DEGREE PROJECT IN INFORMATION AND COMMUNICATION TECHNOLOGY,
SECOND CYCLE, 30 CREDITS
STOCKHOLM, SWEDEN 2017

SAV2P - Shared Automated Vehicle to Pedestrian Communication

Exploring the Impact of an Interface for Shared Automated Vehicles on Pedestrians' Level of Comfort

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Abstract

With the introduction of shared automated vehicles (SAVs), a shift in the communication from driver-to-pedestrian to shared automated vehicle-to-pedestrian (SAV2P) emerges. Having no steering wheel and no responsible person in the inside of an SAV, pedestrians might feel uncomfortable in crossing the street in front of an SAV. To study future communication needs between pedestrians and SAVs, an interface that communicates intentions of SAVs to pedestrians was designed and implemented in a virtual reality (VR) environment. This enabled the exploration of behaviors and experiences of 34 pedestrians when encountering SAVs, both with and without the interface, in several street crossing situations. In a within subject design, all participants assessed the level of perceived safety and comfort in crossing the street encountering the SAV with the SAV2P interface on and off.

This master thesis comprises four phases: 1) requirement analysis, 2) conceptualization and design of an interaction concept, 3) development of an SAV2P interface & a VR environment, and 4) utilization of the VR environment in a user study to investigate the impact of the SAV2P interface on pedestrians' perceived safety and comfort when interacting with SAVs.

The results from the user study show that participants have a high level of confidence in understanding the SAV2P interface and indicate that they prefer to have an interface that is communicating the intentions of the SAV. The pedestrians' level of perceived safety and comfort is higher in encounters of the SAV with the SAV2P interface than in encounters without the interface. This may have a positive influence on the acceptance of SAVs, and implies that future SAVs may gain from this, or similar, interface.

The major contributions of this work encompass: a) knowledge of how pedestrians may interact with SAVs, b) an SAV2P interface prototype that addresses this interaction, c) a VR environment to test interactions between pedestrian and SAVs, and d) a test procedure and method to evaluate an interface prototype in VR.

Future work raised by this thesis project includes the conduction of additional research studies that study more traffic situations, interaction designs and a more heterogeneous participant group. Furthermore, a next step may be the improvement of the VR environment (robustness, quality and control) and to find out in which cases VR is an appropriate method to study interactions.

Keywords: Behavior studies; exterior interaction; HCI; interaction concept; pedestrian; Shared Automated Vehicles; user study; virtual reality.

Sammanfattning

Genom lanseringen av gemensamma självkörande fordon (SAV), uppstår ett kommunikationsskifte från förare-till-fotgängare till gemensamma självkörande fordon-till-fotgängare(SAV2P). Att varken ha bilratt eller ansvarig person inuti en SAV, kan få fotgängare att känna sig obekväma när de korsar gatan framför en SAV. För att kunna studera kommunikationsbehov mellan fotgängare och SAVs, har ett gränssnitt som kommunicerar SAVs avsikter med fotgängare utformats och implementerats i en virtuell reality-miljö. Detta har möjliggjort utforskandet av 34 fotgängares beteenden och erfarenheter vid mötande av SAVs, både med och utan gränssnitt, i flera gatukorsningssammanhang. I en ”within subject”-design, fastställer alla deltagare sin komfort- och säkerhetsuppfattning vid möte av en SAV med SAV2P-gränssnittet på och av när man korsar gatan.

Den här masteruppsatsen omfattar fyra faser: 1) kravhantering, 2) föreställning och utformning av ett interaktionskoncept, 3) utvecklande av ett SAV2P-gränssnitt & en VR-miljö, och 4) användadet av VR-miljön i ett användbarhetstest för att utreda påverkan av SAV2P-gränssnittet för fotgängares säkerhets-, och komfortuppfattning när de integrerar med en SAV.

Resultatet från användbarhetstestet visar att deltagare har en hög förtroendenivå när det gäller förståendet av SAV2P-gränssnittet och pekar på att de föredrar ett gränssnitt som kommunicerar SAV-fordonets intentioner. Fotgängares nivå för komfort-, och säkerhetsuppfattning är högre vid möten av SAV-fordon med ett SAV2P-gänssnitt än möten utan gränssnittet. Detta här kan ha positiv påverkan när det gäller accepterandet av SAVs, och menar på att framtida SAVs, eller liknande gränssnitt, kan vinna på detta.

