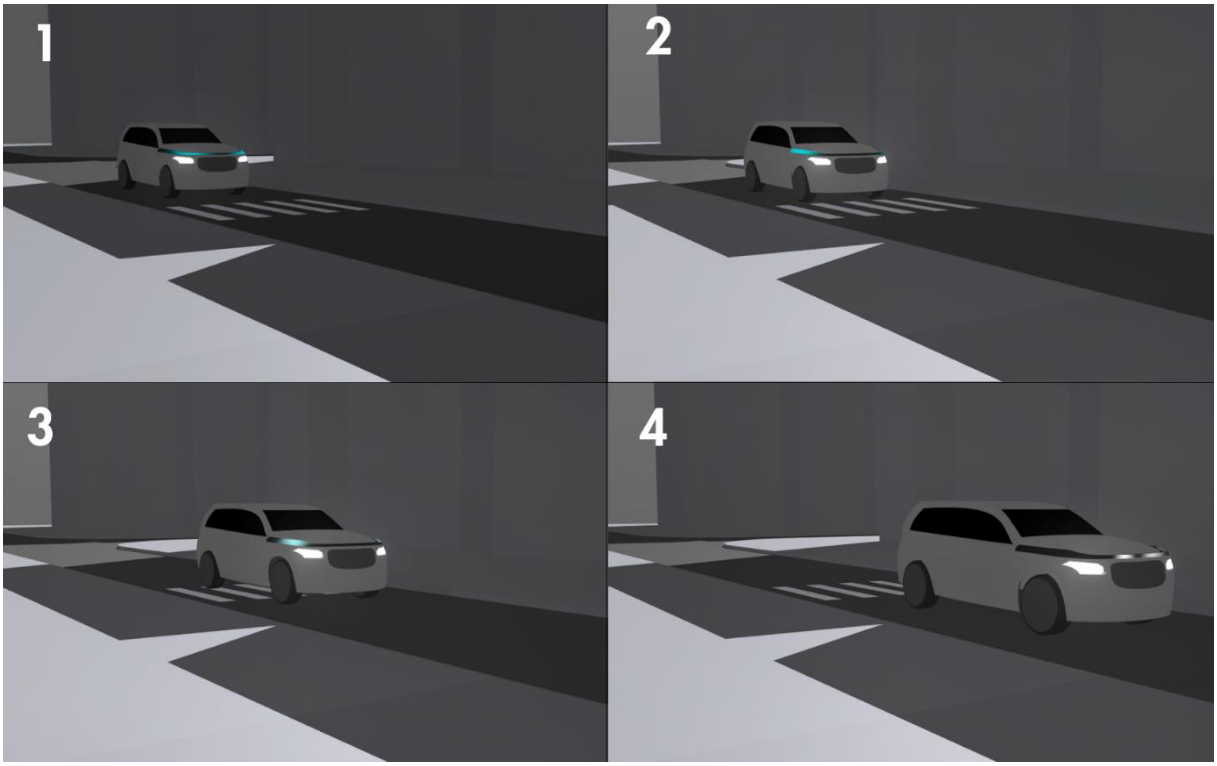


Figure 28: Departing.

The most time-consuming part of this process was the rendering of the animation. The animation had to be rendered plenty of times in order to get the right one and each rendering took a few hours. The higher resolution, the bigger the file got and the longer it took to render the animation. Seeing the animation with a too low resolution would end up with no conclusion for improvement since it would be too difficult to pay attention to small details in the animation. Ending up with a too high resolution and it would take forever to render. Finding the right balance was therefore very difficult. The animation however ended up with a resolution of 992 by 624 with a ratio of 16:9 to fit the canvas of the presentation.

Another obstacle along the process was the Alias-drawing of the Volvo car. The shape of the car was very complex and had a lot of details. Making a car that resembled a Volvo car was therefore extremely challenging. Since the whole process of the 3D animation was very time consuming, there were no time left for a thorough evaluation for the final animation. However, there was a brief desktop evaluation with a few potential users to implement their general thought of the animations. Overall, the concept was perceived well while some people thought it was too small in relation to the size of the car. Since the evaluation was not as thorough as the second evaluation, no conclusions can be made from this study.

