CHALMERS

AVIP - Autonomous vehicles´ interaction with pedestrians

An investigation of pedestrian-driver communication and development of a vehicle external interface

Master of Science Thesis in the Master Degree Program Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenborg, Sweden 2015

Department of Product- and Production Development
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Cover photo: Tobias Lagström
Print: Repro Service Chalmers

ABSTRACT

The development of automated vehicles (AVs) is moving rapidly forward with companies already performing or planning trials in public traffic environment. However, the aspect of how pedestrians will experience AVs and interact with them has so far largely been unexplored.

The purpose of the master thesis project was to investigate if there is a need to enhance the vehicle's ability to communicate with pedestrians when introducing automated driving. Additionally, the project included how the interaction between pedestrians and AVs was affected by introducing an external communication interface.

The project relied on observations and interviews with a Wizard of Oz approach to give the pedestrians the experience of interacting with an automated vehicle. The pedestrians' emotional experiences were mainly gathered using the Self-assessment manikin tool (SAM) and verbal comments.

The results indicate that the pedestrians have a need of knowing when a vehicle is in automated driving mode. This since the decoupled driver's inattentive behavior otherwise is interpreted as uncertain and dangerous, resulting an unwillingness for the pedestrian to cross.

This was addressed by the introduction of a prototype that communicates the vehicle's current driving mode and intentions to the pedestrians. Specifically, a LED strip lights up in different sequences to communicate that the vehicle is "in automated driving mode", "is about to yield", "is resting" or "is about to start". The evaluation showed that the pedestrians were able to understand the signals conveyed by the interface, and that they were confident in their interpretation of the signals, after only a short training. The pedestrians also reported that the interface replaced the role of the driver in encounters with the automated vehicle, and even excelled today's interaction as the communication was clearer and available earlier.

<u>Keywords:</u> Pedestrian, automated vehicle, interaction, emotional experience, external communication interface.

ACKNOWLEDGEMENTS

Both design and research are fields driven by collaboration and the exchange of ideas. It is therefore suitable to start this master's thesis by thanking those who have influenced and contributed to our work.

To start, we would like to thank Viktoria Swedish ICT and Interactive Institute Swedish ICT and SAFER - Vehicle and Traffic Safety Centre at Chalmers for giving us the opportunity to work with such knowledgeable people in such an exciting field as the development of autonomous vehicles. From these organizations, we would especially like to thank Anna Sirkka, Johan Fagerlönn, Maria Nilsson, Jonas Andersson and our company supervisor Azra Habibovic. We are immensely grateful for the insights you have shared with us. Azra, especially, has been there for us, ready to answer any question and give advice on any topic. Thank you for your time and your commitment!

We are also grateful to all the employees at Viktoria Swedish ICT in Gothenburg, you really made us feel welcome and at home in your office.

To Rikard Fredriksson at Autoliv AB, Stas Krupenia at Scania AB, Claes Edgren at Volvo Car Company and to Ellen Hultman, Pontus Larsson and Dennis Saluaar at Volvo Trucks: The interest you have shown for our work has inspired us to come further than we would have hoped. Special thanks to Claes and Volvo Car Corporation for providing the test vehicle; it served us well during the project and we wish it a long and happy test vehicle life.

The test vehicle brings us to the next important group of people that have shaped our results. Namely, the numerous test participants who have sacrificed their time to help us in our pursuit of understanding the interaction between pedestrians and autonomous vehicles. You are too many to name, but we would really like to thank you for your time and participation.

We would also like to thank Dr. Matúš Šucha who took his time to answer our questions about pedestrians and their behaviors. And to Professor Sheila Galt who advised us on the safety risks of lasers. Thank you.

Lastly, we would like to thank our supervisor Erik Ohlson and our examiner Viktor Hjort af Ornäs at Chalmers University of Technology for the advice, feedback and support you have given us during this project. We would also like to take this chance to thank our friends and classmates from Chalmers. Without you we would not have enjoyed these years at Chalmers as much as we have.

Thank you!

Tobias Lagström & Victor Malmsten Lundgren

Gothenburg, 2015

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1. INTRODUCTION

This chapter presents the motivation for the master's thesis project along with its scope, deliverables, limitations and process.

1.1 PROBLEM DESCRIPTION

Road vehicles are becoming more advanced for every day and functions that support drivers in various traffic situations (e.g., Adaptive Cruise Control, Forward Collision Warning, Pedestrian Safety) are already on the market. It is foreseen that this trend will remain, and that automated vehicles (AVs) able to take over the maneuvering control from drivers will become an integral part of the future traffic system (Anderson et al, 2014; Schijndel-de Nooij et al. 2011).

Even though there are regulation and liability issues that need to be addressed before AVs can be commercially available (Schijndel-de Nooij et al. 2011), a lot of research is currently going on. Vehicle manufacturers are conducting or planning field trials with AVs. Volvo Cars is, for example, planning a trial including 100 AVs that will be used by regular customers on designated highway roads in 2017 (Volvo Car Group, 2013). Google's fleet of AVs has as of June 2015 driven over 1.6 million km on public roads (Google, 2015).

From a user perspective the research related to AVs has mainly focused on the driver's experience. How will the driver stay in the loop? How should interfaces be designed and function? How do you enable trust in the system? (Beller, J., Heesen, M. & Vollrath, M. 2013; Szymaszek, 2014; Ju, W & Mok, B. 2014; Johns, M., Ju, W. & Sibi, S. 2014).

The interaction between AVs and vulnerable road users such as pedestrians and bicyclists has been pinpointed as an area of importance (Schijndel-de Nooij et al. 2011). Even so, this topic is still largely unexplored. Today, pedestrians interact with vehicles by interpreting various cues from the vehicle and the driver (see Figure 1). These cues are vehicle-centric like velocity, distance and time to collision as well as social such as eye contact and gestures (Šucha, 2014).

Following a minor project resulting in concept ideas for pedestrian-AV interaction, Viktoria Swedish ICT and Interactive Institute Swedish ICT proposed a master thesis on this theme. A project focusing on the changing role of the driver and how pedestrians would react trying to interact with this new type of decoupled driver.

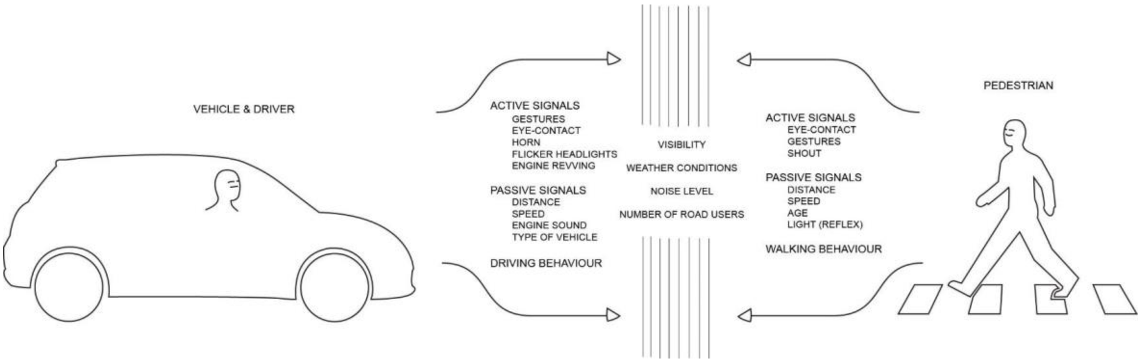


Figure 1. The project's model of pedestrian-vehicle interaction

1.2 PROJECT

This master's thesis project was initiated by Viktoria Swedish ICT and Interactive Institute Swedish ICT. Additional stakeholders and collaboration partners consisted of representatives from Volvo Cars, Volvo AB, Autoliv AB, and Scania AB.

1.2.1 VISION

Road users interact with each other in a complex manner requiring various skills and knowledge such as generic knowledge from childhood, traffic signals, gestures, eye-contact, social interactions, and level of vulnerability. This makes it difficult for pedestrians to get a complete situational awareness and make decisions that balance their goals with other actors' goals.

The main premise in this project is that tomorrow's vehicle fleet will become more and more automated, and thereby gradually transform the driver to a passenger. This will consequently require a holistic design approach where vehicles are designed with regard to how the users' best can take advantage of the possibilities of self-driving vehicles. A fundamental part of this project is therefore to capture pedestrians' needs and views of the future context.

The vision is to improve pedestrians' understanding and feeling of comfort towards AVs. This will in turn facilitate a future where actors can make decisions that maximize freedom of movement in the safest possible way.

1.2.2 PURPOSE AND RESEARCH QUESTIONS

The purpose is to investigate what and how an automated vehicle needs to communicate to achieve understanding among pedestrians. In particular, the following research questions are addressed:

1. *How will the pedestrian-vehicle interaction change when the driver is not maneuvering the vehicle?*
2. *How will the pedestrian-vehicle interaction be affected by introducing an interface designed to enhance the vehicle's ability to communicate with pedestrians?*

1.2.4 GOAL

The project goal is to gather information that will highlight in what way the interaction between pedestrian and vehicle is affected when introducing AVs to the urban context.

The project also aims at developing a functional prototype that will generate additional insights on replacing the driver's role in the vehicle-pedestrian interaction.

1.2.5 DELIMITATIONS

The traffic situation addressed is limited to a human-machine system consisting of **one pedestrian** encountering **one automated car** at an **unsignalized crossing** (i.e. crossing without traffic signals). The following assumptions about the AV were made:

- The AV's driving pattern will be similar to the driving pattern of human drivers.
- The AV will not stand out from standard vehicles regarding its overall physical design.

In consultation with representatives from the automotive industry, the project scope was also set to include level 3 automation on the NHTSA scale (see section 3.1). In short, this means that the vehicle has the possibility to conduct all driving tasks autonomously, while under the supervision of a driver.

The research questions are addressed in a Swedish context and this project has not looked into design solutions any deeper than at prototype level. The goal of the prototype is to facilitate studies regarding AV-pedestrian interaction, rather than to illustrate a final interface design.

1.2.6 PROCESS AND REPORT OUTLINE

After planning and initiation of the project, the project process (see Figure 2) included a state-of-the-art study concerning pedestrian-vehicle interaction. This part of the process also included two studies/investigations aimed at answering the first research question of the project. This phase of the project is presented in Chapter 5 “Phase 1: The changing role of the driver”.

The process then shifted focus towards the second research question, requiring the development of a prototype. This work is presented in Chapter 6 “Phase 2: Design” and Chapter 7 “AVIP-prototype”. The project team then set out to evaluate the functional prototype, which is described and presented in Chapter 8 “Phase 3: Impact of design solution”.

In addition, the report also includes a walkthrough of earlier concept ideas (chapter 2) as well as theory (chapter 3) and methods (chapter 4) that have been central to the project. The discussion (chapter 9) includes a reflection on methods, process and results, and also include recommendations of future work that could be based on the findings of this master thesis. The report finishes with a concluding chapter of the summarized findings from the two studies with the answers to the research questions.

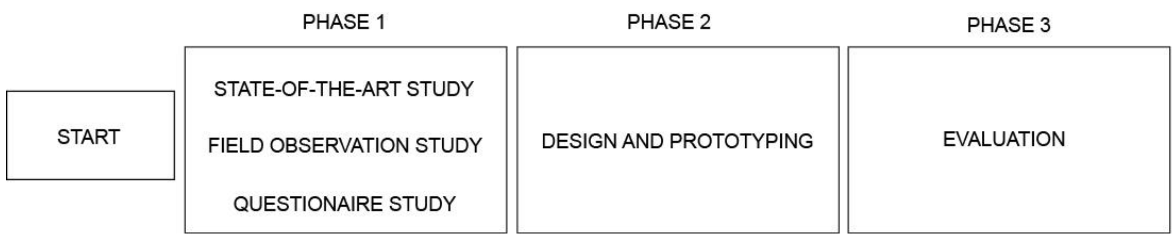


Figure 2. The overall process.

2. EARLIER CONCEPTS ON THE SUBJECT

This chapter presents the concept ideas on autonomous vehicle's interaction with pedestrians that had been generated by Viktoria Swedish ICT and Interactive Institute Swedish ICT in a previous project. It also describes a couple of concepts developed by other actors.

2.1 CONCEPTS FROM VIKTORIA SWEDISH ICT AND INTERACTIVE INSTITUTE

As a result of the previous work in the area, Viktoria Swedish ICT and Interactive Institute Swedish ICT proposed a number of concept ideas on how a possible communication interface could be designed to facilitate a safe and comfortable AV-pedestrian interaction. These concepts will be used as input to the concept phase of this masters' thesis project.

2.1.1 VISUAL

These concepts have the aim to show the possibilities with the visual modality.

LED GRILL

The grill of the car is used to show intentions to the pedestrians through LEDs lights. In the grill there is a LED matrix that allow the car to display signals on a two dimensional plane. The concept utilizes a hair metaphor for the lines in the grill. As the car is moving fast the lines follow the airflow. When the car is still the lines rest. The car also signal that it has registered the pedestrian by "following" the pedestrian with a light signal as he or she passes in front of the car (see Figure 3).

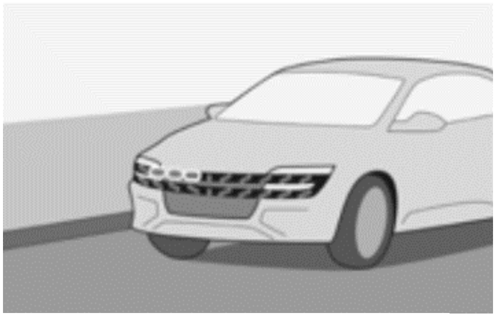


Figure 3. LEDs in grill.

LED WINDSHIELD

Light signals at the top of the windshield are displayed when the car intends to stop. The signal grows from the top side of the windshield towards the middle (see Figure 4). To show that the car intends to drive away, multiple lines are animated as "falling down" from the top of the windshield.

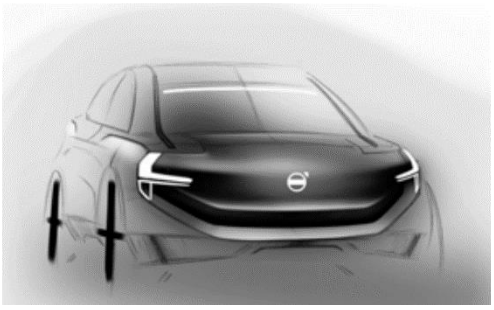


Figure 4. LEDs windshield.

LASER PROJECTION

In this concept, a line is projected on the ground in front of the car to indicate where the car intends to stop (see Figure 5). The projected line then disappears when the car is about to drive of.

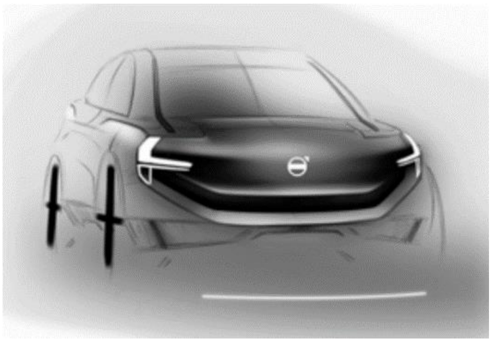


Figure 5. Laser projection.

2.1.2 AUDITORY

Four different audio concepts explored how the vehicle could use sounds to clarify the acceleration, deceleration and intentions.

2.1.3 OTHERS

These concepts represent solutions of slightly higher complexity.

GESTURES

This concept is based on the idea that the vehicle can be equipped with sensors that recognize the pedestrian's gestures, such as waving. The vehicle then gives the pedestrian feedback by using for example one of the visual concepts (see Figure 6).

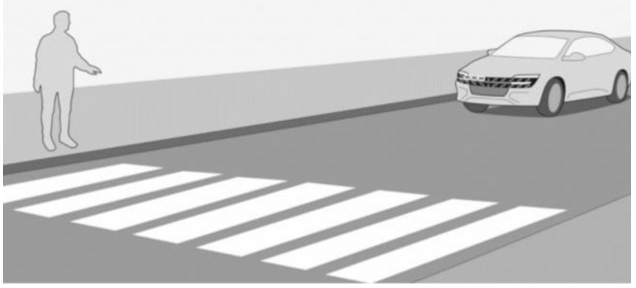


Figure 6. Gestures.

INFRASTRUCTURE

Dedicated infrastructure could be used to display information. Since the vehicle is able to communicate its intention digitally this kind of solution could provide the information to the pedestrian and handle the interaction. For example, a dynamic crossing could light up when it is safe for the pedestrian to pass (see Figure 7).

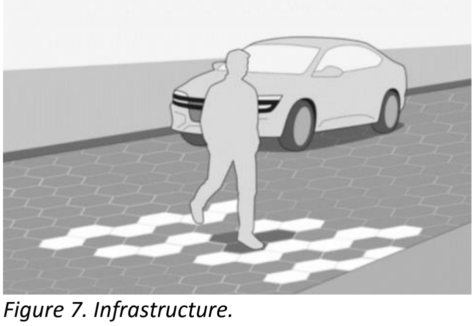


Figure 7. Infrastructure.

WEARABLE DEVICES

By using devices already in use by a large amount of pedestrians, such as phones, the vehicle could connect to the device and share its intentions. The device can then inform the pedestrian via an auditory or visual warning (see Figure 8).

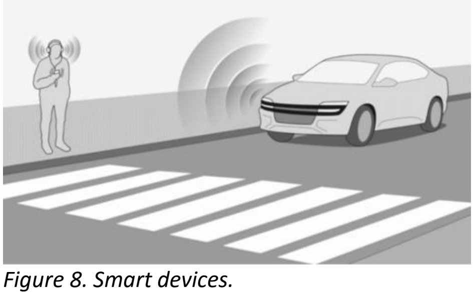


Figure 8. Smart devices.

2.2 CONCEPTS FROM OTHER SOURCES

The following concepts also address a future pedestrian-AV interaction.

2.2.1 LUXURY IN MOTION

Mercedes-Benz has made an effort to be in the forefront of AVs with their concept car Luxury in Motion F 015 (Mercedes, 2015). This vehicle shows of a number of ideas that were described in the previous section, including LED lights for communicating in the front and rear, and projected laser messages (see Figure 9). This concept also provides verbal communication to the pedestrian.

Figure 9. Mercedes Luxury in Motion concept.
Source: https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-motion/

2.2.2 AEVITA

A project at Massachusetts Institute of Technology (MIT) resulted in the AEVITA concept which is a biomimetic vehicle-to-pedestrian communication concept for autonomously operated electric vehicles (Pennycooke, 2012). It uses both directional- speakers and headlights to communicate as well as lights in the wheels that changes color depending on the proximity of the pedestrian (see Figure 10). Furthermore, it has a folding joint mechanism which is used to change appearance and communicate things like activity and aggressiveness of the vehicle.