Majoriteten av medverkan av detta arbete omfattar: a) kunskap om hur fotgängare kan interagera med en SAV, b) ett SAV2P-gränssnittsprototyp som riktar in sig på interaktionen, c) en VR-miljö som testar interaktionen mellan fotgängare och SAVs, och d) en testprocedur och metod som utvärderar en gränssnittsprototyp inom VR.

Framtida arbeten uppstartad av denna uppsats medför överföringen av ytterligare forskning som studerar fler trafiksituationer, gränssnittsutformning och fler heterogena deltagargrupper. Dessutom, ett nästa steg kan vara att förbättra VR-miljön (kraft, kvalitet och kontroll) och att ta reda på i vilka fall VR är en lämplig metod för att studera interaktioner.

Nyckelord: Betendestudier; yttre interaktioner; MDI; Interaktionskoncept; fotgängare; Shared Automated Vehicles; användbarhetstest; virtual reality.

Preface

This thesis represents the final degree project for the fulfillment of a Masters Degree in Human Computer Interaction and Design in a double degree program at KTH Royal Institute of Technology, Stockholm (Sweden) and at the University of Twente, Enschede (The Netherlands). The double degree program is offered in cooperation by the European Institute of Innovation & Technology (EIT) and encompasses a Minor Degree in Innovation Management & Entrepreneurship.

The research has been conducted in conjoint with the Integrated Transport Research Lab (ITRL) and the Research Institutes of Sweden (RISE) Viktoria Gothenburg. The supervision of the project from ITRL is done by Anna Pernestål Brenden and from RISE Viktoria by Maria Klingegård. The academic examiner from KTH is Konrad Tollmar from the department of Information and Communication Technology (ICT).

Parts of this research have been accepted as a Work-in-Progress paper in the Adjunct Proceedings of the AutomotiveUI 2017 ACM International Conference under the title *SAV2P – Exploring the Impact of an Interface for Shared Automated Vehicles on Pedestrians' Experience.*

Acknowledgment

> ”I think that all cars will go fully autonomous in long-term. I think it will be quite unusual to see cars that don't have full autonomy, (...) it will be like owning a horse. You will only be owning it for sentimental reasons.”
>
> – *Elon Musk*

This thesis has presented me challenges and opportunities for interesting research, and I would like to take the opportunity to express my gratitude to all the people that I have met along the way. Without you, this work would not exist.

First of all, I would like to especially thank my main supervisors, Anna Pernestål-Brenden & Maria Klingegård, for their endless support during the whole research project. This includes long vital discussions on my research topic that went even into different time zones. In addition, I would also like to acknowledge Azra Habibovic with her enduring commitment to discussions and improvements of my work.

To my examiner, Konrad Tollmar, for the kind and understanding spirit during our progression meeting and for taking the time and responsibility evaluating this work.

Een speciale 'dank je wel' gaat naar mijn vriend, gang- en werkmaat Martijn Bout voor Nederlandse Stroopwafels (ik hou van ze!) en voor talloze uren van fundamentele discussies over zowel onze onderwerpen als momenten van gedeelde frustratie .

Merci beaucoup a Valentine Creusel pour l'aide à la conduite de mon étude utilisateur et pour m'avoir aidé à manger mes biscuits.

An meine Familie, ohne euch als Inspiration wäre ich nicht halb so stark und ausdauernd! An meine Schwester Anne-Kathrin und an meine geliebten Eltern! Ich bin zutiefst dankbar an euch, ihr habt mich immer in meinen Entscheidungen unterstützt und wart da, wenn ich euch gebraucht habe!

Thanks to Alexandr Emelianov for providing me with 3D SAV models for my work.

—Marc-Philipp Böckle
Stockholm, August 2017

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Acronyms

AV	Automated Vehicle
HCI	Human Computer Interaction
HMD	Head-Mounted Display
ITRL	Integrated Transport Research Lab
SAV2P	Shared Automated Vehicle to Pedestrian
SAV	Shared Automated Vehicle
UCD	User-centered Design
VRU	Vulnerable Road Users
VR	Virtual Reality

Chapter 1

Introduction

This chapter first introduces the background, the motivation and the goal of this master thesis project. Besides, the problem area and -statement, the proceeded research question, respectively the related hypothesis are detailed. Last, a sustainability perspective on the topic and an overview of the document structure is given.