Even though this thesis has been very challenging and time consuming, it has been very instructive. For instance, learning a software that has never been seen before such as After Effects was very difficult at first, but is now a skill that might come in handy later on at work. The thesis has also been very instructive in a way that a lot of essential methods for the design process had to be repeated from old studies in order to execute the different methods. To work together with experts from different companies has also been a great experience which differed a lot from the way school projects are done. Even though it has been challenging, it has been a great experience to mature and grow with knowledge.

5. Discussion

The authors have proposed a solution to the question of AV-pedestrian communication. Through an analysis of the situation appropriate messages to communicate were suggested. These messages have then been translated into communication solutions, which depict the appropriate way to work toward a global standard. It was found that the AV should not communicate explicit directions to the pedestrian but should instead communicate messages regarding its intention and actions. An important part of this thesis was the identification of negative and positive aspects of previously done work, since this might be crucial in a standardization process. It was shown that it is possible to create an intuitive communication interface and avoid problems others have had. It was found that having a clear connection between the speed of the animation and the speed of the car was the best way to communicate the AVs messages. It was also shown that most people made this interpretation intuitively. The significance of this connection, as well as the degree of impact it had on the test persons understanding of the concepts, was somewhat surprising and unexpected. In this way the animation on the interface amplified the AVs body language by providing a second source for reading the speed of the car. This was accomplished through use of non-direct communication with abstract animations and signals.

While environmental sustainability has not had a prioritized focus in this thesis, it does in some ways align with social as well as economic sustainability. Perhaps the most direct sustainable effect of this thesis is the goal to enhance both the perceived and actual safety in traffic. The successful implementation of a solution which fills the conditions set by this thesis would improve the current communication, resulting in a better, more frictionless and safe interaction for everyone involved. Looking at the bigger picture, the general development and introduction AVs might lead to higher mobility for a greater number of people, which also improves the social sustainability aspects. It also progresses the development of the automotive industry which contributes to economic sustainability.

There is no denying that the environmental impact has raised more awareness among people in today's society. Scientist and engineers are constantly trying to find alternative energy sources that could help save the planet. In this thesis, the main focus has been to improve the sustainability at an urban level. As the number of people at cities keep growing and the technology keeps advancing, it is essential that the infrastructure and transportation needs improvements to work as flawless as possible. As for the automotive industry which this thesis has been revolving around, urban cities are going to be filled with self-driving cars which will be surrounded by pedestrians within a near future. Managing a good communication for safety purpose between pedestrian and AVs is therefore essential for maintaining a sustainable urban city. Looking at the bigger picture, the general development and introduction AVs might lead to higher mobility for a greater number of people, which also improves the social sustainability aspects. It also progresses the development of the automotive industry which contributes to economic sustainability. As for the cultural aspects, the light signals are rather abstract with the aim to work anywhere in the worlds regardless of which language you speak.

When it comes to AVs in general, ethical issues have long been debatable. Some people are totally against the development of AVs while some people are totally up for it. It is worth mentioning that the whole purpose of AVs is to make cars safer since 94 % of all the accidents are caused by human error (Lawinfo, 2017). Even though AVs are supposed to be safer, it is debatable regarding the responsibility of the car if the car breaks down or if there is a technical issue causing an accident. In this thesis, there might be a chance that the light signals could break because of technical issues. This could most likely cause trouble for the communication between AVs and pedestrian leading to an accident. And it will be even worse if the society is strongly depended or used to the signal when there is no signal showing because of technical issues. One way to solve this is to have an office with employees handling issues which are reported automatically through a backup system just like the one with the cars today which informs the driver with a red lamp when the car is low with fuel or electricity. But instead of having the driving being notified, people at the office gets a notification and are in charge to control the car from thereon. Other risks with the light signals would be for the people that are blind. However, this could be solved with a sound system, complementing the lights and making it clearer for the other pedestrians. Even though are risks of errors, the possibility to eliminating the 94 % of the accidents caused by human factors is far more superior than the risks itself.