2.2.3 AutonoMI

AutonoMI is an autonomous mobility interface concept developed at the ISIA Roma Design Institute (Leonardo Graziano, 2014). The external communication part of the concept uses a display which light indication points towards the pedestrian. This indicate that he or she has been noticed as the light follows the pedestrian across the road (see Figure 11).

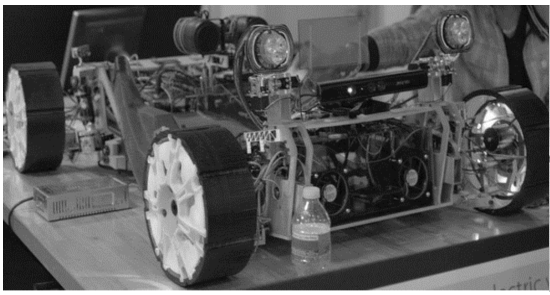


Figure 10. AEVITA concept.

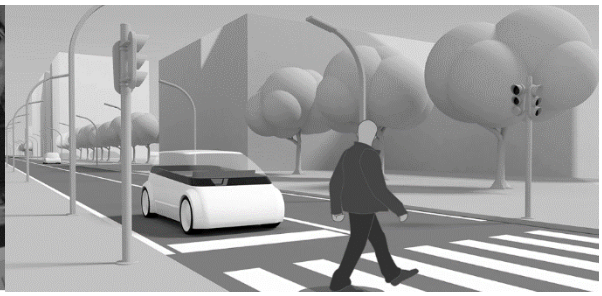


Figure 11. AutonoMI concept
Source: http://vimeo.com/99160686

2.3 IMPLICATIONS FOR THIS PROJECT

In order to find out which of the ideas reviewed in this chapter are most suitable for facilitating safe and comfortable AV-pedestrian interaction, an in-depth investigation of user needs is required. This work will therefore have a strong user focus, exploring how pedestrians behave today and how they react to AVs. From this, a concept can be developed based on true user needs and experiences. The aim is to achieve a practical and plausible concept and evaluate this using a functional prototype in a naturalistic setting.

3. THEORY

This chapter contains theory that has been central to the project.

3.1 AUTOMATED VEHICLES

Automated (or autonomous) vehicles are vehicles that are able to take over the control of the vehicle's operations (Anderson et al, 2014). These vehicles use a "sense-plan-act" design to make decisions based on programmed goals. To understand their surroundings, they use multiple sensors such as cameras, radars, lidars, and ultrasonic sensors. The data from these sensors are merged, ensuring that weaknesses of one sensor are handled by others. The sensor data is then processed according to the controlling algorithms, and commands are sent to actuators controlling steering, throttle, braking, etc.

The National Highway Traffic Safety Administration defines automation in 5 levels (NTSHA, 2013).

> *Level 0:* The driver is in complete control of the vehicle at all times.
>
> *Level 1:* One or more specific functions are automated.
>
> *Level 2:* Specific functions are automated to work in unison in order to let the driver let go of control of these functions.
>
> *Level 3:* The vehicle is able to completely take control in certain conditions. The driver needs to be able to in some degree monitor the system and take back control occasionally.
>
> *Level 4:* The vehicle is able to handle all safety critical driving functions by itself. The vehicle is able to function with or without human supervision.

The introduction of autonomous vehicles has the potential to radically change the transportation context and possibly reduce traffic accidents, energy consumption and environmental impact (Anderson et al, 2014). In addition, there is the benefit of saving time for people by removing the active driving task and by limiting traffic congestion. A fully autonomous vehicle also has the potential to offer individuals who are unable to drive the freedom of personal transportation.

3.2 HUMAN-MACHINE INTERACTION

The field that study the interplay between humans and machines is called human-machine interaction. To understand the pedestrian and how she will experience the interaction with the AV, it is important to understand how the human mind works and how it interprets the world around it.

3.2.1 COGNITIVE PROCESSES

Christopher Wickens describes the human cognitive process as a number of activities that are happening both in parallel and in series. As described in Figure 12 stimuli enter into the system through the senses. This information gives us a perception which is affected by our attention and our long-term memory. This perception of the world gives the basis of our decision-making, which is also affected by the attention to the problem and the short-term memory. The response made affect the world around us and creates stimuli that comes back to us via our senses creating a feedback loop (Wickens, 2004).

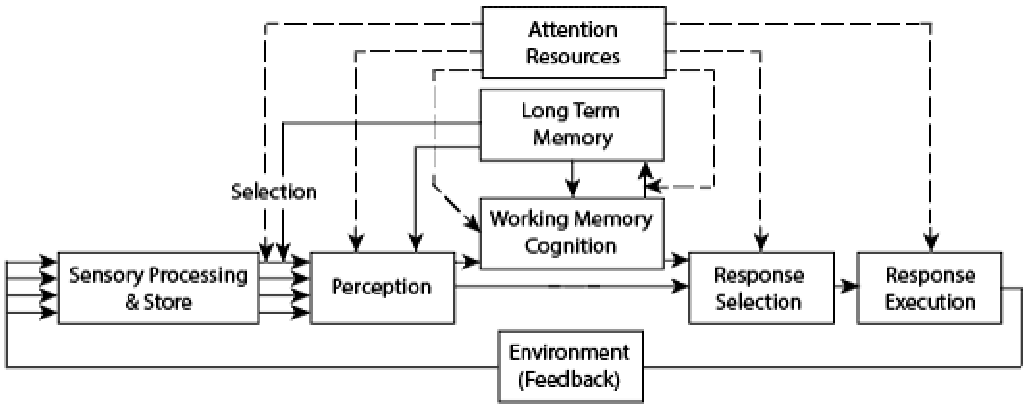


Figure 12. Wickens' information processing model.

3.2.2 BOTTOM UP & TOP DOWN PROCESSING

They way stimuli is processed by brain can be categorized into two sorts, bottom up and top down. When the brain is working with the bottom up process it has to build an understanding of the situation or information using only sensory input. The bottom up process is affected by the amount of information that is available to be analyzed. As an example, bad visibility affects the bottom up process negatively because the amount of information decreases (Wickens, 2004).

The top down processing on the other hand pulls information from our experience and knowledge to understand the stimuli that is presented. This approach enables the mind to get a correct understanding of stimuli even though important information is missing, since the parts of information that is visible are recognized through the experiences stored in the mind (Wickens, 2004).

These two processes work together and can often compensate for each other if one approach fails to interpret the sensory input in a meaningful way.

3.2.3 VISION & HEARING

80% of the sensory input a human collect is visual and humans have a field of vision of 170 degrees horizontally. When designing visually presented information one should consider the intensity, color choice, contrast, strength of lighting and angel of vision. It is also important to understand how the stress affects the user and to design cues that enable both bottom up and top down processing (Bohgard et al, 2008).

Sound is the most attention grabbing sensory input. Unlike vision it cannot be turn off. The ability to locate sound is very sensitive. When the frequency is below 1500 Hz the phase difference registered by the ears is used to calculate the direction the sound is coming from. When above 3000 Hz the intensity change is used. This can be exploited when design sound that need to be located by the user. From a design perspective it is important to keep in mind that humans can only distinguish three to five different levels of frequency or amplitude (Bohgard et al, 2008)

3.2.4 MENTAL MODELS

A mental model can be described as "the mechanisms whereby humans are able to generate descriptions of system purpose and form" (Rouse and Morris, 1986).

This involves how humans understand and interpret their surroundings and how they make predictions of a system's future state. A mental model can be resembled to an internal representation that is linked to other humans, animals or machines in the environment. These internal models are often simplified versions of reality, and modified and complemented with increased experience of the system. Mental models are similar in structure to the concept they represent and they help humans in understanding, explaining and predicting their interactions (Norman, 1983).

In the context of designing for pedestrian-AV interaction, it was important to keep in mind the pedestrians' established mental models of the traffic domain. In addition, any attempt of creating an external communication interface should promote development of new mental models that are useful and intuitive.

3.2.5 USABILITY

Usability is described as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241-11, 1998). It is a way to understand how people and products interact and what the barriers between the product and the user are. It relates to the combined part and interplay between the user, context, product and task, and has been further divided as (Jordan, 1998):

> *Guessability*
> The ability of first time users to guess what functions are doing.
>
> *Learnability*
> How easy a system is to learn.
>
> *Experience User Performance*
> How well an experienced user performs.
>
> *System Potential*
> The optimal performance level achievable with the system.
>
> *Re-usability*
> How easy it is to start using a system after not using it for a significant time.

These are the components of usability and can each be studied to understand how the user and product interact and how the product compares to other products.

When design for good usability, Jordan has also describes ten important parameters.

> *Consistency*
> Tasks that are similar should be performed in the same way.
>
> *Compatibility*
> How the user expects something to work based on other products or situations.
>
> *Consideration of user recourses*
> The attention and cognitive power a user can apply is limited. Products should use more than needed.
>
> *Feedback*
> When an action is preformed the user should be given feedback of the new state the product is in.
>
> *Error prevention and recovery*
> The product should minimize the risk of errors and help users undo mistakes.
>
> *User control*

The product should maximize the users control over the product.

Visual clarity
Interpreting the information from the product should be easy.

Prioritization of functionality and information
Functions should be prioritized where the highest priority functions are the easiest to find and use.

Appropriate transfer of technology
The technological level of the product should be decided of what is helpful for the user.

Explicitness
The product should have oblivious cues for how to operate the product.

3.2.6 QUALITATIVE INFORMATION DEVICES

When a system only displays a limited number of states, a qualitative information device is a good choice (Bohgard et al, 2008). These kinds of systems give the user an overview of what is happening but not a detailed picture. Audible qualitative information devices have two states, where one is no sound that represents normalcy and the other a warning signal that informs that something is wrong. If the system displays three or more states a visual system is better suited.

There are three general design criteria's for information devices (Bohgard et al, 2008). The information must be discoverable, recognizable and understandable.

Design principles that supports attention from the user are (Bohgard et al, 2008):

- Minimize the time and effort for finding the information.
  Display information that is frequently used where it is easy to find.
- Proximity.
  Using proximity is show how information sources are connected with each other.
- Using multiple sources of information.
  To display a large amount of information it can be to advantage to divide the information on different sensory inputs, for example using both visual and auditory channels.

3.3 CIRCUMPLEX MODEL OF AFFECT

Affect is the experience of feelings or emotions. Overall, there are two theories regarding the affect: a) humans have a discrete and limited set of independent emotions and b) humans have a limited set of interrelated emotions. This thesis applies the Circumplex model of affect described by Russell (1980) that is in line with theory b).

The Circumplex model describes the different dimensions of affect in a circle. The circle follows the order of: pleasure (0 °), excitement (45 °), arousal (90 °), distress (135 °), displeasure (180 °), depression (225 °), sleepiness (270 °) and relaxation (315 °). The dimensions of affect are ordered around the circle on using a bipolar system where the horizontal axis represents valence, pleasure to displeasure. The vertical axis represents the activity from arousal to sleepiness (see Figure 13). This theory was useful for the project when it came to understand and visualize the quantitative emotional data that was collected with the Self-Assessment Manikin method.

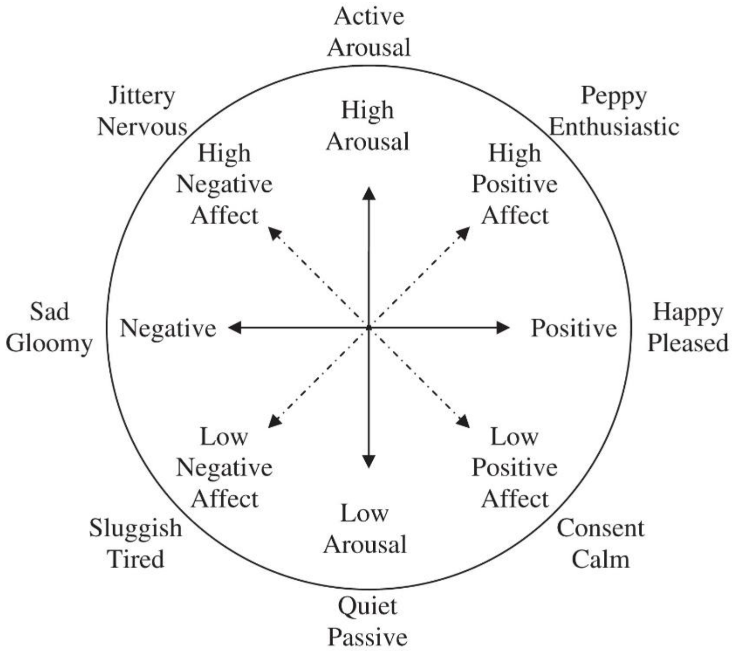


Figure 13. Circumplex model of affect.

3.3.1 EMOTIONS AFFECT ON DECISION MAKING

Emotions are an important part of the human experience, and will probably play a part in the experience pedestrians will have with AVs. Emotions can be divided into valence, which describe a spectrum from pleasant to unpleasant feelings, and arousal which describes the magnitude of these feelings (Resnick, 2012). Positive emotions have been shown to increase flexibility, efficient decision-making and creativity. Positive emotions also decrease risk perception and increase optimism, but can make people underestimate negative outcome and overestimate a positive one (Resnick, 2012).

Negative emotions lead to pessimistic predictions and higher perception of risk, especially sadness or fear (Resnick, 2012). Anger on the other hand gives individuals a higher tolerance of risk. It also enables faster decision making, while a sad person makes slower decisions than a person not affected by emotions. Negative emotions affect the certainty a person feels about judgments made.

4. METHODS

This chapter describes generic methods that have been used as a basis for the different parts of the project.

4.1 DATA COLLECTION METHODS

In this project, six different data collection methods were used. Each of them is described in the following sections.

4.1.1 OBSERVATIONS

Observation study is an objective method for data collection (Bohgard et al, 2008). The method focuses on how people behave in different contexts, or situations, that are interesting to the observer.

One of the greatest strengths of this method is that it enables identification of behaviors that the subject is not aware of, or do not want to talk about in an interview. A weakness is that the method does not give much information about the reasons a subject behaved as she did.

The method can be used in natural or laboratory settings with subjects who either know or do not know that they are being observed. The observations can also be systematic, where the observer look for a certain type of information or event in a certain context, or unsystematic, where the observer notes anything of interest. Result can be both quantitative and qualitative.

The use of an observational field study approach was chosen because it was regarded that subjects when asked would not be able to imagine experiencing an AV to a sufficient degree. There for studies where focus to capture participants reactions to an interaction with an AV, and to use this as a basis for interviews with participants. Observation studies are used in chapter 5.2, 6.4 and 8.1.

4.1.2 INTERVIEW

Interviewing is one of the basic methods for finding out how people feel and think. By means of an interview, the interviewer is able to collect data on a subject's experienced feelings, values, opinions, dreams, fears, etc. An interview may also provide information about a subject's reasoning.

There are three broad types of interviews: unstructured, semi-structured and structured. Which of these is chosen depends on the research questions and the type of information that needs to be gathered.

The unstructured interview is typically used when the interviewer has not much information about the topic that is being investigated. The semi-structured interview follows a pre-designed structure which addresses the topic through a number of open or defined questions. The interviewer can also ask follow-up questions about any subjects of interest. In the structured interview, the layout is strict and the subject can answer a question freely or from a defined scale. It is important that the questions are clear and unequivocal so that the subjects do not interpret them differently (Bohgard et al, 2008).

Interviews are used in chapter 5.1, 5.2, 6.4 and 8.1.

4.1.3 WIZARD OF OZ

The Wizard of Oz technique is used to test products with users before the products are actually developed (ref). The technique makes use of a hidden human operator, who secretly performs the action of the product. The user of the Wizard of Oz product should in a best case not be able to distinguish it from a finished product. By using this approach, a product can be user-tested much earlier in the development process, and important input can be gained to further develop the product before any expensive production begins (Buxton, 2007).

As the current level of AV technology did not give an opportunity to test the interaction between pedestrian and AV with an actual AV the solution was use the wizard of Oz method. The experienced would in theory be no different from using an actual AV. The method was used in chapters 5.3 and 8.1.

4.1.4 QUESTIONNAIRE

A questionnaire is a subjective method to collect data from subjects. Questionnaires follow the same style as structured interviews, but on the contrary to structured interviews, the interviewer does not have direct contact with the subject. A questionnaire can be used to collect both quantitative and qualitative data, but it is mostly used for quantitative studies. The primary goal with this method is to collect data from a large sample of subject in a short amount of time, collect data from subject who are hard to reach, or to validate results from previous studies with a qualitative approach (Bohgard et al, 2008). The method was used in chapters 5.3.

4.1.5 SAM

The Self-Assessment Manikin (SAM) is a nonverbal assessment method that measures the pleasure, arousal, and dominance associated with a person's affective reaction to an experience (Bradley et al, 1994).

As shown in Figure 14, the pleasure dimension is represented by five figures ranging from a smiling, happy figure to a frowning, unhappy figure. Similarly, the arousal dimension is represented by figures that range from an excited, wide-eyed figure to a relaxed, sleepy figure. The dominance, or experienced feeling of control, dimension is represented by different sizes of the figures.

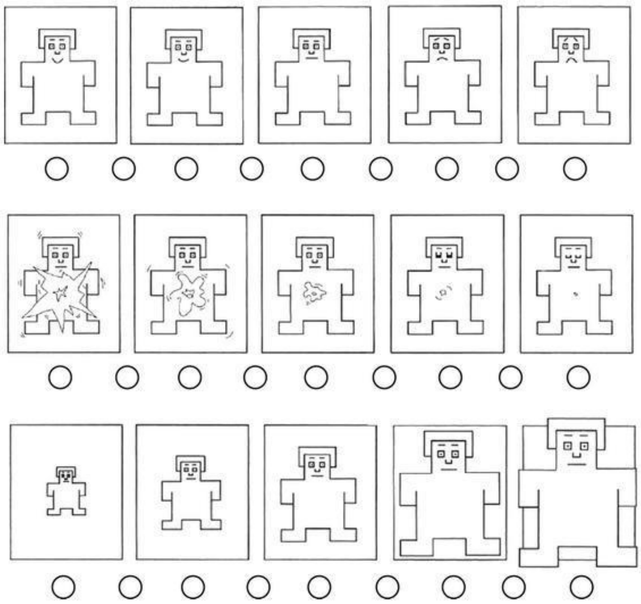


Figure 14. The Self-Assessment Manikin grades.

The method has been used effectively to measure emotional responses in a variety of situations, including reactions to pictures (Bradley et al, 1994).