1.1 Background & motivation

The introduction of automated vehicles (AV) is a major interest for governments, manufacturers and researchers in the automotive domain (Frisoni *et al.*, 2016). Among others, a potential increase of traffic safety, improved land use and a higher accessibility are reasons for vehicle automation. Nowadays, our cities are full of: vehicles using many parking space and traffic jams polluting the environment, causing a huge loss of time for commuters just as for the people taking their private vehicle to get around in an urban area (Penzenstadler *et al.*, 2014; Statista, 2014). To address these challenges as well as bring advantages in safety, AVs bring new opportunities for future public transport and mobility. However, with the introduction of AVs, a higher traffic density is predicted caused by an increased travel demand in general, and improved accessibility for new user groups such as elderly, young- and disabled people (Frisoni *et al.*, 2016). Therefore, to tackle the future transportation challenge, sharing as a paradigm shift will be necessary and the establishment of shared automated vehicles (SAVs) as a part of the public transport system, is a vital step for the prospective urban mobility. According to the Automated Driving Roadmap by ERTRAC (2015), the first solutions of highly automated (SAE level 4 (SAE, 2016)) SAVs in an urban context, which are not running on dedicated streets, will be deployed starting from the year 2022. These vehicles will operate on streets with mixed traffic and therefore need to interact with other road users, such as pedestrians.

Research on vulnerable road users (VRUs) interacting with AVs (Matthews, 2016; Lundgren *et al.*, 2016) and SAVs (Alessandrini and Mercier-Handisyde, 2016; Rodriguez *et al.*, 2016) provide the first insights of pedestrian to vehicle communication and the users' preferences of modalities for specific driving situations (e.g. the vehicle starts moving). To investigate the AV-to-pedestrian communication, prototypes of communication interfaces were built (Lagström and Malmsten Lundgren, 2015; Matthews, 2016). Despite, to the author's knowledge, no research has been conducted that includes SAVs using an interface examining the shared automated vehicle-to-pedestrian (SAV2P) communication. As from communication perspective, SAVs do not have any driving responsible person in the inside of the vehicle and the vehicle form factor is different compared to AVs, more research is needed. Hence, to further investigate the communication between SAVs and pedestrians, the user-centered design of an Human Computer Interaction (HCI) concept, including the ensuing development of a prototype, is part of this work.

The first tests with SAVs have started (Frisoni *et al.*, 2016), however, the barrier to research the SAV2P communication with real vehicles is at the current stage very high as it is costly and time consuming. One factor is the immense costs to perform experiments caused by a low availability of SAVs and the long legislative process to allow tests. Secondly, it is difficult, costly and time consuming to build a hardware prototype of an interface that fits into the design of an SAV. Third, real world tests are not easily repeatable as environmental factors can lead to different results (ADDREF!!!(Fox *et al.*, 2009)). Several of those challenges were encountered in this master thesis project. Initially, a research study involving real vehicles in Kista was planned to be performed, as in May 2017, as part of the Test Site Stockholm – Autopiloten project[1], two EasyMile EZ10s should have started driving a pre-determined route on the public road in Kista (Stockholm, Sweden). However, the project Autopiloten got delayed several times due to legislative issues and therefore a new way of studying the SAV2P communication had to be found. For the mentioned reasons, a new approach of testing the SAV2P communication in a Virtual Reality (VR) environment was chosen in this research project.

1.2 Problem area & statement

In a study by Šucha (2014) the majority of pedestrians (84%) are seeking for eye contact with car drivers when they are indicating their intention to cross a road at a zebra crossing. Pedestrians are using active (gestures)- and passive signals such as distance or walking speed to communicate their intentions towards the driver of a car (Lundgren *et al.*, 2016; Maurer *et al.*, 2016). Without a steering wheel and any person responsible on board of an SAV, pedestrians must get feedback from the SAV itself to improve the understanding of the vehicles intentions and replace the seek for an eye contact (Merat *et al.*, December 2016).