It might be necessary to discuss whether the result of this thesis can be reproduced. The answer will likely be yes when considering for example the finding of the effectiveness of correlating the animation with the vehicle speed, since it is based on the cognitive processes of the users. However, considering some design methods like ideation methods, it is natural that everyone individual person will come up with different ideas. In that aspect, if the methodology of this report is repeated, an entirely different result or conclusion might be reached. Regarding the validity of the result, the goal was to gain insight in to how potential pedestrians might understand different concepts. In this respect, the validity is considered to be high since this was the focus for all testing done. Lastly, it should be mentioned that this thesis only suggests an approach to the stated problem since it is still in an early concept development phase. It needs more development and testing of the solutions with users on a deeper detail level, since there are some constraints missing the thesis did not consider.

6. Conclusion and Future Work

It is clear that the work to develop a global standard for AV-pedestrian communication needs to continue. The approach of using intuitive and abstract signals is a potential candidate since it might work regardless of geographic location. However, this needs to be verified through testing with geographically diverse test participants. It is also possible to test specific factors such as different speeds, frequencies and the timing of animations. This was originally intended to be the focus of the thesis but had to change due to time restrictions from the overarching project the thesis was a part of. Furthermore, the impact of different possible placements of the communication interface needs to be examined. The integration of sound signals is also a very large area that needs to be explored in order to further the research.

The thesis focused on testing qualitative understanding of the concepts which fit the goal of the thesis. However, it was also possible to focus more on quantitative measures. Going forward it will also be important to try to use larger test groups and that are more diverse in geographic locations. An important insight from the thesis is that another approach is to focus on the learnability of the communication rather than the intuitiveness. Another insight that the thesis did not have an opportunity to explore was to examine how simplistic a concept could be before it loses it its effectiveness.

A high level of continued development is expected in this field and most car manufacturers will chose some sort of communication, standardized or not. However, even further into the future when the majority of cars are self-driven, human drivers might be the problem. At this point the roles might be reversed and it will be the human driven vehicles that will need special communication lights.

References

Amazon. (n.d.). Amazon Mechanical Turk. Retrieved June 11, 2019, from https://www.mturk.com/

Benyus, J. M. (2009). *Biomimicry: Innovation inspired by nature*. New York, NY: Perennial.

Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability Evaluation in Industry, 194*, 189-194.

Charisi, V., Habibovic, A., Andersson, J., Li, J., & Evers, V. (2017). Children's views on identification and intention communication of self-driving vehicles. Proceedings of the 2017 Conference on Interaction Design and Children, 399–404. https://doi.org/10.1145/3078072.3084300

Department for Transport. (2015). The Highway Code. Retrieved February 22, 2019, from https://www.gov.uk/guidance/the-highway-code/using-the-road-159-to-203

Dey D, Eggen B, Martens M, Terken J. (2017). *The impact of vehicle appearance and vehicle behavior on pedestrian interaction with autonomous vehicles*, Presented at Automotive User Interfaces Conference, Oldenburg, 2017.

Diamler. (2019). Autonomous concept car smart vision EQ fortwo: Welcome to the future of car sharing. Retrieved May 7, 2019, from https://media.daimler.com/marsMediaSite/en/instance/ko/Autonomous-concept-car-smart-vision-EQ-fortwo-Welcome-to-the-future-of-car-sharing.xhtml?oid=29042725

Ding T., Wang S., Xi J., Zhang L., Wang Q. (2014). Psychology-Based Research on Unsafe Behavior by Pedestrians Wh–en Crossing the Street. Retrieved May 7, 2019, from https://journals.sagepub.com/doi/full/10.1155/2014/203867

Goodyear S. (2014). The Swedish Approach to Road Safety: 'The Accident Is Not the Major Problem'. Retrieved May 7, 2019, from https://www.citylab.com/transportation/2014/11/the-swedish-approach-to-road-safety-the-accident-is-not-the-major-problem/382995/

Habibovic A, Malmsten Lundgren V, Andersson J, Klingegård M, Lagström T, Sirkka A, Fagerlönn J, Edgren C, Fredriksson R, Krupenia S, Saluäär D & Larsson P (2018) Communicating Intent of Automated Vehicles to Pedestrians. In *Frontiers in Psychology.* 9:1336. doi: 10.3389/fpsyg.2018.01336

iKörkort. (2019). Vanliga körkortsfrågor. Retrieved May 7, 2019, from https://www.ikorkort.nu/vk_korkortsfraga_464.php

Jordan, P. W. (1998). *An Introduction To Usability*. Taylor Francis, London.