This method was chosen because of the projects focus on the pedestrian emotional experience in interaction with an AV. The method offered a fast and easy tool to quantify an experience and allowed the data to be interpreted using the circumplex model of affect. The method is used in chapters 5.2, 5.3 and 8.1.

4.2 ANALYSIS TOOLS

The following analysis tools where used to analyze information from the data collection.

4.2.1 CONTENT ANALYSIS

Qualitative content analysis is defined as: “a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns” (Hsieh et Shannon, 2005). A content analysis can be made by clustering printed or written qualitative data, or with the aid of different coding software. The method was used in chapters 5.2, 5.3, 6.4 and 8.1.

4.2.2 DESCRIPTIVE STATISTICS

Descriptive statistics is used to provide a description of the study result and the sample used in the study. What differs descriptive statistics from inferential statistics is that descriptive statistics do not make any conclusions about the world beyond the data of the study (Trochim, 2006). The method was used in chapters 5.2, 5.3, 6.4 and 8.1.

4.3 CREATIVITY METHODS

Creativity methods were used during the concept phase of the project.

4.3.1 PERSONA

Different user models, or personas, are “detailed, composite *user archetypes* that represent distinct groupings of behaviors, attitudes, aptitudes, goals, and motivations observed and identified during the research phase” (Cooper et al, 2014). The method was used in chapters 6.1.

4.3.1 SCENARIO

A scenario, in the context of design work, is a form of narrative linked to the user’s (or persona’s) interaction with a system or product (Cooper et al, 2014). This method focuses on the broader goals of the user and can act as an effective concretization and communication tool in the design- team and process.

The scenario should for example contain a description of the usage and context that influence the use situation. When constructing the scenario, it is important to capture thoughts and emotions of the user. The method was used in chapters 6.1.

4.4 VISUALIZATION METHODS

This section describes the visualization methods that were used in the second half of the project.

4.4.1 PROTOTYPES

Prototyping can be done in different ways, both physical and digital, with the common goal of evaluating the performance of a product or a concept. Various prototypes can be made to represent different degrees of functionality in order to test different aspects of a design (Cooper et al, 2014). The method was used in chapters 6.4 and 7.

4.5 EVALUATION METHODS

The following methods were used for the evaluation of different approaches and designs.

4.5.1 SME-OPINIONS

Subject matter experts (SMEs) are often invaluable to a project. These authorities on the domain can often be seen as expert users. They are therefore useful to identify early in the development process, and bring in at different stages to perform “reality checks” on the design details (Cooper et al, 2014). The method was used in chapters 6.5.

4.5.2 USABILITY TESTING

Usability testing is an important tool to test design solution with real users. The method can be used efficiently to examine naming, organization, first-time use, and discoverability and effectiveness of an interface. A weakness in a usability testing is that the method is focused on first-time use.

There are two types of usability testing: summative evaluation and formative evaluation. Summative evaluations are thorough evaluations most performed before the re-design of a product to test it and compare it to its competition. Formative evaluations are quick and qualitative tests that help the designer understand the users, and how they react to the tools and information in the design solution (Cooper et al, 2014). The method was used in chapters 6.4 and 8.1.

4.5.3 SOUND IMAGERY

This method tests what sound is the best and most feasible to send a certain signal (Simpson and Gardner, 1992). A test subject is exposed to a number of sounds, one at the time. After each exposure, the test subject matches the sound to a specific meaning from a multiple-choice list. Among the alternatives is also a “no matches” alternative. The strength of the association is then rated between 0-10, where zero refers to “no association” and ten to “an excellent association”. The method was used in chapters 6.4.

5. PHASE 1: THE CHANGING ROLE OF THE DRIVER

This section focuses on the interaction between pedestrians and vehicles and is directly related to the Research Question 1.

First, a state-of-the-art study was carried out to provide information on the current interaction principles. Based on these findings, a field observation study and a questionnaire were then designed to study effects of automated driving on the interaction. In particular, the focus was on finding out if, and how, the interaction may change when the driver is not maneuvering the vehicle.

The chapter is divided into the subsections State-of-the-art study, Field observation study and Questionnaire study, followed by a concluding section.

5.1 STATE-OF-THE-ART STUDY

A state-of-the-art study was conducted as a first step in the data collection process.

5.1.1 PURPOSE

The purpose of this study was to investigate the current principles of pedestrian-vehicle interaction and to get an overview of the research that has been done in the field.

5.1.2 GOAL

The goal was to get an indication of what conclusions that could be made from previous work and what information that had to be specifically generated in this project.

5.1.3 METHOD

Given the Research Question 1, the following words were identified as relevant: autonomous, automated, pedestrian, vulnerable road user, road, interaction, trust, attention, communication, intention, identification, interaction, eye contact, pedestrian behavior, vehicle speed. The information databases Scopus and the Transport Research International Documentation (TRID) were used to find these words, and different constellations of them, in the titles, abstracts, and keywords of scientific articles.

Initially, the titles of the articles were reviewed, and 70 of them were selected for further investigation. In the next step, the abstracts of these articles were reviewed, which resulted in 36 articles being selected for detailed reading.

In addition, a Skype-interview with Dr. Matúš Šucha was conducted. He specializes in traffic psychology and human factors with focus on vulnerable road users.

5.1.4 RESULTS

Several aspects are relevant for a pedestrian's decision making in the traffic situations involving vehicles. When deciding whether to cross the street or not, a fundamental part is the initial speed of the approaching vehicle and the distance to it (ref). As the vehicle approaches, it continues to communicate its intention through the driving pattern, where a pedestrian most often is interested in if the vehicle is decelerating.

Šucha (2014) mentions pedestrian-driver contact, and explicitly eye-contact, as a factor which pedestrians consider when deciding to wait or go. Additionally, the pedestrian's familiarity of the context, viewing conditions and overall traffic density is highlighted as affecting the decision. The type/size of vehicle, current weather conditions and own limitations (e.g., physical state) are also factors that pedestrians commonly use in their decision making (Šucha, 2015).

Varhelyi (1998) states that the situations in which a pedestrian passes before the vehicle could be divided into three scenarios.

- The pedestrian crosses before the arrival of the car without influencing its speed.
- The approaching car is provoked to brake by the pedestrian who does not stop before crossing.
- The approaching car brakes on the driver's own initiative in order to give way to the pedestrian.

Today, there is a correlation and influencing factor between the driver's choice of speed and the crossing strategy of the pedestrian. These choices and the interaction between the actors can be connected to their strategies to "gain a maximum, whether it means time, safety or comfort" (Šucha, 2014).

Based on 1584 observations at four different locations in a city in the Czech Republic, Šucha concluded that a "great majority of pedestrians searched for eye contact" and that they waited for confirmation before crossing the road. In contrast to this, a majority of drivers did not actively search for eye contact with the pedestrian (see Figure 15).

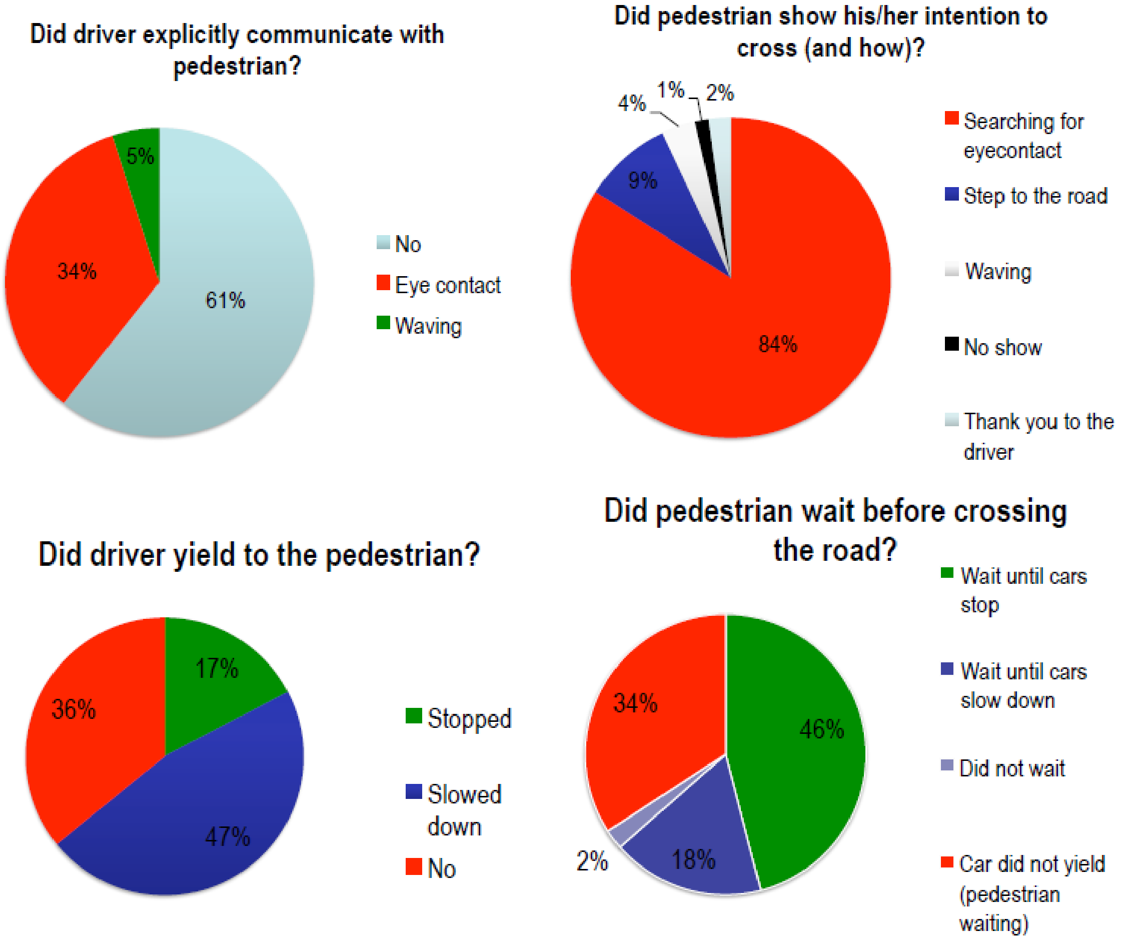


Figure 15. Pedestrian-driver interaction.
Source: Šucha, M. (2014), Fit to drive: 8th International Traffic Expert Congress. 8-9 May, 2014, Warsaw

Pedestrians are often influenced by other vulnerable road users with a similar goal, and might change strategies based on what other pedestrians are doing. The communication, and social interaction, between pedestrians and drivers is often restricted. In some situations, it might be difficult to actually see the driver and intentions have to be shown quickly. At the same time, pedestrians want to be absolutely sure that they have interpreted the intentions of the driver, and the future state of the vehicle, correctly. Because of the limited possibility of communication in traffic, misunderstandings and misinterpretations often occur, which may result in irritation or even accidents among road users (Šucha, 2015).

At a general level, it can be said that “the skilled pedestrian knows where to look to obtain the most useful information. We learn how and where to look based on the reward we receive for looking” (Geruschat et al, 2006).

5.1.5 CONCLUSIONS

The goal was to get an indication of what conclusions that could be made from previous work in the field of pedestrian-vehicle interaction. The conclusions are the following:

- A lot of aspects affect the pedestrian’s willingness to cross the street. This include:
    - speed of the vehicle
    - distance to the vehicle
    - vehicle deceleration
    - eye contact with driver
    - Familiarity of environment, viewing conditions, traffic conditions.
- A majority of pedestrians are seeking eye contact with the driver, but a majority of drivers are not seeking eye contact with pedestrians.
- Misinterpretations between pedestrians and drivers are common due to a limited possibility of communication.
- Pedestrians are seeking information that result in the highest possible reward when deciding how to act.

The goal was also to conclude what information that had to be specifically generated in order to answer the first research question. Since a delimitation of the project was that the driving pattern and appearance of the AV will be the same as a standard vehicle, the crucial difference will be the role of the person in the driver’s seat. The conclusion was that this aspect had to be thoroughly investigated in order to understand how it will affect the pedestrian’s interaction with AVs.

5.2 FIELD OBSERVATION STUDY

The study was developed to investigate the pedestrian’s experience with changing driver behavior. In the study the participants first got to experience drivers showing different levels of distractions ending with the car being completely empty. This was done maximize the impact on the participant that the car was automated, observing their behavior when interaction with it and be a mediating experience for an interview.

5.2.1 PURPOSE

The purpose of the field observation study was to get an indication on how pedestrians’ experience and willingness to cross the road are affected by the fact that the driver in the vehicle that they are encountering is directing his/her attention to non-driving related tasks.

5.2.2 GOAL

The goal was to measure the difference between pedestrians' emotional state when encountering a vehicle in which the driver is performing a) a driving related task and b) a non-driving related task.

5.2.3 METHOD

The method presented here is a result of numerous iterations and re-design in order to make it suitable for the given purpose.

PARTICIPANTS

In total, 13 participants were recruited (7 male and 6 female). After reading about the experiment and getting instructions on their role in the test, all participants gave their formal consent on participating in the test.

The test participants were mainly students at the Chalmers University of Technology. They were recruited since they are familiar with the test site and travel mainly on foot (and by means of the public service).

The age of the participants ranged between 20-29 years. Twelve of them were holding a driver's license at the time of the test. Furthermore, 7 of the participants did not report any eyesight correction, while 6 others reported a correction (one of which did not were neither glasses nor lenses at the time of the test).

MATERIAL

The test material included the following:

- A test vehicle (described in the section Stimulus material)
- A smartphone for audio recording.
- Two walkie-talkies (for keeping the test leader and the vehicle driver in contact)
- A newspaper
- A folder with Background questionnaire, SAM-questionnaires, and interview questions.

DATA COLLECTION

The data were collected using a Background questionnaire, Self-Assessment Manikin (SAM) method, and through semi-structured interview questions. The interviews were audio-recorded with a recording application on a smartphone, and then transcribed by the project team.

TEST ENVIRONMENT

The tests were carried out at Betongvägen at the Chalmers University of Technology (campus Johanneberg). This test site was chosen because of the closed off location and limited use. Also, its central location was beneficial when recruiting the test participants.

Betongvägen (see Figure 16) is a dead-end street that only can be used to access the Chalmers campus, though this is mostly occasionally done by service vehicles. The road, which starts at Sven Hultins gata, first leads through a parking lot and continues past another parking area called Betonggården. The far end of the street ends in a small parking zone and a turning space.

The biggest downside of the test site is lack of a marked pedestrian crossing. The lighting is also somewhat insufficient; one side of the road faces a large building and the other one faces a hill with lots of small trees. Though, the fact that Betongvägen is a secluded street with closeness to potential test participants outweighed these limitations.

STIMULUS MATERIAL

A Wizard of Oz inspired method was developed in order to give the test subjects a perceived experience of an automated vehicle. The solution was to use a right-steered car, a Volvo V40 provided by VCC, and modify it to look like a left-steered car. The modifications consisted of installing a dummy steering wheel and elevating the dashboard to match the location of the steering wheel (see Figure 17).

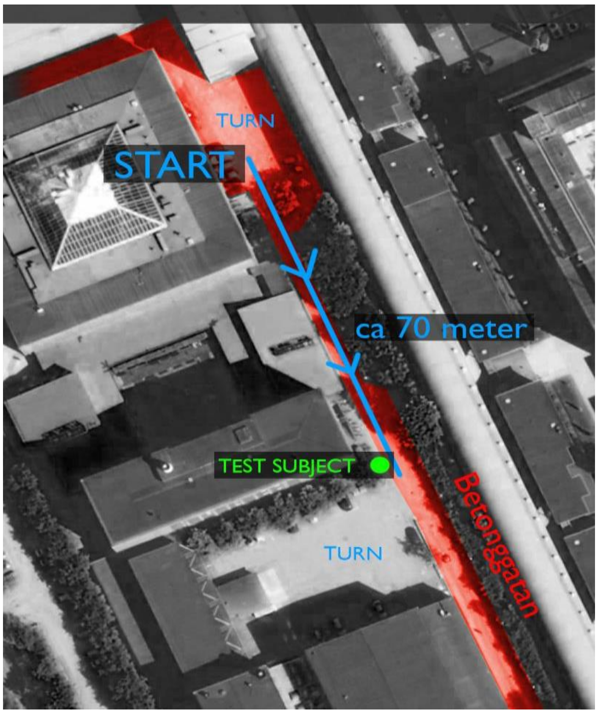


Figure 16. Betongvägen.

In order the "hide" the real driver from the participants, the right side window was covered with a tinted film (the car had all windows in the back tinted from the start). Also, the driver lowered the sun protective cap and put a piece of dark clothing on top of the dashboard (see Figure 18).

The four behaviors that used in the test were: eye contact, talking on phone, reading newspaper and no driver. Making *eye contact* was chosen as it gave the pedestrian a clear indication that the driver had seen them. The *talking on phone* and *reading newspaper* behaviors show an increasing amount of distraction of the driver. While the *no driver* behavior was chosen to help test subject think about a self-driving car. When choosing the behaviors, considerations were also made towards how visible they would be for the test subject. Reading the newspaper represents a driver completely engaged in another task than driving. A similar example would be someone working on a laptop, but that would have been harder for the test subjects to see.

Figure 17. Dummy steering wheel.

Figure 18. Outside view.

TEST PROCEDURE

The test focused on the participants’ experience of different driver behaviors. The test was therefore designed to maximize the chance that the participant would look in to the car.

First, the participant was informed about the procedure through a written test-brief. The participant was then asked to fill in a background form concerning his/her age, gender, familiarity with the test site, possession of a driver’s license, and the current eyesight status.

Next, the participant was asked to take a position at the curb and then he/she experienced two different scenarios in a random order (i.e. some participants started with A, while some others started with B):

<table>
<tr><th>Drive #</th><th>Scenario</th><th>Vehicle/driver</th><th>Acting driver’s task</th><th>Test subject’s task</th></tr>
<tr><td>1</td><td rowspan="3">A</td><td rowspan="3">Constant speed 7-10km/h</td><td rowspan="3">Eye contact
phone
newspaper</td><td rowspan="3">Turn when uncomfortable at crossing</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td rowspan="3">B</td><td rowspan="3">Stop in front of test subject</td><td rowspan="3">Eye contact
phone
newspaper</td><td rowspan="3">Choose GO/NO-GO</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td><td rowspan="2">C</td><td>Same as B</td><td rowspan="2">No driver</td><td>Same as B</td></tr>
<tr><td>8</td><td>Same as A</td><td>Same as A</td></tr>
</table>

Table 1. Test procedure.