A bi-directional communication should be performed, otherwise deadlock situations might occur as a cause of the discarded communication between pedestrian and vehicle. A deadlock situation describes a situation in which neither the SAV

[1]Drive Sweden – Test Site Stockholm. Accessed on 11.April 2017: `http://www.vinnova.se/sv/Resultat/Projekt/Effekta/2015-07014/Drive-Sweden-Test-Site-Stockholm/`

nor the pedestrian will move. Such a deadlock situation could occur when the SAV will most probably be designed in a risk averse way and the pedestrian might feel uncomfortable in crossing the street in front of the vehicle. Especially, in the introduction phase of such vehicles, not all pedestrians might know the capabilities of an SAV (Sivak and Schoettle, 2015) and feel unsure, as there is no responsible driver nor a physical steering wheel in the inside of the SAV, which can higher the chance of deadlock situations (Millard-Ball, 2017).

In contrast, this could also lead to the fact that pedestrians, knowing that the SAV will stop for humans, might behave with impunity stepping in front of the SAV and overestimate the physical capabilities (e.g. breaking and accelerating) (Millard-Ball, 2017). This can lead to a serious risk of injury, as there will be situations in which the SAV is physically not capable of breaking in time (Sivak and Schoettle, 2015).

To enable the goal of future transportation with the utilization of SAVs, pedestrians are one group which must feel comfortable and trust the novel technology of SAVs. As the communication is shifting from driver-to-pedestrian to SAV2P (see Figure 1.1), research is necessary in terms of, how HCI can enhance the SAV2P communication so that the pedestrian receives the driving status and is able to interpret how the vehicle is driving and acting. Thereby, the SAV2P communication must lower the possibility of deadlock situations with a clear acknowledgement and intention signalization. Furthermore, to increase the acceptability of SAVs as a new type of road user, the cognitive biases (e.g. the technology is ready and safe to use) about the usage of SAV services must be overcome (Pankratz *et al.*, 2017).

Research is necessary as there is no known interface existent that can be used to investigate into the SAV2P communication.

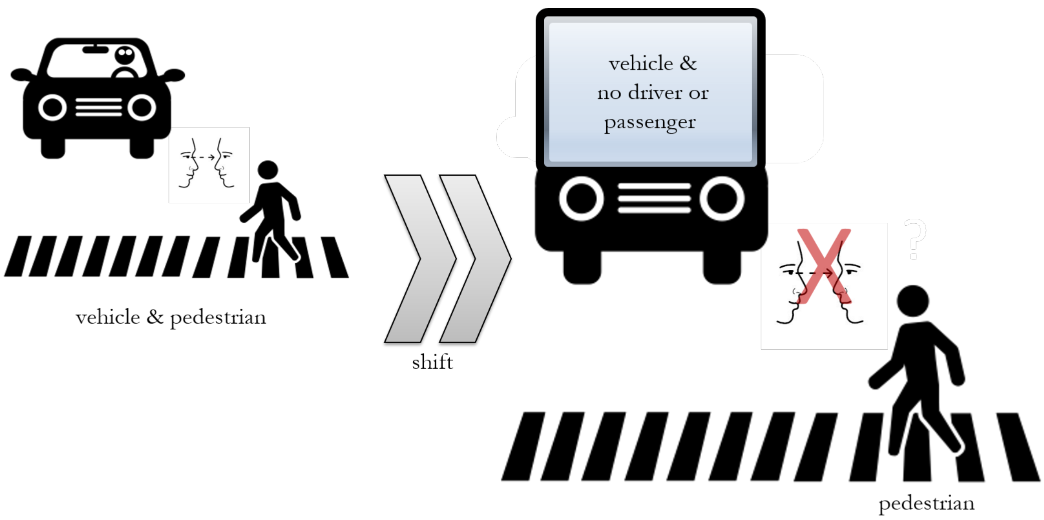


Figure 1.1: Shift from driver-to-pedestrian towards SAV2P communication.

1.3 Hypothesis

SAVs will need to co-exist with other road users, and must be able to interact with them in a safe and smooth manner. Hence, to avoid deadlock situation, in the field of robotics (Hancock *et al.*, 2011; Chadalavada *et al.*, 2015), and in recent studies on interactions between automated vehicles and pedestrians (Lundgren *et al.*, 2016), it has been shown that this can be achieved by letting all agents clearly communicate their intentions to each other. Given that SAVs will not have a driver who actively communicates with surrounding road users by means of, for instance, eye contact and body posture, these vehicles may require new communication means.