Lawinfo. (2017). Human Error Causes 94 Percent of Car Accidents. From https://blog.lawinfo.com/2017/09/06/human-error-causes-94-percent-of-car-accidents/

Lundgren, V.M., A. Habibovic, J. Andersson, T. Lagström, M. Nilsson, A. Sirkka, and D. Saluäär. 2017. Will There be New Communication Needs When Introducing Automated Vehicles to the Urban

Context?. In *Advances in Human Aspects of Transportation*, 485–497. Cham, Switzerland: Springer International Publishing.

McNeil J. (2019). Introducing Lyft Driver Service. Retrieved May 7, 2019, from https://medium.com/@jmaclyft/introducing-lyft-driver-services-ac1ab9488ac6 els/

Merat N., Madigan R., Nordhoff S. (2016) Human Factor, User Requirements, and User Acceptance of Ride-Sharing in Automated Vehicles. International Transport Forum Roundtable on Cooperative Mobility Systems and Automated Driving.

Mercedes-Benz. (2017). The Mercedes-Benz F 015 Luxury in Motion. Retrieved February 18, 2019, from https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-moti

Nielsen, J. (2010). Mental Models. Retrieved February 22, 2019, from https://www.nngroup.com/articles/mental-modon/

Nissan Motor Co., Ltd. (2015, October 25). Together We Rise [Mp4]. Retrieved May 7, 2019, from https://www.youtube.com/watch?v=9zZ2h2MRCe0&t=149s

Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors, 39,* 230-253.

Rothenbücher, D., Li, J., Sirkin, D., Mok, B., & Ju, W. (2016). *Ghost driver: A field study investigating the interaction between pedestrians and driverless vehicles* (pp. 795-802, Tech.). IEEE.

Statistika Centralbyrån. (2009). Historisk statistik för Sverige. Retrieved May 7, 2019, from https://www.scb.se/Grupp/Hitta_statistik/Historisk_statistik/_Dokument/Statistiska-oversiktsabeller-utover-i-del-I-och-del-II-publicerade-tom-ar-1950.pdf

Stickdorn, M., Lawrence, A., Hormess, M., & Schneider, J. (2018). *This is service design doing: Applying service design thinking in the real world: A practitioners handbook*. Sebastopol, CA: OReilly Media.

Sveriges trafikskolors riksförbund. (2018). *Körkortsboken* (31st ed.). STR service.

Wang, N., Pynadath, D., Hill S. (2016). Trust calibration within a human robot team: Comparing automatically generated explanations. Proceedings of the 11th ACM/IEEE International Conference on Human Robot Interaction (HRI). IEEE, Piscataway, NJ

Österlin, K. (2016). *Design i Fokus*. Liber, Stockholm.

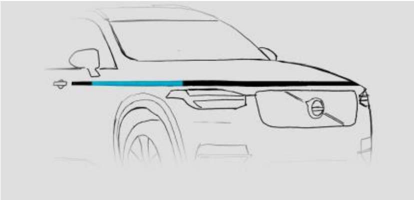
Appendices

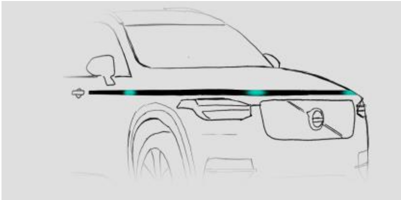
Appendix A: Interview guide
Appendix B: Links to animations from first iteration
Appendix 3: Links to final concept animations

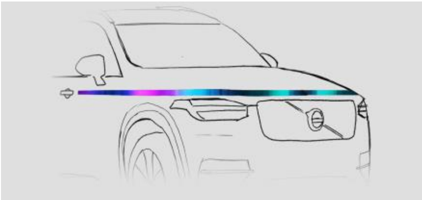
Appendix A: Interview Guide

Försöksperson _____ **Datum** _______

AB **BA** **BC** **CB** **AC** **CA**







A) Reflection B) Knight rider C) Northern lights

→ *GDPR*

→ *Demografisk*

→ *Ljudinspelning*

→ *Bakgrunden:*

"Du kommer nu att se animeringar av en självkörande bil i en stadsmiljö med ett övergångsställe. Efter varje videosekvens kommer jag att ställa några frågor kring din förståelse om vad som hände i videon. Jag dömer dig utan du får säga exakt vad du vill så våga tänka högt. Jag kommer att börja med att visa dig halva klippet på två koncept, därmed kommer du att få se hela klippet. Hela undersökningen tar ungefär 15 min."