A. The car was approaching with a constant speed of about 7-10 km/h with the real driver on the right-hand side, and an acting driver on the left-hand side. The task of the participants was to stand at the curb as if he/she was about to cross the street and to decide when he/she was no longer comfortable to cross the road. When this decision was made, the participants had to turn away from the road. The vehicle passed, and the test leader asked the participant to fill in the SAM-form and answer the following question:

What caused you to make the decision to no longer (be willing to) cross the road? The procedure was repeated for different behaviors of the acting driver in the left seat: looking at the participant, talking on the phone, reading newspaper. If the participant experienced the scenario A before scenario B, his/her first encounter was then "looking at the participant", which was repeated twice. This in order to get familiar with the test situation and to practice filling out the SAM-chart. The other behaviors were always encountered in a random order.

B. The car approached with a speed of about 7-10 km/h, decelerated gradually, and eventually came to a complete stop three meters from the participant. The participant was facing away from the road until the car stopped. The participant had then to: a) Turn around, b) Look at the car, c) Express if he/she would cross or not (go/no-go), and d) Walk back to the test leader. The test leader provided the participant with a SAM-chart and asked the following:

    A. Did you decide to cross or not to cross?
    B. What caused you to make your decision?

The procedure was repeated for different behaviors of the acting driver in the left seat: looking at the participant, talking on the phone, reading newspaper (see Table 1). If the participant experienced the scenario B before scenario A, his/her first encounter was then "looking at the participant", which was repeated twice. This was in order to get familiar with the test situation and to practice filling out the SAM-chart. The other behaviors were always encountered in a random order.

After completing scenarios A and B, the participant finished the test by experiencing the following scenario:

C. If car motion and the participant's task was the same as in the previous scenario (i.e. either A or B). The real driver is alone in the car (the seat of the acting driver is empty). This scenario was carried out to make the participants truly question the role of the driver. It acts as a mediating experience to the questions about autonomous vehicles in the finishing interview.

This final interview consisted of the following questions:

- Did you experience any differences between the encounters?
- How did you feel when you encountered the vehicle?
- In what meeting did you feel the most vulnerable/uncomfortable?
- In what meeting did you feel the most safe/comfortable?
- What driver behaviors are OK/not OK?
- What vehicle encounter would you describe as being with an autonomous vehicle?

The total time of the test was approximately 30-45min, depending on the length of the answers.

DATA ANALYSIS

The impact of driver behavior was studied by means of a within-group comparison. The data were plotted and analyzed graphically through a bubble-diagram. To separate answers that were obscuring each other, the valence and activity data were jittered. The SAM data were color-coded by driver behavior and plotted with the valence on the horizontal axis and activity on the vertical one, to align with the Circumplex model of affect. Control data were represented as the size of the bubbles. The average value, the median and the standard deviation of each parameter on driver behavior could also be compared.

The Go/No-go data were mapped to their corresponding behavior, in order to see if there were any indications of how it related to driver behavior.

The recorded interviews were transcribed and imported into Nvivo qualitative research software. A content analysis was carried out to identify common themes among the participants.

5.2.4 RESULTS

The emotional experiences of the participants in scenario A (moving vehicle) and B (standing still vehicle) are shown in Figure 19 Motion and Figure 20 Still, respectively.

Vehicle in Motion

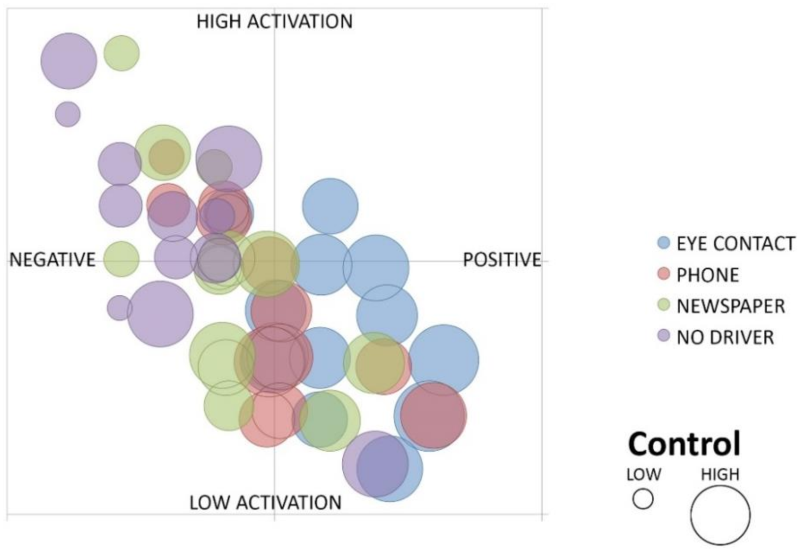


Figure 19. SAM results, vehicle in motion.

Vehicle is Still

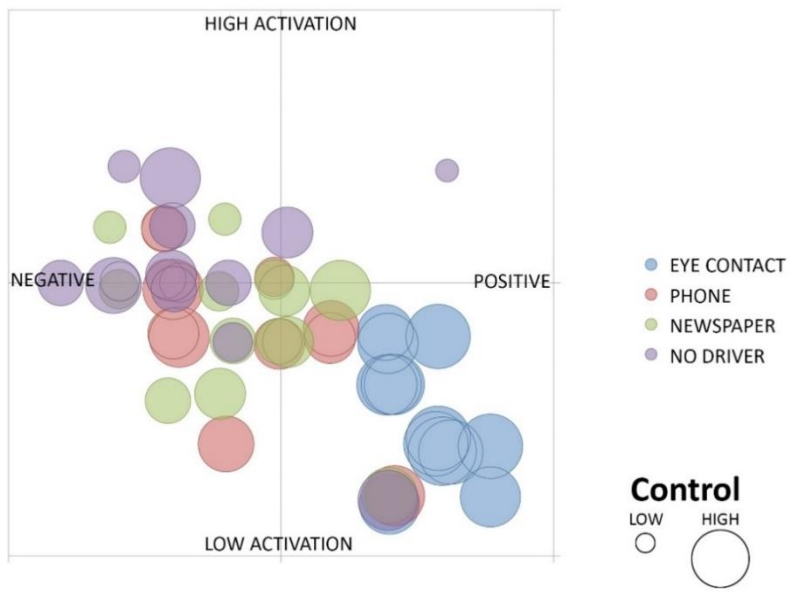


Figure 20. SAM results, vehicle standing still.

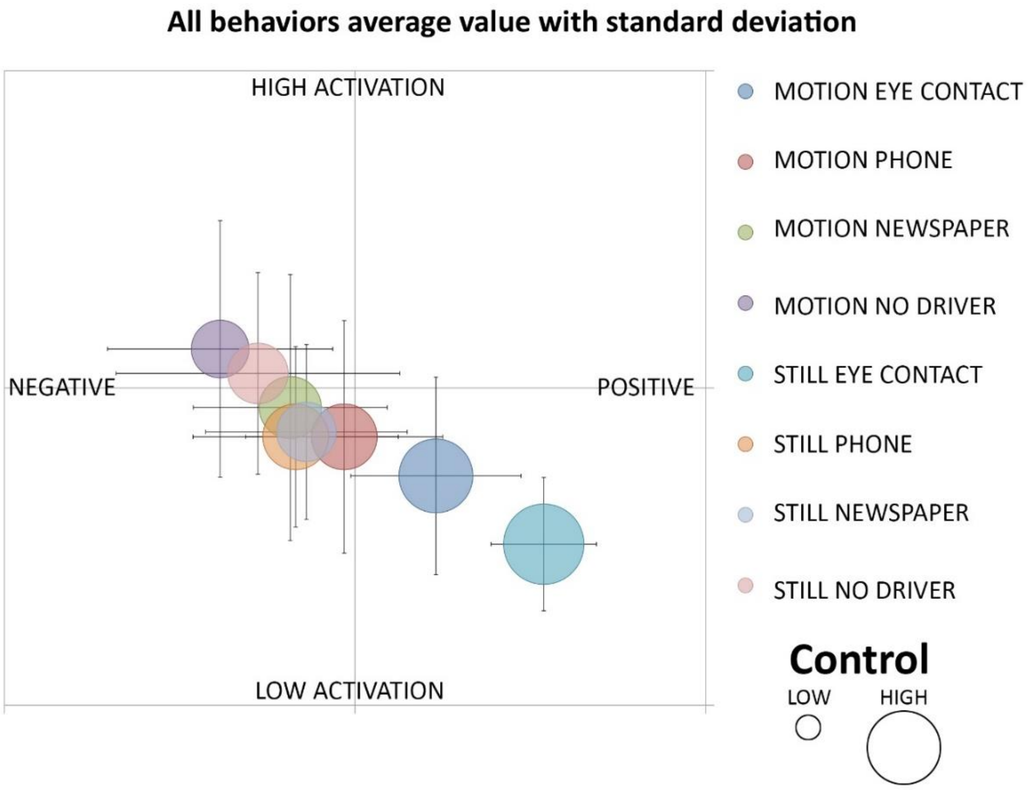


Figure 21. SAM average results.

The trend of the SAM results is visualized in Figure 21, where the average values construct the points on what can be imagined as a diagonal line.

Starting from the fourth quadrant in the lower right corner of the chart, one finds the blue dots linked to the driver looking in the direction of the pedestrian in the driving scenarios A and B. This quadrant is connected to positive experience/low activation, indicating a calm or content emotional state of the pedestrian. The dots then appear on a path towards the second quadrant in the top left corner as the driver behavior changes from talking on the phone to reading newspaper, and lastly no acting driver at all. The top left area of the chart is connected to the negative experience/high activation, which can be interpreted as a nervous or stressed out emotional state of the pedestrian. A score further away from the center represents a stronger emotional response, where in this case calmness and nervousness seems to be the central aspects of the tested experiences. On the question if he experienced any differences between the encounters, one participant replied that:

"Yes, a huge difference. It was feeling best when she (acting driver) was smiling and looking at me. It was like a scale, where the phone was the second best, even if it didn't feel that good either, and then the newspaper, and lastly when there wasn't anyone, when I didn't see someone at all. So yes, it was a big difference and a rather big jump even to the phone. It was basically best when she looked at me, everything else was bad, just different levels of bad."

When isolating the same type of encounters (eye-contact, no driver etc.) and comparing the scenarios A and B, the results show that the average emotional state is slightly shifted on the diagonal axis. This suggests that there is more calmness involved in encountering a vehicle that is standing still than a moving one. This was described by one of the participants in the following way:

"Yes, the big difference is when I experience the car when it has stopped compared to when it approaches me. There is always some uncertainty in if it will stop at all, if it has seen me at all."

The analysis of the data in scenario B where the participants were asked whether they would feel comfortable to cross the road, show that all participants (N=13) would cross when they got eye-contact with the acting driver (see Figure 22). In situations where the participants encountered the acting driver talking on the phone, or reading the newspaper, the number of those who would cross was reduced (N=10 and N=8, respectively). This number was even more reduced when the participants encountered an empty vehicle (i.e. no acting driver); only 5 of 13 participants would feel comfortable to cross.

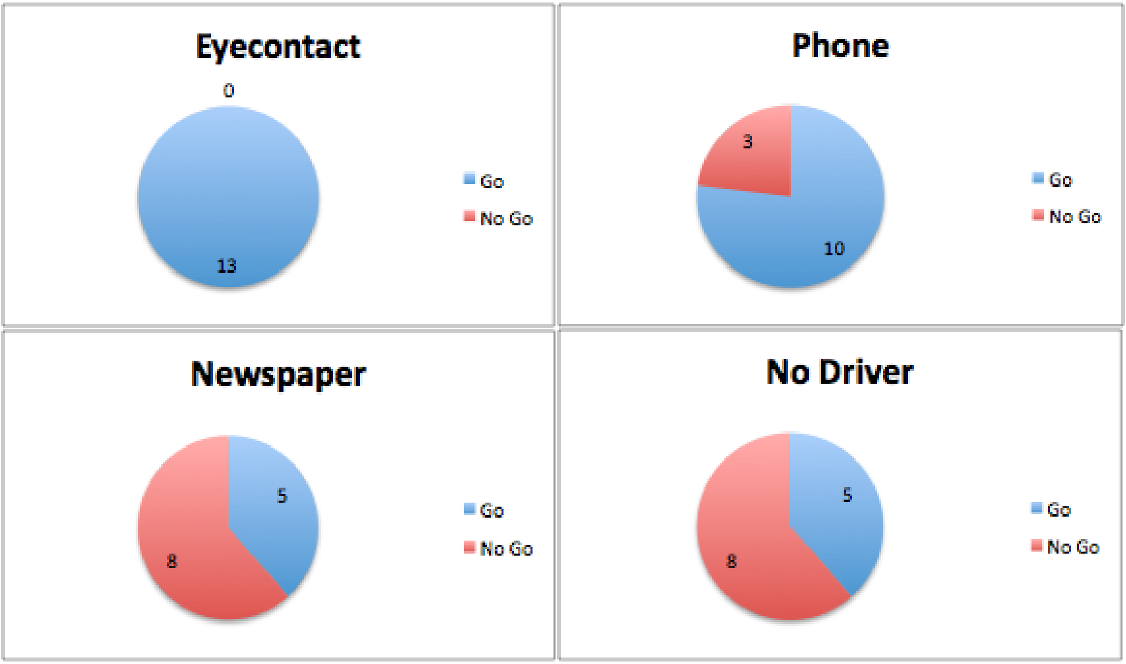


Figure 22. Go/No-Go decision of the test participants.

In scenario B, it was found that the test subjects used very different grounds to justify their decisions. Below are quotes from the interviews that show some different motivations on how test subject's reasoned about meeting the driver reading the newspaper in the still car (see Table 2).

Question	Decision	Motivation
Did you decide to cross or not to cross? (newspaper, vehicle standing still)	*"To cross."*	*"I was thinking that even if the person is reading the newspaper, it is something that you could do if you have stopped at a pedestrian crossing. You get kind of a small paus... But I still thinks she has noticed I'm here, and is letting me pass. (TP7)* *"I took it as a sign that when she took up the newspaper, she kind of said, "I'm not driving now"." (TP15)*

	"Not to cross."	*"The driver was reading the newspaper and wasn't focused on the driving task what so ever. If I start to walk, the person might as well start driving, since she has no attention that I am here." (TP13)* *"She was reading a newspaper so it was clear that I wasn't seen. It was obviously dangerous to cross, so it was an easy decision to make." (TP6)*

Table 2. Interview-answers linked to Go/No-Go decision.

In scenario B (standing still), the test subject got the two questions "*Did you decide to cross or not to cross?"* and "*What caused you to make your decision?"* after encountering the four different driver behaviors. This resulted in a total of 52 encounters, with 33 leading to a decision to cross and 19 not to cross. Table 3 lists the themes that were found to be most common when motivating the decision.

GO (33)	**NO GO (19)**
Pedestrian believed he/she had been noticed (24)	Pedestrian believed he/she driver was distracted (13)
The car had stopped (21)	Pedestrian believed he/she was not seen (12)
Pedestrian felt calm (9)	Pedestrian felt uncomfortable (11)
Car have stopped at a safe distance (8)	Pedestrian felt confused (5)
Driver is doing a waiting activity, e.g checking phone (7)	
Driver looks happy (3)	

Table 3. Themes linked to the total of 52 Go-No-Go decisions.

As seen in the table 3 the themes most related to crossing the street was that the pedestrians thought that she was seen and that the car had stopped. The participants also expressed that the distance to the car played a part in convincing them to cross.

A distracted driver was the most influential theme to why the participants did not want to cross. Though, as soon as the participant thought she was noticed, the distracted driver sometimes served as a signal that "I am not in a hurry, please pass at your own pace" i.e. a positive impact on the decision to pass. When the participants did not think that the driver had noticed them it had a large impact on their decision not to cross.

The emotional experience did also affect the participant's willingness to cross, and especially if the pedestrian felt calm. Even that the driver looked happy was mentioned as a motivation to cross. On the other hand, participants who felt uncomfortable or confused did not want to cross.

These themes are supported by the SAM data that showed that if the participant had a pleasant/low activation (i.e. calm) experience they were more likely to cross.

5.3 QUESTIONAIRE STUDY

A questionnaire measuring pedestrians' emotional state when encountering a vehicle where the driver is engaged in various tasks was constructed. In this study the participant was not told or led to believe the study was interested in automated vehicles as it was deemed that the participants would not be able to imagine how they would react to AVs with any credibility.

5.3.1 PURPOSE

The purpose of the questionnaire study is to further explore how pedestrians experience different driver behaviors. This study explored the topic using a larger sample with a more varied age spread than in the field observation study.

5.3.2 GOAL

The goal is to measure pedestrians' emotional state when encountering a vehicle where the driver is engaged in various task. Their emotions are based on the interpretation of driver behavior from static images.

5.3.3 METHOD

PARTICIPANTS

In total, the study involved 50 participants who gave their formal consent on participating in the study after reading about it and getting instructions on their role. They were selected randomly based on the following criteria: at least 18 years old, speak Swedish, and use public transportation frequently. A great majority of the participants (N=43) were recruited when they were traveling on the free ferry between Rosenlund and Lindholmen (Gothenburg). This is a popular way for pedestrians to cross the Göta Älv. The remaining participants were recruited in the Lindholmen Science Park area.

The participants were in the following age-groups: 18-20 (8 %), 21-30 (40 %), 31-40 (30 %), 41-64 (16 %) and 65 and above (6 %). About 46% of them were women. Approximately 80 % hold a driver's license at the time of the participation.

MATERIAL

- Ring binder with test descriptions, scenario, SAM-questionnaires and demographic questions.
- Five pictures of a driver displaying five different behaviors: eye contact, looking forward with hand on steering wheel, talking on the phone with no hand on steering wheel, reading a newspaper, sleeping (see section Stimulus material).

DATA COLLECTION

Data were collected using the SAM method and the yes/no question: Would you cross immediately? As well as three demographic multiple choice questions. Any comments from the participant were noted by the test leader.

TEST ENVIRONMENT

Most of the test participants were questioned while crossing the Göta Älv on the free ferry. Some of the test participants were asked while sitting in the public space in the Science Park Lindholmen.

STIMULUS MATERIAL

The images used in the study were taken using the same vehicle as in the field observation study (see Section 5.2.3). The images showed a driver engaging in five behaviors ranging from behaviors that are common today to what is safe only in a completely autonomous vehicle. The behaviors used in the test can be seen in Figure 23.

Figure 23. Acting driver behaviors.