Therefore, it is hypothesized that the provision of an SAV2P interface that enables and enhances the communication between SAV2P, leads to an increased level of perceived safety and comfort in crossing the street for pedestrians. Additionally, this might lead to a higher acceptability and attractiveness of SAVs as it optimizes its usability (Hoff and Bashir, 2015; Merat *et al.*, December 2016) and lower the chance for deadlock situations.

1.4 Goal & research questions

The goal of this master degree project is to investigate, if an SAV2P interface can enhance the communication between SAV2P and thereby increase the perceived safety and comfort in crossing the street for pedestrians. This comprises the steps: *a) to identify which user requirements are present for the SAV2P communication.* Based on these findings, *b) to create an interaction concept, c) to design and develop a prototype of the interaction concept as an interface* and last, *d) to evaluate the interface and find out which impact it has on the SAV2P communication.*

More specifically, the following research question has been identified:

– *How will pedestrians be affected by the introduction of an interaction concept within the context of SAV2P?*

To answer this research question – two sub-questions must be answered first:

a) *How can an SAV2P interaction concept look like?*, and
b) *Does the introduction of an interaction concept increase the level of comfort for the pedestrian in a crossing situation?*

Level of comfort – The level of comfort is defined as the willingness to cross the street and the perceived safety of the pedestrian.

Research questions connected to hypotheses
The following hypotheses are investigated related to the research question:

a) The interface uses auditory and visual communication modalities to show the intentions of the SAV towards the pedestrian.

b) H_0: There is no difference in the level of comfort of crossing the street
H_1: There is a difference in the level of comfort of crossing the street

Dependent variables	comfort
Independent variables	SAV2P interface (switched on vs. switched off)
Further variables	demographics, driving situation, auditory- and visual modalities

1.5 Aspect of sustainability & ethics

This master degree project aims for the target to fulfil the codex, rules and guidelines for research, implemented by the Swedish Government in the Higher Education Act (Högskolelagen)[2]. Thereby, the work shall: "support a sustainable development that creates a good, healthy environment for this and future generations, economical and social welfare and justice" (ibid.). As the successful introduction of AVs and SAVs is a vital step for a prosperous future mobility, this work tries to contribute for that purpose in the area of HCI.

This research is carried out with humans as test participants in the center of the research, therefore an additional ethical perspective has to be considered that is described in the research methodology (see Chapter 3.1).

1.6 Delimitations

The user study would in the best case, be performed in a real traffic situation on a street, using an SAV equipped with a hardware prototype of the SAV2P interface. Due to the lack of an available SAV, the user study was performed in a simulated VR environment. In the VR environment the participants might not be fully immersed and therefore, might change their behavior in a real street environment.

The traffic situations addressed in the user study are limited in terms of variety. Only one specific environment of crossing the street at an unsignalized zebra crossing is part of the research. Furthermore, no other VRUs were part of the VR environment and there is a low amount of ongoing traffic.

The target of this research is to enable investigations into the interaction between SAV and pedestrian. Thereby, the focus did not lay on presenting a final interface design.

[2]Codex – The humanities and social sciences. Accessed on 1.March 2017: `http://www.codex.vr.se/en/forskninghumsam.shtml`

1.7 Structure

This document is split into three parts (see Figure 1.2): *introductory part, main part* and *discussion*.

The *introductory part* introduces the reader into the background information and points out the motivation, as well as the problem area and statement of the master thesis. Furthermore, the goals and the related research questions are highlighted with the respective hypothesis. The first chapter ends with a short note on the aspect of sustainability & ethics and this structure overview. The second chapter, the *theoretical framework*, consists of a definition of SAVs, including the SAE levels of driving automation, besides, concept vehicles are presented, exposing possible ways to design the SAV2P interface. Last, HCI related works of AV-to-pedestrian communication and the application of VR environments are detailed. The third chapter concludes the introductory part with the *research methodology*.

The *main part* compounds the four phases *requirement analysis, concept generation, prototype development* and *user study*. In chapter four, *requirement analysis*, requirements are gathered through means of literature review, field studies and expert interviews. Those requirements and insights are translated in the second phase, *concept generation* (Chapter 5), into an HCI concept. Based on the concept, the *prototype development* will be performed (Chapter 6), and last, in chapter seven, the *user study*, consisting of study setup, conduction and results, is detailed.