Första delen

Koncept ___

1. Kan du beskriva det du just såg?

2. Märkte du något speciellt med bilen?

- Varför tror du att den gjorde så?

3. Hur skulle du beskriva samspelet mellan bilen och fotgängaren?

- Vad är bilens intentioner tror du?

4. Tycker du att ljussignalen var begriplig?

- Vad gjorde att den var begriplig?
- Vad, hur?

5. Hur tycker du att man borde göra för att förstärka tydligheten hos ljussignalen på bilen?

6. På vilka sätt kan ljussignalen missuppfattas?

Antal omstart:

Första delen

Koncept ___

1. Kan du beskriva det du just såg?

2. Märkte du något speciellt med bilen?
    - Varför tror du att den gjorde så?

3. Hur skulle du beskriva samspelet mellan bilen och fotgängaren?
    - Vad är bilens intentioner tror du?

4. Tycker du att ljussignalen var begriplig?
    - Vad gjorde att den var begriplig?
    - Vad, hur?

5. Hur tycker du att man borde göra för att förstärka tydligheten hos ljussignalen på bilen?

6. På vilka sätt kan ljussignalen missuppfattas?

Antal omstart:

Hela videon

Koncept ___

1. Kan du beskriva det du just såg?

2. Märkte du något speciellt med bilen?

- Varför tror du att den gjorde så?

3. Hur skulle du beskriva samspelet mellan bilen och fotgängaren?

- Vad är bilens intentioner tror du?

4. Tycker du att ljussignalen var begriplig?

- Vad gjorde att den var begriplig?
- Vad, hur?

5. Hur tycker du att man borde göra för att förstärka tydligheten hos ljussignalen på bilen?

6. På vilka sätt kan ljussignalen missuppfattas?

Antal omstart:

Hela videon

Koncept ___

1. Kan du beskriva det du just såg?

2. Märkte du något speciellt med bilen?
   - Varför tror du att den gjorde så?

3. Hur skulle du beskriva samspelet mellan bilen och fotgängaren?
   - Vad är bilens intentioner tror du?

4. Tycker du att ljussignalen var begriplig?
   - Vad gjorde att den var begriplig?
   - Vad, hur?

5. Hur tycker du att man borde göra för att förstärka tydligheten hos ljussignalen på bilen?

6. På vilka sätt kan ljussignalen missuppfattas?

Antal omstart:

Appendix B: Links to animations from first iteration

Knight rider: https://www.youtube.com/watch?v=A04ENq6NQfQ
Reflection: https://www.youtube.com/watch?v=CgT14XLuAn4
Northern lights: https://www.youtube.com/watch?v=CgT14XLuAn4

Appendix 3: Links to final concept animations

Yeild:
https://www.youtube.com/watch?v=RPK_XChQ3a8&feature=youtu.be&fbclid=IwAR15vtv3TiO5Jc2ZWJE7vM_ik0RtZS8aXbsGhv72pPa5HYDoQP-lLNP-ffU

Departure:
https://www.youtube.com/watch?v=r5HxryZay3c&feature=youtu.be&fbclid=IwAR0sibSVvWkdFMeoXt2Bh7BsvGSKbh-J6DkH21UFsuzsJDjzion0PZj-y-8

Bachelor of Science Thesis IMSX20

Development of an intuitive pedestrian interaction system for automated vehicles
Bachelor of Science Thesis in the Thesis Degree Program Design and Product Developement

Chalmers University of Technology
SE-412 96 Gothenburg, Sweden
Phone +46(0) 31-772 1000
Cover photo: Alexander Karlsson & Tim Hedlund
Print: Repro Service Chalmers