TEST PROCEDURE

The test procedure was based on the questionnaire that was design to this study. The questionnaire was one page containing a background of the study, information about the participant's role and rights, and a scenario about a pedestrian walking through a city:

> *Scenario:*
> *You are walking through a city center and are just about to cross an unsignalized zebra crossing. A car has just stopped and you look into the car before passing the crossing, you see what is shown on the picture. How do you feel about crossing the road?*

The form also had a SAM to be filled in and the Go/No Go question:

> *Would you cross immediately?*

The test started with the test leader asking a randomly selected person if he/she was willing to take part in a survey about traffic safety that would take about two minutes. If the person agreed, and was fulfilling the selection criteria, he/she was given the questionnaire form. The test leader would read aloud the scenario description and show one randomly selected image of the driver behavior (see Figure 23). After viewing the picture, the participant was asked to complete the SAM and answer the Go/No Go question, as well as to fill in the demographic information. Any notable comments where written down by the test leader.

DATA ANALYSIS

The data collected were used to do a between group comparison of the driver behaviors. The mean value and median as well as the standard deviation were derived. The data were then plotted and graphically interpret in a bubble diagram. To separate the results that were obscuring each other, the valence and activity data were jittered. The SAM data were plotted with the valence on the horizontal axis and activity on the vertical one, to align with the Circumplex model of affect. The control values from the SAM data were represented by the size of the bubbles.

The Go/No Go data were visualized using pie charts for each of the driver behaviors.

A combined analysis of the SAM and Go/No Go data was also performed by plotting all the results in a bubble chart and color code for Go/No Go.

The comments from the participants were grouped according to the driver behavior.

5.3.4 RESULTS

The analysis of the emotion data show that the participants had in general the most positive experience when the driver's attention was directed towards them (i.e. towards the pedestrian), as seen in Figure 24 and Figure 25. Also, these results follow a diagonal line from the quadrant of the positive low activation affections such as calmness, to the negative, high activation affections such as distress.

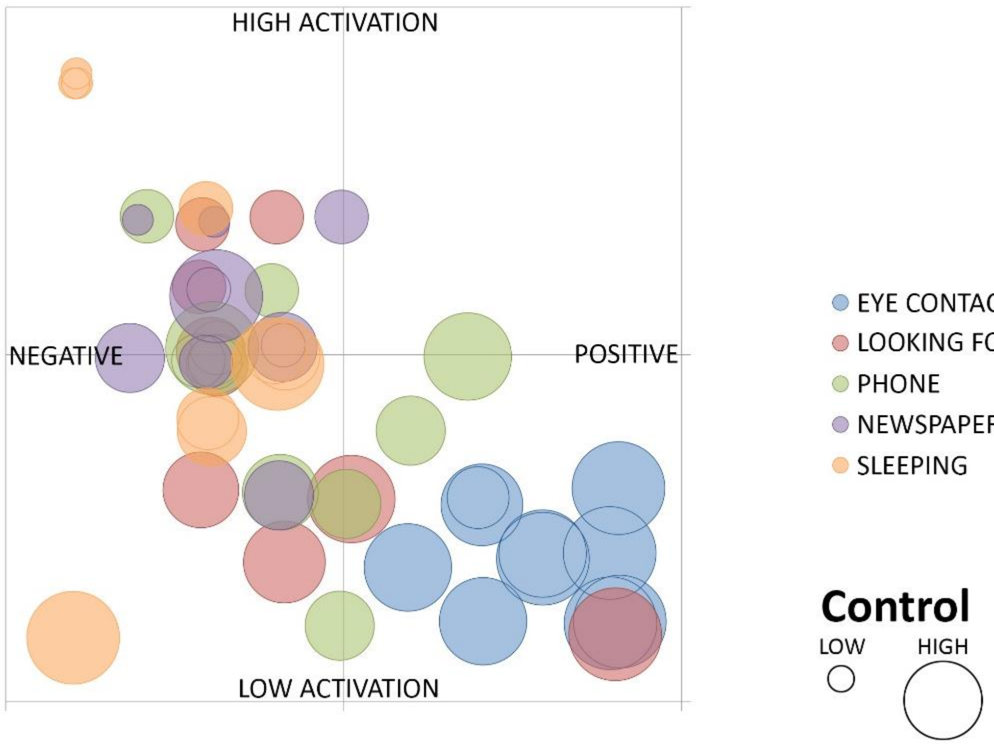


Figure 24. All SAM results.

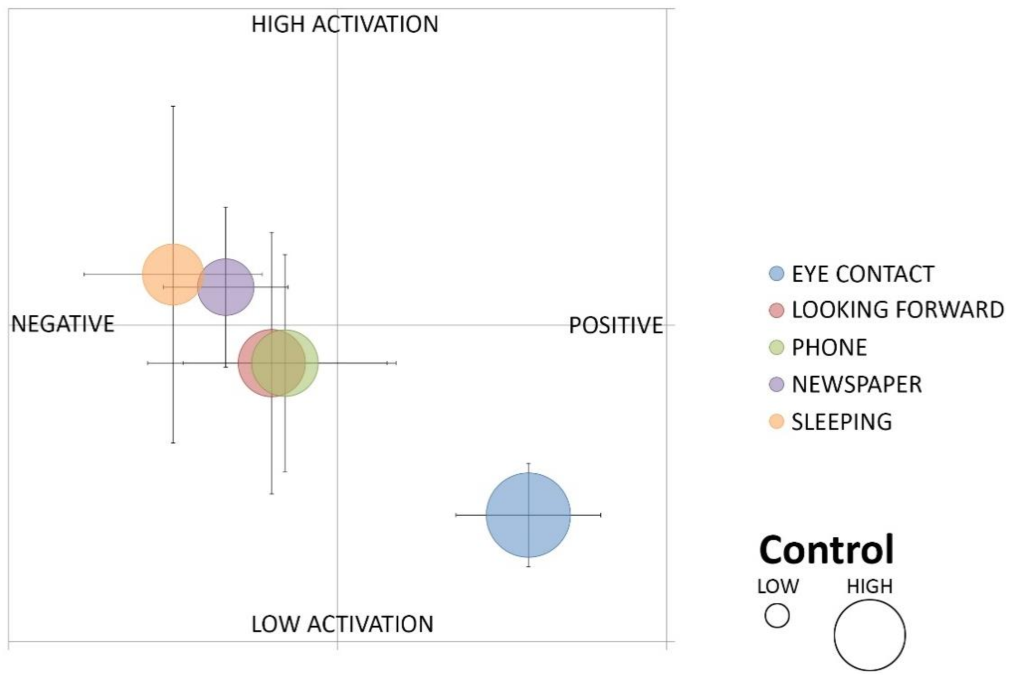


Figure 25. Average SAM values with standard deviation.

As shown in figure 25, eye contact with the driver did give the participants a pleasant, calm experience. The other driver behaviors showed to move over the diagonal line between calm and distress.

The looking forward and phone behaviors resulted in similar emotions. These behaviors were perceived as unsafe and the participants commonly concluded that the driver was not seeking any contact with the pedestrian. In the phone behavior, the driver was interpreted as being somewhat more distracted than the driver who was looking forward. Even so, participants stated that the person in the phone speaking picture looked passive, with comments as: *"judging from her eyes, she didn't look like she was going to drive"* and *"seems like she had stopped, do not have any hands on the steering wheel"* supports.

Comments from the looking forward behavior on the other hand stressed the lack of eye-contact. This could indicate that the subjects judge it more likely that the driver looking forward is going to drive. This is supported from the GO/NO-GO question where subjects were more willing to pass the phone behavior than the looking forward behavior, explaining why the less distracted looking forward behavior got a more negative rating than the phone behavior.

The other two driver behaviors, reading newspaper and sleeping, pulled more to the high activity negative valence. The first mentioned resulted in less negative emotions than the latter. This indicates that the level of driver distraction affects the emotional state of the pedestrian. The strong emotional response was also accompanied with the comments describing actions that the respondent said they would do when seeing a sleeping driver. One of the participants said, for instance, that she would call the police, while another one said he would knock on the window. Some other participants expressed concern for the sleeping driver's health.

The analysis of the participants' answers on the question whether they would cross the road shows that the tendency to immediately cross (see Figure 26) depends on the attention given to the pedestrian from the driver.

The participants (N=50) were divided among the 5 pictures. Only 2 of 10 would feel comfortable to cross when judging the looking forward, newspaper and sleeping behavior. When talking on phone, 4 of 10 wanted to cross, and participants viewing the eye contact picture were most likely to cross (N=8).

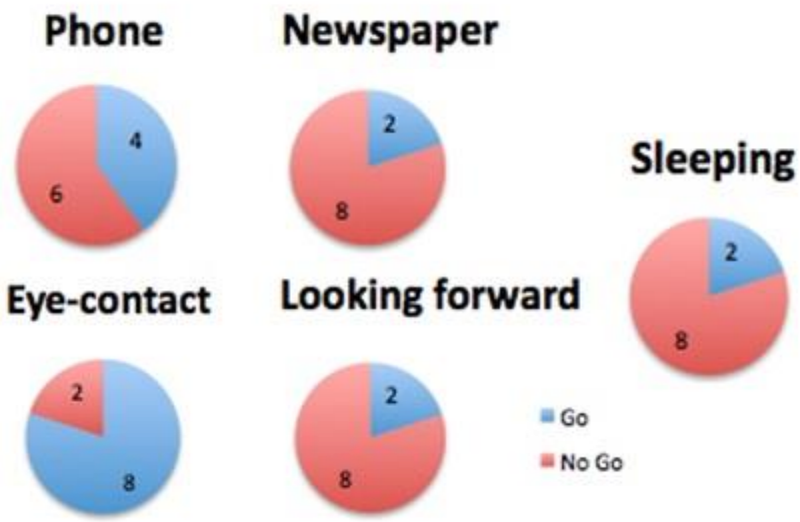


Figure 26. Go/No-Go decision of the test participants.

The behavior "talking on the phone" stands out, which could be explained by the perceived passivity of the driver described earlier. Another contributing factor is that pedestrians are used to drivers using the phone in the car. For example, one of the participants clarified: *"A bit unpleasant, but you are kind of used to drivers talking on the phone".* In summary, the questionnaire results indicate that a pedestrian emotional state changes depending on the driver behavior. More specifically, the emotional state of the pedestrians seems to be related to the attention they receive from the driver; a pedestrian feels calmer if he/she perceives that the driver has seen him/her. If the pedestrian thinks that the driver is distracted, he/she will feel more distress depending on the perceived level of distraction.

Driver behavior does affect the pedestrian's decision to cross the street, where the attention pointed towards the pedestrian increases the likelihood that the pedestrian decides to cross the street. But it is not the only contributor, passed experience also play a part as well as vehicle speed and context.

5.4 CONCLUSIONS FROM PHASE 1

Overall, the findings from the field observation study and the questionnaire study are in line with each other.

- Pedestrians' perceived safety might decrease when the driver is not maneuvering the vehicle (i.e. when the driver does not represent current or future actions of the vehicle).
- When pedestrians feel unsafe due to mixed signals from the vehicle and the driver, they may choose to wait until the vehicle has completely stopped, or to see how the situation develops.
- Risk of critical misinterpretation of the situation, pedestrians can interpret a occupied driver as that the vehicle will be parked until the driver decides to operate it. This interpretation would be wrong for an AV, which could lead to accidents.
- There is a risk that pedestrians experience drivers as reckless and dangerous when the drivers are focusing on other tasks (e.g., reading newspaper) instead of driving.
- There are indications that pedestrians want, and need, to know when a vehicle is driving autonomously.

6. PHASE 2: DESIGN

Phase 1 show that pedestrian's interaction is negatively affected by the introduction of AVs, primarily due to the change of driver behavior. This section describes the design of a proof-of-concept prototype. The goal with the prototype is to investigate if it's possible to improve the pedestrian-AV interaction with an external communication interface. First, methods used to develop the interface are described, starting with the use context. The what, how and where are detailed and explored. Next, the prototype is presented along with the evaluation methods and the chapter ends with the evaluation results.

6.1 USE CONTEXT

The information from Phase 1 is gathered into the use context that helped shape the design to fit the observed users and defined environment. The data collected was mainly from user interviews with the participants of field test in study one.

6.1.1 ENVIRONMENT AND CONTEXT DEFINITION

The system should be able to operate in various weather conditions such as rain, snow, wind and sunshine. The system should also work in various light conditions, from complete darkness to strong sunlight.

6.1.2 PERSONAS

Based on the interviews from the field test, three personas were constructed. Their needs were describe and an inspirational solution to their problem was produced.

Personas	**Careful Carl-Philip**	**Self-confident Madeleine**	**Stressed Daniel**
Needs	Carl-Philip does not trust drivers. He is often inclined to wait for the car to come to a complete stop before he feels comfortable to cross the road. He becomes upset when he perceives that the driver is arrogant. **Carl-Philip wants confirmation that he has been noticed.**	Madeleine feels that she is in control of her own situation. Independently of the car characteristics, and the traffic situation, she is the one deciding when to cross the street. She makes decision based on the car deceleration. She only looks at the driver while crossing, by curiosity. **Madeleine wants to know early on whether the car will yield.**	Feels in control but pushes the limit of what he feels is safe to make it to the bus. **Daniel wants to know what when the car intends to drive.**
Scenario-solution	Carl Philip is walking through the city to eat lunch. He is just about to cross a narrow two-way street over a non-signalized crossing. Before stepping from the curb, he looks to the left and notices a car approaching the crossing. He notices immediately that the car is driving in the automated mode and indicating that it will stop (yield?). Carl Philip finds it a bit uncomfortable that a driver does not maneuver the car, however, he feels safe since the car is indicating that it has detected him. Carl Philip waits a few seconds to ensure that the car will yield.	Madeleine must walk through the city to collect her laundry at the dry cleaners. She is about to cross a narrow two-way street over a non-signalized crossing. She looks to the left and notices a car in the vicinity. She feels that she would like to see the car slowing down before she starts crossing. She notices then that the car is driving in the automated mode and signaling that it will stop. Suddenly, she feels safe to cross even though the car has not started slowing down yet. She starts crossing and after a few seconds the car begins to slow down. The car comes to a stop when Madeleine is about to finish her crossing maneuver. The car does not detect any more pedestrians at the crossing and continues on its path.	Daniel is running down the street to catch the bus. While approaching an unsignalized crossing, he notices that a car has stopped to let a group of pedestrians cross the road. When Daniel arrives at the curb, the pedestrians have finished their crossing maneuver and he starts wondering if he could run across the street before the car starts moving. At the same, he notices that the car is in the automated mode showing that it intends to start moving. Daniel decides to let the car proceed rather than to run in front of it.

6.2 INTERFACE CHARACTERISTICS

This section presents requirements on what information needs to be communicated by an AV to a pedestrian, as well as when and how it should be communicated.

6.2.1 FUNCTIONAL REQUIREMENTS

The overall function of an external interface for AVs is to facilitate an interaction similar to the interaction that pedestrians experience when encountering manual vehicles (i.e. to replace the driver-pedestrian communication).

Phase 1 indicates that a pedestrian's possibility of interpreting a given traffic situation is affected by several aspects. As summarized through the personas and scenarios, there are some basic requirements and preferences that the pedestrians have on the interaction, in order to feel confident and safe.

- **Driving mode of the AV.** An indication that the vehicle is in autonomous mode is crucial in order to know whether to take the driver's behavior into account when interpreting a given traffic situation. When pedestrians have this information, the actual difference between an AV and a manual vehicle is the lack of information from the driver.
- **Future state of the AV.** There is little motivation of letting the system communicate what the AVs are doing right now, as this is communicated via the car velocity. Instead, the focus should be to allow the vehicle to communicate what it is *about* to do, i.e. about to stop and about to start. Phase 1 also gave indications that emphasizing certain states of the AV could be of benefit and add to a more pleasant experience of the pedestrian. In particular, the car's *stop and go* function (which turns the engine off when the car stops, and on when it's about to start) added an extra reassurance to the pedestrian. The vehicle was clearly not going anywhere as long as the engine was off and you got a clear indication when it was about to drive again.
- **Eye-contact replacement.** In Phase 1, the participants described eye contact and indication of being seen as a silent agreement with the driver. This agreement was based on the pedestrian's perception of being noticed by the driver. The fact that it was sometimes rather difficult to get a good view into the car did not matter as long as the pedestrian got a feeling that the driver was paying attention to him/her and the traffic situation. What might be described as eye contact by the pedestrians, is in reality derived from the direction of the driver's head and body. This indicates that that replacing eye contact could be done with a system that informs the pedestrian that they have been noticed. A clear change of intention when approaching a crosswalk can be used to indicate to the pedestrian that they have been noticed and that the AV is acting accordingly.
- **Make pedestrians feel calm.** According to the participants in the field observation study a calm feeling is important for the decision to cross the street. This means that the interface should try to express calmness in the interaction with a pedestrian.

In summary, pedestrians need to know what the vehicle is about to do, for instance slow down, stay still, or drive away. As seen in Phase 1 and as described with the personas, pedestrians have different needs when it comes to the feedback they want in the interaction with vehicles. It is important that the AV can facilitate these needs.

Imagining automated vehicles as intelligent agents, they should communicate the following to pedestrians:

- I'm in automated driving mode (AD mode)
- I'm about to yield
- I'm resting
- I'm about to start

How these messages correlates to the needs described with the personas can be seen in Table 4.

Needs fulfilled	**Message**
The need to know who is controlling the vehicle.	I'm in automated driving mode (AV mode)
The need to know early on whether the car will yield.	I'm about to yield
The need for confirmation that she/he has been noticed and a calm experience.	I'm resting
The need to know what when the car intends to drive.	I'm about to start

Table 4. User needs and their corresponding message.

The requested "I have seen you message" is regarded to be difficult to implement in situation with multiple actors. For a single pedestrian the change from "I'm in AV mode" to "I'm about to yield" should be enough that they can deduce that the vehicle has noticed them and is acting accordingly. Otherwise the "I'm resting" message can give them the feedback needed to be confident when they cross the street.