The final part, *discussion*, concludes the work in giving the research results, aspects on sustainability and ethics, a reflection on the research process and used methods and a prospect for future work.

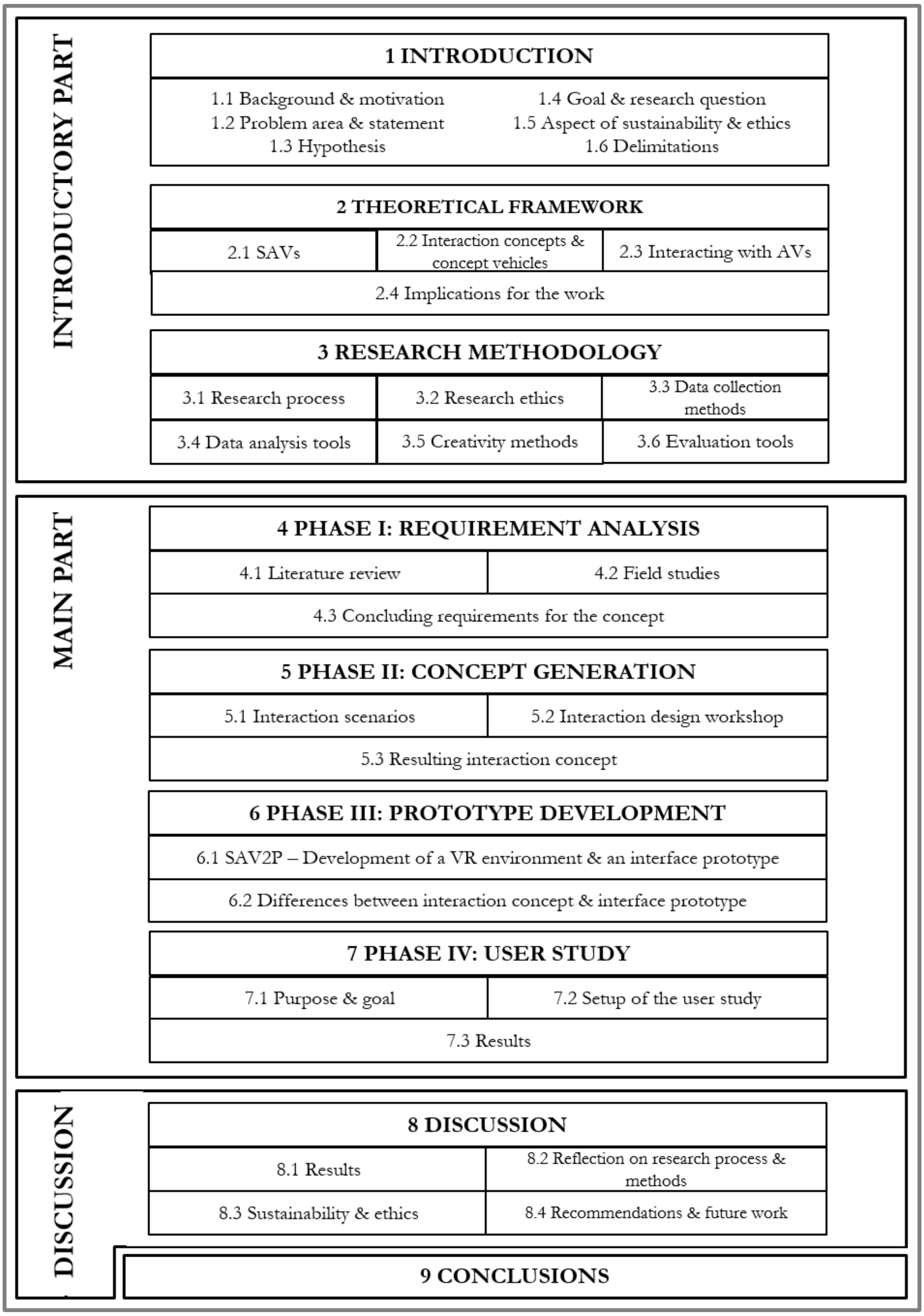


Figure 1.2: Thesis structure.