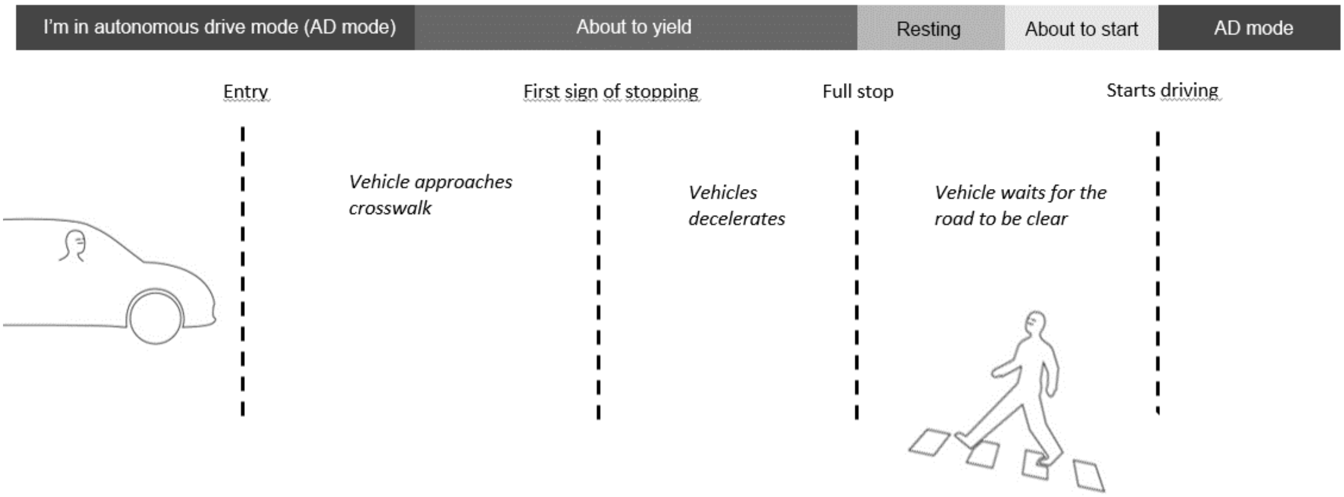


Figure 27. Touch points, vehicle-pedestrian interaction.

To find out *when* these messages should be communicated, the interaction between the pedestrian and vehicle has been divided into four touch points that were observed in Phase 1 to represent important states of the interaction (see Figure 27):

- Point of entry: *The moment when the pedestrian notices the vehicle*
- First sign of stopping: *The moment the pedestrian notices that the vehicle is decelerating.*
- Full stop: The moment the pedestrian notices that the vehicle has come to a complete stop
- Starts driving: *The moment the pedestrian notices that the vehicle is accelerating to continue on its path.*

Table 5 summarizes the fundamental features of the interface.

Message	**When message is active**	**Motivation**
I'm in automated driving mode (AV mode).	Always be visible when the vehicle is in automated mode.	Since seeing a distracted driver is giving an unpleasant experience, as seen in Phase 1. An AV needs to show who is in control even when not in the presence of a crosswalk.
I'm about to yield.	Show before the car has started to break when stopping in a crosswalk.	Giving the pedestrian feedback to cross as early in the interaction as possible is stated in the design vision for the project.
I'm resting.	Show when the AV has stopped and is waiting for the pedestrian to cross.	To enforce that the vehicle is waiting. Phase 1 pointed to that a calm emotional state had a positive impact on the pedestrian's choice to cross.
I'm about to start.	Show before the AV drives off.	To inform the pedestrian that the car is going to drive off.

Table 5. The message, when it is active and the motivation for including it.

6.2.2 MODALITY AND FEATURES OF THE SYSTEM

Given the complexity of the traffic environment and the variability in pedestrian characteristics, a reasonable conclusion is that a system for communication between automated vehicles and pedestrians should incorporate different interaction modalities. Such a multimodal design would enable as many users as possible to access the system.

However, designing such a system within the time frame of this master's thesis work would not be feasible. The design process was instead guided by the idea that the system should in its fundamental configuration include a modality that applies to many pedestrians. Such a system could, in a later step, be complemented with some other types of modality to meet needs of a broader population.

In order to decide which modality is the most appropriate for the fundamental system configuration, a comparison of advantages and disadvantages of different modalities was performed.

Based on a literature review and expert discussions, visual and auditory modalities were selected for a more detailed comparison. Other modalities were regarded as technically unconceivable, and were therefore excluded from the detailed comparison.

COMPARISON BETWEEN VISUAL AND AUDITORY MODALITIES

As shown in Table 6, both visual and auditory signals have their advantages and disadvantages. A system based on visual signals is more likely to have a clear sender and operate over longer ranges than a corresponding system based on auditory signals. This is especially important in complex traffic situations where multiple cars and pedestrians interact with each other.

A system based on auditory signals, on the other hand, gives pedestrians a 360 degrees input, as the sound direction is easy to distinct. Also, auditory signals are likely to be useful for pedestrians with vision impairment. However, a clear disadvantage of auditory signals is that pedestrians are commonly using various head-sets, making them less likely to capture auditory signals from the surroundings. There is also a convention that visual signals are used for "normal" communication from vehicles to other road users (e.g., turn indicators, brake lights) and audible signals for awareness rising (e.g., horn, engine revving). That is, auditory signals for communication of AVs intentions could be perceived as warnings.

From this it can be concluded that a system using visual modality as a basis would be more suitable then auditory modality. However, an auditory signal might be integrated to complement the visual information. In particular, auditory signals might be useful when pedestrians and AVs are in the vicinity of each other.

Visual advantages	Auditory advantages
Clear sender	Attention grabbing
Long range	360 degree input
Not affected by headphones	

Table 6. Listing of visual and auditory advantages.

6.2.3 PLACEMENT OF THE SYSTEM

Chapter 2 describes a number of system concepts for facilitating communication between pedestrians and AVs that were generated prior to this project. Some of them are based on the visual modality: projecting messages on the ground and LED.

The first mentioned where messages are projected on the ground under, or in front, of the vehicle raises some questions regarding ease of accessibility. Displaying such messages under the AV may be difficult to notice, depending on the pedestrian's position. On the other hand, displaying such messages further away might be difficult for the pedestrians to perceive and associate with the AV. That is, information that the pedestrian is used to seek from the driver should be placed near the driver to fit the pedestrians mental model. It also raises questions on how smooth the road surface needs to be to successfully display the messages. In addition, there may be some technical limitations, especially if the projection is to be visible in various light conditions, including daylight. A laser, which is the most plausible solution, must likely exceed legal limits to achieve this, according to Sheila Galt, professor at the apartment of Micro-technology and nanoscience at Chalmers. Also, finding an optimal placement for the laser in the current design of vehicles may be challenging. Together, this implies that projection of messages on the ground is currently problematic. However, such a system could be valuable for communication with pedestrians during low light conditions.

The two concepts involving LEDs as means of communication were here simplified to represent two different placement options for the LEDs on the vehicle: grill and windshield. Placing the system in the girl of the AV makes the system close to the pedestrians. Also, it is often a natural area of attention, with the headlights and grill representing something of a face or eyes of the vehicle. At the same time, this could also result in the communication system being mixed up with other light signals, such as driving lamps and styling. Furthermore, it could interfere with an important branding surface of the vehicle, at least since the scope is to aim for a generic system design that can be utilized on many types of vehicles and different manufacturers. The windshield, on the other hand, is a neutral area that should allow for good visibility. It is also close to the driver which is a beneficial as the goal is to replace and enhance the information that the pedestrian normally seek by looking there. The top area on the windshield was thus selected as an optimal placement of the system.

6.3 SIGNAL DESIGN

This section specifies how the previously defined messages should be communicated to the pedestrians. For the system not to interfere with the driver's field of vision it was decided that the system should be thin and wide to maximize the display area on top of the windshield. Given those requirements, a 1m strip of 60 LEDs was selected as a viable hardware solution. Several different signal implementations using the LEDs were explored. The three most promising are described here.

An ideation session was initiated to brainstorm different types of visual signals able to convey the previously defined messages by means of the LEDs. The main focus was on exploring how to convey the messages by changing the following characteristics of LED signals:

- *Frequency*
  The idea of using light pulses at different frequencies and changes in frequencies was explored.
- *Area/Motion*
  Another area of investigation was using changing the area of the lit LEDs to communicate was also explored. Animation an object in motion could be a good analogy for the car in motion, a black object that moves back and forth across a horizontal bar, which changes speed to communicate changes. This solution also references KITT, the autonomous vehicle from the 1980's TV-series Knight Rider, which could give users an indication that the system is autonomous.
- *Color*
  Color plays an important part to separate the system from the dim/headlights and indicate to users that this is a signal and not a light source. In the traffic environment there are already a lot of colors used to given certain types of signals. The color of the system was not fully explored but in discussions with industry experts a white-yellow shade was

chosen. Some colors could be written off however: red (illegal to use in the front of the car), green (to strong connection to a traffic signal, can wrongly be interpreted as it is safe to pass which is might not be), blue (used by police and rescue vehicles), amber (used by service vehicles).

The three most feasible ideas were chosen for further development. These ideas were chosen because of their perceived ability to be read at distances (see Table 7).

All of these concepts intend to convey information to the pedestrians by using a metaphor of the vehicle as an intelligent agent whose activity is displayed by the system.

When the vehicle is in AD mode the system is turned on, and when the human driver operates the vehicle the system is turned off.

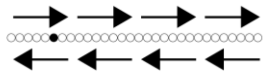
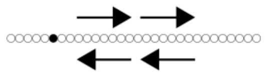
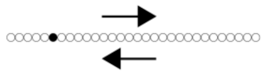
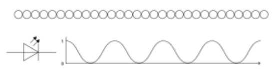
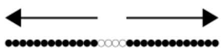
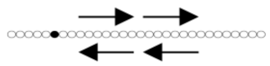
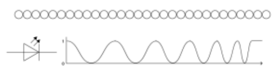
Message	Area	Motion	Pulse
I'm in AD mode			
I'm about to yield			
I'm rest-ing			
I'm about to start			

Table 7. Three alternative signal designs.

AREA

Different sizes of the lit area are used as a metaphor for the intelligent agents desire to drive forward. When the area is completely lit, the AV expresses a strong desire to continue to drive. As the desire decreases, so does the lit bar. This concept could work with a number of geometric shapes, such as circles or rectangles, which were explored but the concept uses a bar to show the information. The bar was chosen because of the decision to use a LED strip to show the signals.

MOTION

This concept uses motion of a dot as the metaphor in the same way as the Area concept. By using a lit bar of LEDs, a single turned off or black LED is moving back and forth across the bar. Its speed is changing to communicate intention.

PULSE

This concept uses the same metaphor but communicates by pulsating the light.

6.4 CONCEPT EVALUATION

The three concepts were evaluated by means of two formative tests with pedestrians: Signal-Message Association and Concept Guessability. Also, an evaluation in form of a semi-structured workshop with Subject matter experts was carried out.

6.4.1 SIGNAL-MESSAGE ASSOCIATION TEST

To test how users perceive the signals, a test based on the Sound Imagery method was carried out. In this reference method, the subject's task is to pair a message to a sound and rate their association. Here, instead of pairing a message to a sound, the participants were asked to pair a message to a visual signal.

PURPOSE
The purpose is to investigate the signal design concept's association to the vehicle's four AD messages.

GOAL
Get an indication of what signal pattern to use for the functional prototype.

METHOD
The user viewed a video of an AV with animated light signals on the top of the windshield. The task was to connect the visual signal to the correct message.

PARTICIPANTS
The participants were recruited at the bachelor program Industrial Design Engineering at Chalmers University of Technology (campus Johanneberg) for convenience. A total of 11 participants (6 female, 5 male) were recruited. The average age was 23 years (S.D 1.6).

STIMULUS MATERIAL
The test material consists of three videos with the signal communication messages represented either through a pulsing or sweeping light or through a change in the lit area. Each video shows a still picture of the front view of a Volvo V40 that has been modified with animations in After Effects to imitate the different light patterns (see Figure 28).

The four AD messages were shown in each video in the following order:

1. The vehicle is in AD mode
2. The vehicle is Yielding
3. The vehicle is Resting
4. The vehicle is Starting

Figure 28. Screen capture of video.

MATERIAL
The following material was used in the tests:

- Laptop to show videos
- Writing material to note interesting comments
- Recording equipment, phone with recording app
- Forms?

DATA COLLECTION
The participants were asked to fill in a form with their age and gender, and the same form was also used by the participant to fill in test answers.

TEST PROCEDURE
The test, and answering form, was divided into three segments corresponding to the three videos, shown in randomized order.

The test subject's task was to locate four different signals in each animation and connect it to the message that they thought it symbolized. This was done by drawing a line between the described signal, for example: "Slow pulse", to one of the four system messages (Section 6.2.1). An additional task was to rate how strong they experienced the connections on a scale from 1-5, where 1 indicated a weak connection and 5 a strong connection. At the end, the test subjects were asked to select a signal that was most/least appealing to them.

DATA ANALYSIS

The data analysis consisted of reviewing the test forms and noting if the participants were successful at connecting the signal to the intended message. The error rate for each concept was calculated. The concepts could then be compared by their ability of conveying the message and by ranking the least and most appreciated design.

RESULTS

The result showed that *Pulse* had the highest error rate (5 of 11). The messages ”The vehicle is in AD mode” and ”The vehicle is Resting” were difficult to distinguish. Pulse was, on the other hand, the most appealing concept (N=6), followed by Area (N=4) and Motion (N=1). At the other end, the Area was the most disliked concept (N=6), closely followed by Motion (N=5). Based on these findings, the Motion concept was excluded from further investigation.

Figure 29 shows how strong the test subject’s association is between signal and intended message.

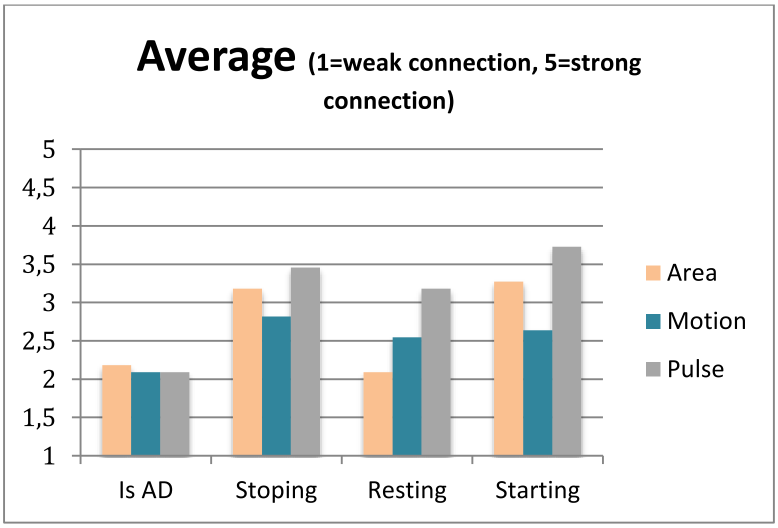


Figure 29. Signal-Message Association

6.4.2 CONCEPT GUESSABILITY TEST

This evaluation looked at the first encounter and guessability of the concepts that were selected for further investigation: Area and Pulse.

PURPOSE

The test aimed at identifying experiences of the pedestrians when they were exposed to only one concept, in a between group comparison.

GOAL

The goal is to compare the concepts in terms of guessability and to identify any previously unknown strengths or weaknesses of the concepts.

METHOD

Each participant viewed a video of a car with the system and answered questions about the system.

PARTICIPANTS
The participants were recruited in the building of the Interaction Design Master Program at Chalmers University of Technology (campus Lindholmen). These participants were chosen because their knowledge in the field of interaction design. A total of 8 participants were recruited (4 male, 4 female). The, average age was 26 years (S.D=3.8).

The participant was informed that the test required him or her to watch the same video three times and then answer questions about what they saw. They were also informed that the test was voluntary and that they could quit at any time.

STIMULUS MATERIAL
The test is based on a video that was recorded on an empty parking lot in Frihamnen in Göteborg in good weather and light conditions. The video depicts a car driving towards the camera, which is positioned to give a pedestrian's point of view of the interaction. The camera is positioned on the side that is furthest from the driver, at approximately 1.7 meters above the ground. The footage was shot using a focal length of 50 mm with an image sensor that was 35 mm. At the start of the video the car is 70m from the camera, driving 30km/h. Figure 30 shows the point where the car starts to brake, coming to a complete stop 5 meters in front of the camera. After a couple of seconds, it starts driving again.

The video footage was imported to the video editing software After Effects to animate the two different concepts onto the car. In both videos the vehicles starts with signaling that it is in autonomous drive mode before signaling that it intends to yield half a second before it starts to brake. When the car stops it shows the rest signal. In the Area concept video the resting signal now changes size slightly in a calm pulsing manner. 2 seconds before the car drives off it shows its intention by sending the starting signal.

Figure 30. Screen capture of video for the Gueassability test.

MATERIAL
- Laptop to show video
- Writing material to note comments
- Recording equipment, phone with recording app

DATA COLLECTION
The data was collected in form of an interview. The answers were noted and recorded to allow a more systematic analysis.

TEST PROCEDURE
A between group test design was used, meaning that 4 participants evaluated the Area-concept and 4 evaluated the Pulse-concept.

Each participant viewed the video three times, and afterwards the test leader asked the following:

1. Can you describe what you just saw?
2. What function had the lights on the windshield?

In the next step, the test leader explained the concept to the participant and the participant got the opportunity to view the video one more time. This was followed by the question:

1. Do you think that the system could be helpful?

DATA ANALYSIS

The collected comments were grouped to the corresponding concept and question. The content was gathered as summarized quotes that the test leaders though best represented the total data.

RESULTS

The Pulse concept got a more positive response from the participants than Area. Especially on the first question: - *Can you describe what you just saw?* subjects in the Pulse-group gave more positive and elaborate responses , explaining what they thought the purpose of the system was.

The pulse concept also got more positive feedback as the test subject's thought it would work well and be able to replace the driver-interaction. The Area concept was also perceived to be helpful but the participants stressed the importance of explaining it before use.

Concept	Q1: Can you describe what you just saw?	Q2: What function had the lamps in windshield?	Q3: Do you think that the system could be helpful?
Area	Some sort of velocity gage.	Something with velocity. Show that the cars stops. That the car has seen me.	Yes. If it have been explained.
Pulse	A car that showed what it was doing.	Show movement and intentions. Show if the car is stopping or not.	Yes. It can replace the interaction with the driver.

None of the participants expressed any unforeseen weaknesses or strengths. The Pulse concept seems to have better guessability than the Area concept, even though eight participants is a small sample size to say anything definite. The important result was that both concepts seem to be acceptable.

6.4.3 EVALUATION WITH INDUSTRY EXPERTS

At the end of this stage a workshop with the SME was conducted to find out what the industry though of the concepts and how the project should continue.

They expressed that the system should be as discreet as possible, and to do this, the area signal concept could be inverted. In this way, the interface also gets more visible the closer it gets to the pedestrian. It was also discussed that features from the two concepts could be combined to achieve the best possible variant.

The industry experts stressed that first-encounter issues and guessability was not of great importance, and that test participants should get some training on reading the system before conducting any user tests.

6.5 FINAL CONCEPT

The final concept design is based on a combination of the features of the Area and Pulse concepts (see Table 8).

When operating in AD-mode the system is turned on. If the vehicle is in manual-mode the system is turned off. Compared to the previous design, the meaning of the Area-concept signals is inverted. The new design uses the minimal number of lit LEDs during the main part of the time when the vehicle is driving.

This external interface should aid the pedestrian in understanding the vehicle’s current drive mode and its future actions. The interface can therefore be seen as a way for the pedestrian to collect additional, and more detailed, information than what is possible in today’s interaction with the driver. It is important to highlight that the “about the yield” message is strictly meant to communicate that the vehicle is about to decelerate, and if the vehicle changes plan, this will also be displayed. Much like a turning indication light, this signal is an indication of what the vehicle is about to do, which can be aborted without the action taking place.

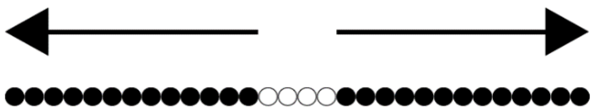
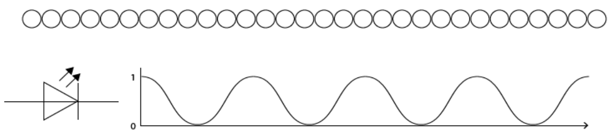
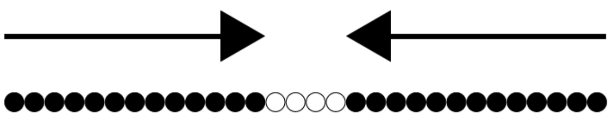
Message	Final Concept
I’m in AD mode	 As long as the vehicle is In autonomous drive mode, the middle part of the signal bar is lit.
I’m about to yield	 When the vehicle has identified an approaching pedestrian, and intends to stop and yield, the light expands towards the sides until the LED strip is completely lit.
I’m resting	 When the vehicle has stopped, it shows that it’s waiting/resting by pulsating the signal bar calmly.
I’m about to start	 When the car intends to drive, the lit LED strip shrinks down before the car drives away.

Table 8. Final LED communication sequences.

7. AVIP PROTOTYPE

In order to test the AVIP-system in practice, a physical prototype of the system was developed based on the final concept described in chapter 6. The prototype is adapted to accommodate evaluation in a Wizard-of Oz set up. However, it is visually refined to not affect the test subject experience in a negative way. The prototype consists of a 1m strip of 60 LEDs that are positioned on the outside of the vehicle, at the top of the windshield (see Figure 31).

Figure 31. AVIP prototype.

The 60 RGB LEDs on the strip can individually be controlled via an Arduino Uno microcontroller. After programming the intended light patterns onto the Arduino, these are controlled by the vehicle driver using a push-button. Each press of the button triggers the next sequence in a four-step loop (showing the four concepts patterns).

1. Vehicle start: A starting sequence lights up all the LEDs to check that they are functioning.
2. The system automatically ends up in “AD mode” signal.
3. Press button: Initiate “About to Yield” signal.
4. Press button: Initiate “I’m Resting” signal.
5. Press button: Initiate “About to start” signal.
6. The system is back at step 2.

A driver feedback LED monitor was constructed and mounted inside the car in order for the test driver to be aware of the current state of the system. Figure 32 shows an overview of the system, which hardware and software is further described in the following sections.

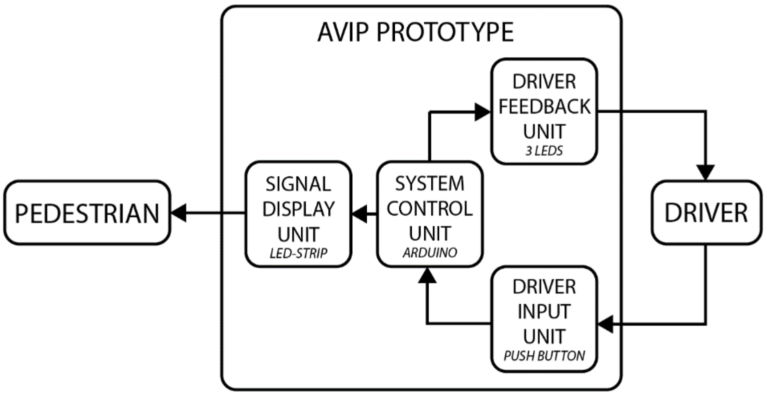


Figure 32. System overview.

7.1 HARDWARE

This section presents the components of the prototype and how these are connected. The hardware also includes solutions for preventing exposure of direct sunlight and waterproofing of the LED strip.

7.1.1 ELECTRONICS

The prototype was based on an Adafruit Neopixel 1m (60 LEDs) strip controlled via a pull-up push-button through an Arduino microcontroller. An Arduino microcontroller is a small computer, it has several input and output channels that are programmable, which makes it easy to control electronic components. The Neopixel strip allows individual control of each of the 60 LEDs through a single data input channel, which made it ideal for this prototype. The circuit diagram is shown in Figure 33.

The material used in the prototype includes:

- Arduino Uno microcontroller board
- Adafruit Neopixel 1 meter/ 60LEDs strip (RGB)
- Breadboard
- Push-button
- Two 2.1A USB car adapters (5V)
- Two 1000 microF 25V Capacitors
- Four 330 Ohm Resistors
- 10 kOhm Resistor
- Connection wires
- Three LED diodes (green, yellow, red)

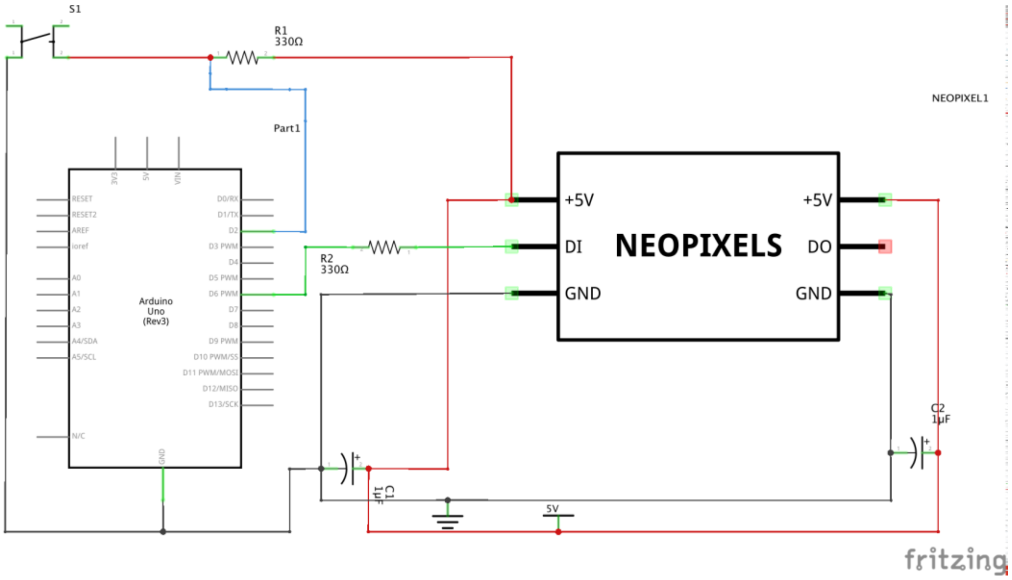


Figure 33. Circuit diagram of the AVIP-prototype

7.1.3 SHADER & WATER PROTECTION

As the prototype was to be mounted on the outside of the windshield, it had to be waterproof. The LED strip was fitted in a transparent plastic tube that was then siliconed at the ends for water sealing. This tube also added some resistance against both wind and wear for the quite sensitive LED strip, as well as allowed the diodes to be directed forward, rather than upward. The case when the LED-strip was placed on the windshield.

A sun protective cap was constructed in order to make LED strip visible in daylight (see Figure 34). This sun-cap was made out of a large piece of plastic sheet and was bent and cut to fit the test vehicle.

Figure 34. Shader.

7.2 SOFTWARE

The software for the prototype was developed in the Arduino IDE (Integrated Development Environment). It is in principle based on a loop function that checks the state of a variable and calls a function given by that variable (see Appendix 2). The function called dictates the behavior of the LED-strip. The loop function checks also if the push-button has been activated, and if so changes the state of the variable. This in turn changes the function, which is controlling the LED-strip, and thus how the LEDs light up. The variable state also dictates which of the driver feedback LEDs should be activated.

7.3 INSTALLATION

The prototype was developed for installation in a Volvo V40. However, the prototype could easily be adapted to other types of vehicles.

The Arduino microcontroller is secured between the front seats together with the breadboard connection plate (the breadboard could be removed by connecting each wire directly for a more enduring, but less flexible, set up) (see Figure 35). The LED strip gets its commands from the Arduino, which are in turn initiated by the driver via a push-button connected to the microcontroller and mounted on the dashboard. In other words, each activation of the button activates the next state of the LEDs. The state of the LEDs is showed to the driver by means of the colored diodes mounted on the dashboard (see Figure 36). The LED strip was powered by two USB car adapters à 2.1 A connected to each end of it.

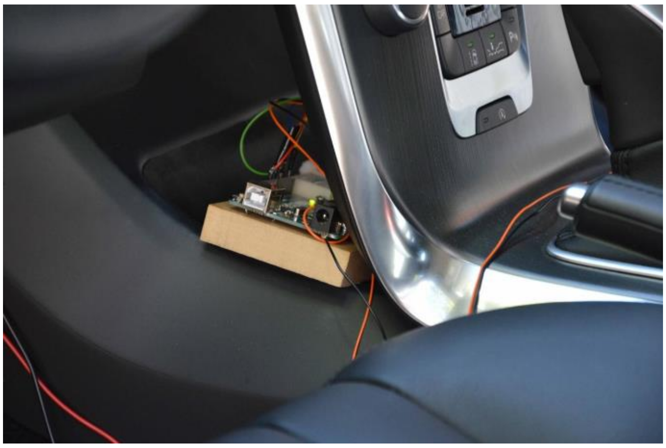


Figure 35. Arduino

Figure 36. AVIP Monitor.

8. PHASE 3: IMPACT OF DESIGN SOLUTION

In this chapter the answer to the second research question is explored by a field test of the designed prototype.

8.1 FIELD TEST OF THE AVIP SYSTEM

The test was designed to explore if pedestrians are able to perceive the message sent by the system and if that information alters their behavior in terms of decision making.

8.1.1 PURPOSE

The purpose is to obtain an indication if the AVIP-prototype is understandable and if it can provide any aid for the pedestrian in the interaction with an AV at an unsignalized crossing.

8.1.2 GOAL

The test was developed to gain information regarding the project’s second research question:

2. How will communication be affected by introducing an interface designed to enhance the vehicle’s ability to communicate with pedestrians?

To answer this, the following sub-questions needed to be answered.

- Are test subjects able to decode the signal?
- Are test subjects confident in their interpretation of the signal?
- How does the test subject emotionally respond to the system?
- Do they feel safe to act on the signal?

8.1.3 METHOD

PARTICIPANTS

The test group was selected to be comparable with the test group of the first field in Phase 1. Therefore the same selection criteria were used.

The test involved 9 participants (5 male, 4 female). Seven of them were 20-29 years old. The rest were between 30-39 years. Five out of the 9 participants did not have a driver license. Two of the participants were not students at Chalmers. However, both of them were well-familiar with the area.

MATERIAL

- Test vehicle (Volvo V40 described in chapter 5)
- Portable audio recording equipment
- Walkie-Talkies (for keeping test leader and driver in contact)
- Newspaper
- Ring binder with SAM-questionnaires, pass/fail and confidence rating scale questionnaires and descriptive pictures of the AVIP-systems functions
- AVIP system prototype

DATA COLLECTION

The test leader noted answers on the Pass/fail questions. The test leader also entered the confidence rating scale data. Emotions data were collected using the Self-assessment manikin method (see fig.2 SAM) and through structured interview questions. Interview answers were recorded by means of a recording application on a smartphone.

TEST ENVIRONMENT

The test used the same environment as the field test in chapter 5. In the test another set of distances was used in the interaction between the vehicle and participant (See Figure 37).

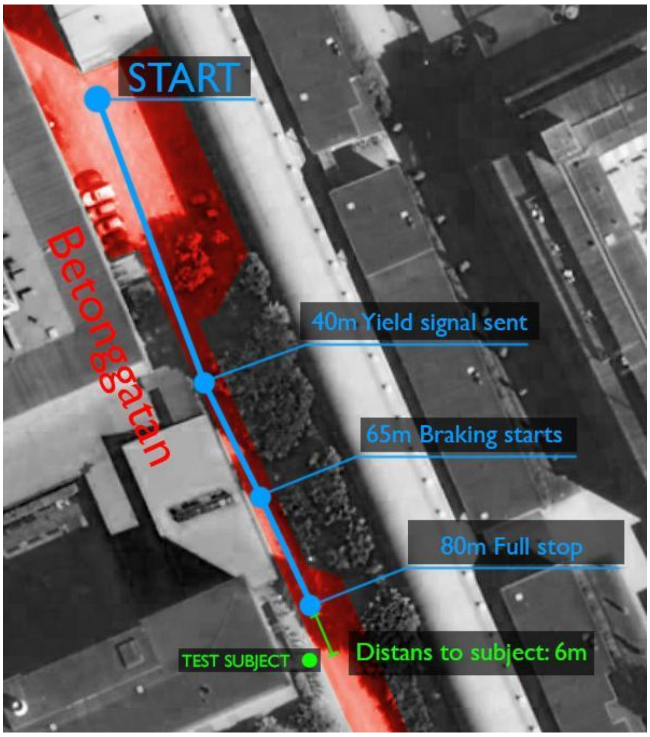


Figure 37 Distances used in the interaction with the test subjects.

TEST PROCEDURE

The test starts with the test leader greeting the participant and asks him/her to read a short description of the project and that the purpose of the test is to examine how pedestrians react to AVs. The participant is then asked to stand at a given position on the curb. Each participant experienced 6 encounters (see Table 9) with the AV.

Drive 1: The first drive is testing the AVIP-system in a first encounter so the test participant is not informed about the system. The subject is standing at the curb and is given the task to observe the AV while pretending to stand at an unsignalized crossing. In each event the vehicle drives along the road where the test subjects stands. Every event the vehicle brakes and stops in front of the test subject. Here the vehicle rests for a little while before driving off. The vehicle then drives back to the starting point when the test subject is answering questions. When the AV passed, the test leader asked the participant:

- Describe what you saw?
- How did you experience the light signals in the windshield?
- What function did the light signals in the windshield have?
- How did you experience the traffic situation?

Drive 2: Before the second drive started, the test leader explained the system and its function with the help of the pictures (see Figure 38). The subject was then instructed to observe the AV. When the AV passed, the test leader asked the participants:

- Do you have any questions about the system?
- Have you understood how the system works?
- Do you have any comments about interacting with a self-driving car and its attempt to communicate with you?

When the subject had answered that they understood how the system worked the next part of the test started.

Order	Drive #	Signal		Purpose
Fixed order	Drive 1	AD mode (0-40m) About to yield (40-80m) Resting (80m) About to start (80m-)		First encounter
Fixed order	Drive 2			Training test subject
Randomized or-der	Drive 3	(In motion 0-40m) AD mode OR Yield	(Still 80m) Resting OR Start	Test understanding and confidence
	Drive 4	(In motion 0-40m) AD mode OR Yield	(Still 80m) Resing OR Start	Test understanding and confidence
Randomized or-der	Drive 5	Without AVIP-prototype		Measure emotions and compare with or without system
	Drive 6	With AVIP-prototype, all signals		Measure emotions and compare with or without system

Table 9. Test set-up.

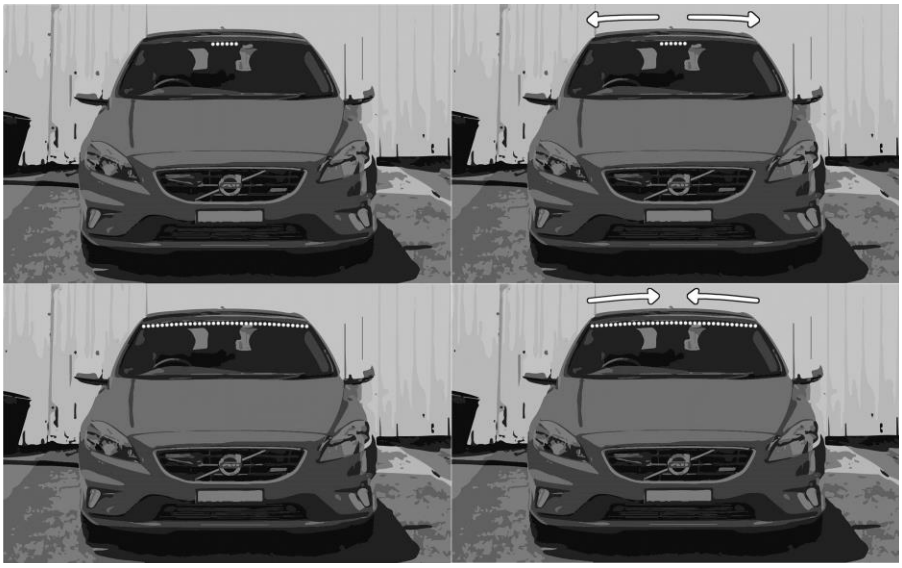


Figure 38. Top left: AD mode. Top right: Yielding. Bottom left: Resting. Bottom right: Starting.

Drive 3-4: The participant was asked to look at the car until the test leader asks them to turn around and answer questions about the AVIP-signal that they just experienced. There were two possible signals, either they were asked to turn while the car was still in AD mode or they were asked to turn later when the car had shown its intention to yield. The vehicle behaved in the same way in both cases. The test leader asked a question depending on which behavior the car had showed.

If the car was in AD mode, the subject was asked:

- What signal did the car show?
- How confident are you on your answer on a scale from one to five where one is uncertain and five is very certain

If the car was showing that it would yield, the subject was asked:

- Will the car yield?
- How confident are you on your answer on a scale from one to five where one is uncertain and five is very certain.

After they had answered the question they were instructed to do the next test. In this test the vehicle had stopped behind the participant while they were answering the last question. The participant's task was now to turn around and assess if the car signaled that is was in a resting mode or if the car was about to start. They were informed that they had two seconds to make that assessment before turning back towards the test leader and answer the question. They were also told that regardless of what signal the car showed it would drive away after turning but the task was to assess what the signal was sent. The car could be giving one of two signals, either the car was resting or that the car was about to start. The questions to the test subject were:

- What will the car do? Wait or Start?
- How confident are you on your answer on a scale from one to five where one is uncertain and five is very certain.

After the test subject had answered they were asked to answer for both of the signals they had seen:

- Was the signal clear?
- How did you interpret the signal?

This drive was then repeated asking the test subject to answer the question that was not asked in the previous drive and with the car showing the wait or start signal that had not been used.