Chapter 2

Theoretical framework

This chapter introduces the topic of vehicle automation, listing the levels of driving automation by the SAE and outlines the current state and future scenario of SAVs on public roads. Moreover, interaction concepts for vehicle-to-pedestrian communication are presented as well as concept vehicles and prototypes. In the last section of this chapter, HCI related work on interaction within the field of AVs is outlined.

2.1 Shared Automated Vehicles (SAVs)

2.1.1 A definition of the terminology

The term SAV includes the sharing aspect of AVs and is related within the context of this work with a shuttle or "pod" that carries around six to sixteen people. It is a commercial vehicle that complements the public transport system. There is no explicit definition of an AV in literature. However, organizations like the German Federal Highway Research Institute BASt (Die Bundesanstalt für Straßenwesen, 2012) and the Society of Automotive Engineers (SAE) (SAE, 2016) have developed frameworks to specify and differentiate between levels of driving automation. The specifications on the different automation levels by the SAE are detailed in the next section 2.1.2.

Technically, SAVs use sensors such as cameras, lidar, ultrasonic, stereo cameras and positioning systems such as GPS and high resolution maps to sense the environment, determine the exact position of the vehicle and autonomously navigate (Maurer *et al.*, 2016).

Compared to AVs, SAVs are mostly allocated for the public and not equipped with a steering wheel, gas- and brake pedals. This changes the role of the persons in the vehicle from an active driver perspective to a passive passenger role at all times of the ride (Merat *et al.*, December 2016).

2.1.2 Levels of driving automation by SAE

Several levels of driving automation exist in between the full-manual drive of a vehicle, assisted driving and the fully autonomous driving operation. A taxonomy and standard on the different levels of vehicle driving automation was worked out by the global expert and engineering association for automotive SAE in their document J3016 (SAE, 2016). The SAE standard is split into six different stages of automated driving from level 0 to 5, illustrated in Table 2.1. SAVs have no steering wheel and no human driver, in this work, an SAV is considered to be at least a level 4 to level 5 vehicle (marked red in Table 2.1). This means that it is capable of performing all critical driving functions fully autonomously, without the necessity of a human having to monitor the driving activities or intervene at any time during the ride.

SAE level	Name	Narrative Definition	Execution of Steering / Ac-/ Deceleration	Monitoring of Driving Environment	Fallback / Performance of Dynamic Driving Task	System Capability
0	No Automation	Full-time performance by human driver of all aspects of the dynamic driving task, even in enhanced driving by warning or intervention systems	Human driver	Human driver	Human driver	n.a.
1	Driver Assistance	Driving mode specific execution by a driver assistance system (either steering or ac-/deceleration) using information about the driving environment, human driver performs all remaining aspects of the dynamic driving task	Human driver & system	Human driver	Human driver	Some driving modes
2	Partial Automation	Driving mode specific execution by one or more driver assistance systems of both steering and ac-/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving	System	Human driver	Human driver	Some driving modes
3	Conditional Automation	Driving mode specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	Human driver	Some driving modes
4	High Automation	Driving mode specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some driving modes
5	Full Automation	Full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	All driving modes

Table 2.1: SAE taxonomy and levels for driving automation. Retrieved from https://www.sae.org/misc/pdfs/automated_driving.pdf. Copyright [2014] by SAE International.

2.1.3 SAVs on public shared & non-shared road space

The general concept of SAVs is not a recent innovation. Since 2006, there is a fleet of SAVs running in an urban context as a park shuttle in the Dutch city of Capelle aan den Ijssel[1]. However, the SAVs are running on limited and dedicated routes and therefore, do not share public roads with other vehicles or VRUs. The

[1] Source: `http://www.2getthere.eu/projects/rivium-grt/`

implementation was done by the Dutch company 2getthere. A method to accurately navigate the SAVs on a pre-determined route with the help of magnets built into the road surface that enables a high reliability for navigation is used (S. van der Zwaan, CTO of 2getthere, personal communication, February 28, 2017). As the route is only frequented by the park shuttle, there is no direct interaction happening between the vehicles and pedestrians, apart from passengers entering and exiting the vehicle through gates. The in-built sensors are distance sensors that make the vehicle stop in case of an animal or an object is blocking the route.

Figure 2.1: SAV – Easymile EZ10 (WEPods – Wageningen). Photo by author.