In the last two drives the test subject was instructed to stand and observe the vehicle as she or he had done in the first two drives. This time the test measured the subject's emotional response with the help a SAM and interview questions. In this part the test divided the subjects into two groups were one group had the AVIP-system turned off for the first of the two drives and the other group had the AVIP-system turned off for the second of the two drives. The subjects were informed that the system would be turned off and that the vehicle was still in AV-mode. When the vehicle had passed the subject they were asked to first fill in a SAM questionnaire and then asked the following questions:

- How did you experience the situation?
- Would you have begun to cross the street before the car had stopped?

After the last drive when subject had been questioned about his or her emotional response with and without the AVIP-system the subject was also asked to compare with or without the system.

- Could you compare the experience with or without the system?

After this the test ended, each test took around 20 minutes to complete.

DATA ANALYSIS

The mean value and median as well as the standard deviation were looked at. The data was then plotted and graphically interpret in a bubble diagram. The SAM data was plotted with the valence on the horizontal axis and activity on the vertical one, to align with the circumplex model of affect. The control data was represented with the size of the bubbles.

The average value, the median and the standard deviation of each of the confidence ratings was calculated and compared. The results were compared with- and without the system.

The answer to the pass/fail questions were also counted and grouped and the percentage of right answer was calculated.

Transcriptions of the audio recordings were written and content analysis was performed.

8.1.4 RESULTS

Overall, the results show that the prototype helped the pedestrians to understand the AVs intentions. After the training session (Drive 1), a great majority of the participants were able to successfully decode the AVIP-signals (see Table 10). The participants who failed to answer the "AD mode" question were confused about who was in control of the vehicle.

Signal	AD mode	About to yield	Resting	About to Start
Success Rate	78%	100%	100%	100%

Table 10. Successful decoding rates

In addition, the participants felt confident in their interpretation of the signals. Table 11 shows the average values of the 9 participants, in which the data input consisted of a 1-5 certainty scale.

Signal	AD	Yield	Rest	Start
Average	3,9	3,8	3,9	4,8
Standard Deviation	1,54	0,67	0,91	0,47

Table 11. Confidence level. 1=not confident, 5=very confident.

The system increased the pedestrians' willingness to cross the road before the vehicle had stopped. When encountering the AV without any AVIP-system, only about 13% of the participants said that they would start crossing before the car stopped. This number increased to 38% when the AVIP-system was activated.

The participants reported that it was easy to get used to the AVIP-system and they would trust it more after some time.

"Now I have learned to recognize the signal. I think that, with a little more experience, I can probably interpret it much faster than I did now." (TP5)

The system had a positive effect on the participants in terms of emotional experience. This became especially apparent when comparing their emotions in encounters with- and without the system (see Figure 39).

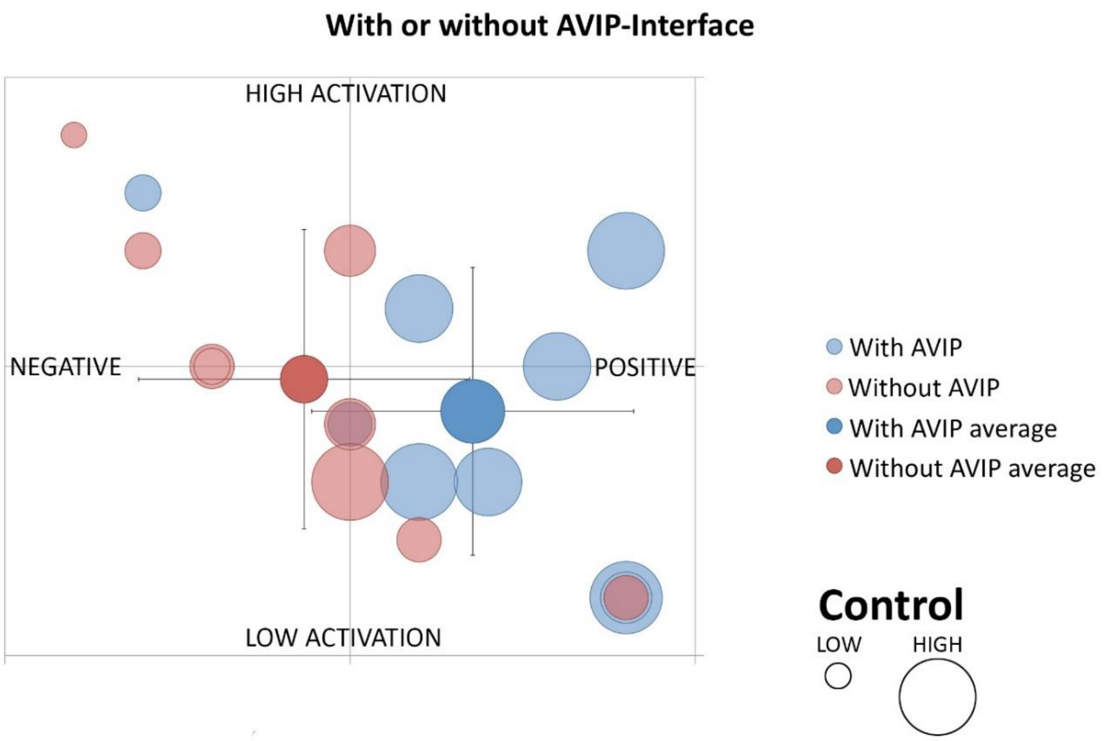


Figure 39. SAM values.

The interviews with the participants revealed also that they missed the system when it was not active, and that they felt that the AV needed something that presented its intentions.

"When it was driving itself without the system the situation becomes very weird. It is like I am losing all control. But with the communication system, when you get used to it, it was crystal clear. Then I really want to keep it."

The participants also expressed that the system did not only "replace" the eye contact with the driver, but also outperformed it, as the system provided early access information in an intuitive manner.

"From when I got to see the lights for the first time, after that I looked first at the lights and then at the driver, it was quite intuitive, I must say. I knew that I would get more information from the lights than from watching the driver in this case." (TP1)

8.2 CONCLUSIONS FROM PHASE 3

- After some basic training, subjects were to a large extent successful at decoding the AVIP external communication system, and also confident in their ability to do so.
- Automated vehicles equipped with a system such as AVIP could help decrease the crossing time of the pedestrian. That is, the AVIP system enables pedestrians to find out that an automated vehicle is yielding before they can notice any reduction in the speed of the vehicle. Vehicle speed is a cue that is commonly used today by pedestrians to predict whether they will get the priority to cross the road. Also, even when pedestrians notice reduction in a vehicle's speed, it takes some time for them to be sure that the observation is correct and that the vehicle is about to stop. This uncertainty could be reduced by a system such as AVIP. Another benefit is decreased stop time for the vehicle as the pedestrians are able to act faster.
- Pedestrians' trust in the interface must be developed in order to approach the desired design vision of a smooth and efficient traffic flow.
- For the investigated scenario, the AVIP system was experienced as a substitute for the feedback from the driver.
- The SAM result shows a pleasant experience for the AVIP-prototype. The participants were missing the system when it was not activated.
- On a final note, it can be concluded that future automated vehicles should be equipped with the AVIP, or a similar system, to facilitate a safe and pleasant communication with pedestrians. This type of system could also be applied for manually-driven vehicles to augment the communication with pedestrians. However, the current thesis has not explored this topic and the recommendation is to consider it in more detail in the future work.

9. DISCUSSION

The chapter presents a discussion regarding the results, methods and the overall process. It also addresses sustainability and ethic aspects, as well as recommendations for future work.

9.1 RESULTS

A central aspect of the work has been the role of driver contact in today's pedestrian-vehicle interaction. The study shows that eye contact plays a crucial part of the interaction in the scenario that was investigated. What the study could not clarify is the precise definition and nature of this eye contact, and if it for example could be broken down into sub-categories such as a social part and a strictly informative part. Even so, the project concluded that a first attempt of constructing an AV external communication system should focus on clearly communicating the intention of the vehicle, without attempting to explicitly mimic the "I have seen you"- part of human eye contact. Any system should be careful at communicating that it is safe to pass since this can be mistaken between multiple pedestrians or be dangerous in a context with a mix of AVs and manually driven vehicles.

It is also interesting to study the impact that the introduction of AVs will have on the essential decision making structures and mental models of pedestrians. In this project, this uncertainty resulted in the question of to what degree it is possible to base an external communication system on the established vehicle-pedestrian interaction today. With this in mind, the prototype was to some extent developed on the thoughts and needs of first encounter users.

The focus of the prototype design and the test to evaluate it has been an interaction between one pedestrian and one vehicle. Implementing this system on the large scale would require extensive exploration of system properties and specifications in order to end up in a product of best performance at an acceptable cost.

It can also be argued if today's driver-pedestrian interaction is the optimal model of achieving intuitive and effective communication between these road users. Rather, it is the case that driver contact is sought out by the pedestrian because of a lack of information, like at crosswalks without any traffic lights. The introduction of AVs could be a potential opportunity at optimizing the existing pedestrian-vehicle interaction and remedy this lack of information. An example of this is the AVIP-prototype's possibility to give early feedback, communicating the vehicle's intention before the pedestrian has even had the chance to spot any person in the vehicle.

The data showed that the phone behavior was perceived as more negative than receiving eye contact, which was confirmed by the survey. The survey data also show that both speaking on the phone and looking straight at the road does give the pedestrian the same emotional experience, and these unpleasant experiences cannot be explained by the fact that the subject was surprised by their occurrence, since test subjects expressed that they were familiar with the situation and based the behavioral response on that memory.

Instead there seems to be some underlying reason for the experienced uncomfort. One possible explanation is that the subjects in the sample group are basing their emotional response on the level of attention directed at them from the driver. When getting eye contact and the driver's full attention they feel the most pleasant and relaxed. As the driver is directing her attention on other things the level of unpleasantness and activation rises in proportion to how much the pedestrians perceive that the driver has attention left for driving safe and observing pedestrians.

9.2 PROCESS

The first part of the project summarized the existing interaction between pedestrian and vehicle and attempted to identify if there were any new requirements when introducing AVs. The second part explored the effects of implementing an external communication interface on the vehicle. A more typical design research approach would ideally have included a deeper investigation into what the requirements look like and an iteration on how they could be quantified. This meant that the design phase in the project had to be grounded in the information that was extracted from available data of Phase 1, which comes back to the fact that there are not yet any established users to do research on. With a more specific design research approach, a more extensive exploration of user goals could have been achieved as well as better knowledge of the user's mental models of autonomous products.

9.3 METHODS

The method used in Phase 1 for testing how the sample group reacted to different driver behaviors, did measure a first encounter and a surprise reaction from the participants. This could mean that the data collected to a larger extent describes how a person would react the first time of meeting an autonomous vehicle. If so, it is difficult to say how long it would take for an initial unpleasant experience to normalize.

The question of test location was also contemplated. One option would have been to use a test facility, and in the region around Gothenburg there were some options in that regard, namely Carson City, Autoliv's test facility in Vårgårda and AstaZero, a newly built test facility with focus on autonomous vehicles. Although using a dedicated test facility would give better options for controlling the tests there was a risk of not being able to recruit enough test participants to get to these facilities. Therefore another approach was chosen, to set the test as close to potential test subjects as possible. The location chosen was a lightly trafficked back alley at the Chalmers campus Johanneberg. This gave the test more flexibility to wait for optimal test conditions, which proved to be important since one of the tests that were done required sunny weather conditions.

9.4 SUSTAINABILITY AND ETHICS

The prototypes focus has been to make the pedestrian's experience in interactions with autonomous vehicles feel comfortable and safe. The design vision was also that the broader goal should been to give the pedestrians a faster and more reliable way of understanding the vehicle's intentions, and thus making pedestrians life easier.

Arguments for promoting AVs include that they would have a positive impact on an environmental as well as social level. On an environmental level the number of vehicles a city need is greatly decreased if the inhabitants share a fleet of autonomous vehicles instead of driving their own cars (International transport forum, 2015). It also opens up possibilities for a large number of people who suffer from different impairment that make them incapable to drive. These groups do often have to rely on public transportation or services provided by municipalities, and the increased independency given to these groups would increase their life quality although this requires vehicles at level four of autonomy (Anderson et al, 2014).

There are also potential problems with the introduction of autonomous vehicles, one of which is that the prize of traveling by car could be decreased to such a low amount that public transportation would struggle to compete, and this could lead to more people preferring a personal vehicle compared to public transportation, which would have a less beneficial environmental outcome (Anderson et al, 2014). There is also a safety aspect that needs to be addressed. Autonomous vehicles promises a safer vehicle which is always vigilant and with reaction times faster than possible by a human driver. But according to Dr. Šucha there is a risk that this added safety from the automotive industry to make their AVs safe would change pedestrian feeling towards their responsibility of their own safety. When the yield rate of vehicles reaches around 90-100% it has a negative impact on pedestrian safety as pedestrians become more reckless, according to Dr. Šucha.

If one agrees that the introduction of AV technology would benefit not just the driver but also the society as a whole. A positive pedestrian user experience would increase the acceptance of this new technology.

9.5 RECOMMENDATIONS AND FUTURE WORK

One aspect is the need to broaden the scope of the investigation to also address other vulnerable road users, such as cyclists, or pedestrians with special needs (e.g., elderly), as well as look at the system's interplay with other vehicles. Further investigations should also include different traffic scenarios and try out how successfully the prototype could be implemented into other types of vehicles such as trucks.

When it comes to the prototype itself, it should go through additional iterations when it comes to specifying features like the number of LEDs used and their exact color, brightness and placement. Another approach would be to make the system as slimmed down as possible, and see if it generates equal results. After this, a bigger task would be to implement the interface in a vehicle with the appropriate sensors, allowing the vehicle to control the prototype instead of the driver. The prototype can then be iteratively tested to come up with the best possible timing of the signals, and under what conditions they should be activated.

Another interesting area to explore is if the information provided from AVIP-system is should be signaled in more directions, such as the sides or behind the vehicle.

The testing of the updated prototype should be done with a larger sample of participants and with more complex scenarios, such as adding road users and a right-turn scenario. As a complement to the conducted approach, future testing should include measurements of relevant time differences, looking at the pedestrian's performance with and without the system.

Another identified aspect would be to investigate how the external communication system could incorporate sound to enhance the intuitiveness and performance of the system. The study shows that a bimodal solution would possibly create a better experience for the pedestrian, as well as work better for visually impaired users. This is also relevant since there is upcoming legislation of adding a substitute for engine sound for the otherwise more quite electric vehicles (Zeitler, 2012).

10. CONCLUSIONS

The major contributions of this thesis are: a) in-depth knowledge on how pedestrians may interact with automated vehicles, b) an external vehicle-based interface prototype addressing this interaction, and c) a method for the evaluation of such a prototype.

The results indicate that pedestrians' perceived safety might decrease when drivers' role changes from active to more passive agents in the traffic system. During automated driving, there is a possible mismatch in the signals given by the person in the driver's seat and the vehicle's behavior. This can lead to critical misinterpretation if the pedestrian makes a judgment based on the driver's behavior. The results also show that the pedestrians perceive this new driver behavior as dangerous and reckless when they are unaware that the vehicle is driving in the automated mode.

A conclusion from this is that pedestrians need additional feedback in the interaction with an automated vehicle to compensate for the loss of information due to the decoupled driver. At least, a method is needed to be able to identify a manually driven or automated vehicle, clarifying if the driver, or the vehicle itself, is responsible for the maneuvering control.

The evaluation of the AVIP-prototype shows that the interaction between the pedestrian and the automated vehicle could be improved with an external communication interface. The pedestrians were able to understand the information that was conveyed to them and the prototype helped them in the decision-making process. An additional conclusion is that this kind of interface would increase pedestrians' perceived safety when interacting with automated vehicles.

The methodology developed for testing AV-pedestrian interaction makes it possible to design, test and iterate solution for the problems that might occur when AVs are introduced to the market. The method is simple and easy to use but further development could be needed to decrease the dependency on for example appropriate weather conditions and positioning of the test participant.

On a final note, it can be concluded that there is a need for an external communication interface such as the AVIP-system. The prototype proposed in the thesis was proven to be efficient in conveying crucial information to the pedestrian. The recommendation is to further explore and evaluate this type of interface in order to make it possible for AVs to be introduced into urban traffic areas. In particular, it should be investigated if this kind of system is applicable in more complex traffic situations and if the AVIP system could improve acceptance and assurance when interacting with autonomous vehicles.

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APPENDIX 1

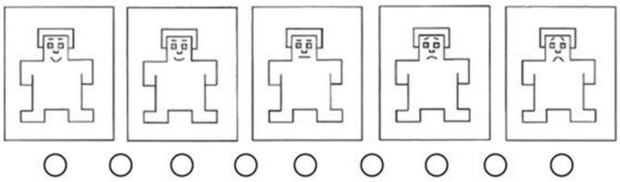
☐A ☐B ☐C ☐D ☐E

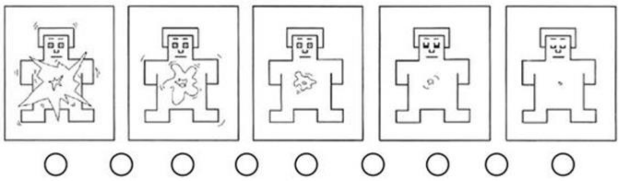
Bakgrund och syfte

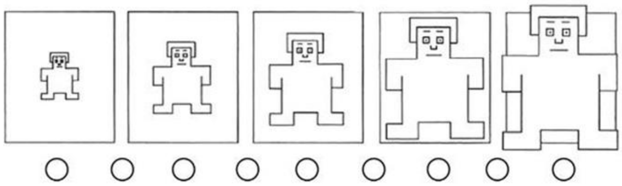
Dagens trafikmiljö blir alltmer komplex med fler aktörer på vägarna och fler möjligheter till distraktioner. Detta är ett test som undersöker fotgängarens känslomässiga upplevelse i trafikmiljön.

Scenario

Du är på promenad genom ett stadscentrum och ska precis gå över ett obevakat övergångställe, en bil har **precis** stannat och du tittar in i coupén innan du går över, hur känner du inför att gå över vägen?

Behaglig  Obehaglig

Uppspelt  Väldigt lugn

Ingen kontroll  Full kontroll

Skulle du gå över direkt?

☐ Ja ☐ Nej

Kontrolluppgifter

Kön

____

Ålder

- ☐ 18-20 år
- ☐ 21-30 år
- ☐ 31-40 år
- ☐ 41-64 år
- ☐ 65+ år

Körkort

- ☐ Inget körkort
- ☐ Under 1 år
- ☐ 1-4 år
- ☐ 5-9 år
- ☐ Över 10 år

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