In contrast to that, the future of transportation is that SAVs share the same road space with AVs, manually driven cars and VRUs to fully evolve their potential. As part of the European funded project City2Mobil (operation from 2012 to 2016), in total 32 SAVS, produced by Easymile (EZ10, see Figure 2.1) and Robosoft, were running in an urban context on dedicated routes, partly sharing the same road space with other manual driven cars and VRUs (Alessandrini and Mercier-Handisyde, 2016). Seven cities (Oristano, Italy; La Rochelle and Sophia Antipolis, France; Vantaa, Finland; Lausanne, Switzerland; Trikala, Greece; Donostia/San Sebastián, Spain) participated in which the SAVs carried over 60.000 passengers covering a total distance of 26.000 kilometers. The SAvs with a capacity of up to 12 passengers (6 seating and 6 standing) were equipped with sensors for localization and obstacle detection. A steward in the inside of the vehicles constantly monitored all driving activities of the SAV for liability reasons and was able to take over in case of emergency.

Figure 2.2: SAV – Local Motors Olli. Photo by Deutsche Bahn AG.

Olli (Figure 2.2) is another SAV implementation built by the US start-up Local Motors with the focus of providing an artificial intelligence to communicate with its passengers with the help of the IBM Watson platform. It offers seats for 12 people and can drive up to 20 km/h. Several parts of the vehicle are 3D printed.[2] Since beginning 2017, the SAV is driving on a route in a quiet industrial area on a research campus in Berlin-Schöneberg. The project is run by the Deutsche Bahn and plans are mentioned to raise the number of used Olli vehicles up to 50 in 2017.[3] The SAV is running eight hours, every weekday, from 9:00 till 5:00.

[2] Source accessed on 3.April 2017 from: `https://localmotors.com/meet-olli/`

[3] Source accessed on 10.May 2017 from: `http://www.abendblatt-berlin.de/2017/01/04/olli-faehrt-selbst/`

Figure 2.3: SAV – Arma by Navya. Photo by Navya.

The French company Navya provides with Arma[4] an SAV that offers a capacity for up to 15 people. At the current stage it is operating on closed road sites only but it is technically prepared for an operation on public roads.

To summarize the aspect of SAV2P communication for the presented SAVs, there are no considerations of using an interface or means of external communication to show the intentions of the SAV towards the surrounding pedestrians or other VRUs.

2.2 Interaction concepts & concept vehicles for vehicle-to-pedestrian communication

Manufacturers, researchers and designers have created concept vehicles and interface prototypes to show how a future communication between pedestrians and AVs could be performed. The concept vehicles and interaction concepts presented in this section serve as an input for the SAV2P interface in this thesis project. The list of concepts is not complete but shall give an impression and examples of the current state of the art. In the following, the concepts are split into *research concepts* & *design concepts* highlighting the difference between concepts that give research details and design studies that are not further evaluated or the insights on the research are inaccessible and therefore elusive.

2.2.1 Research concepts

Research concepts encompass concepts from RISE Viktoria, Semcon and MIT.

AVIP & concepts from RISE Viktoria

The Swedish research institute RISE Viktoria (former Viktoria Swedish ICT) created several concepts on how an interface between AV and pedestrian could look like. The concepts can be categorized into visual, auditory and others (infrastructure, gestures and wearables).

Visual concepts include that the vehicle is communicating its intentions with the help of an LED matrix that is built into the front grill. The velocity of the car is represented with the movement of lines like an airflow on the LED matrix and

[4]Source accessed on 8.May 2017 from: `https://navya.tech/wp-content/uploads/2015/09/NavyaPressRelease.pdf`

rests if the vehicle is standing still. Further, the LEDs follow pedestrians walking in front of the vehicle. Two additional concepts incorporate: an LED windshield for communication and a laser projection in front of the vehicle, showing the point where the vehicle is going to stop.

One concept of RISE Viktoria is the master thesis project automated vehicles' interaction with pedestrians (AVIP) by Tobias Lagström and Victor Malmsten Lundgren that was realized as a prototype (Lagström and Malmsten Lundgren, 2015). An external communication device consisting of a LED strip with 60 single addressable LEDs was mounted on the top of the windshield and programmed to show four different driving states (automated driving mode, yielding, resting, start moving), see Figure 2.4.

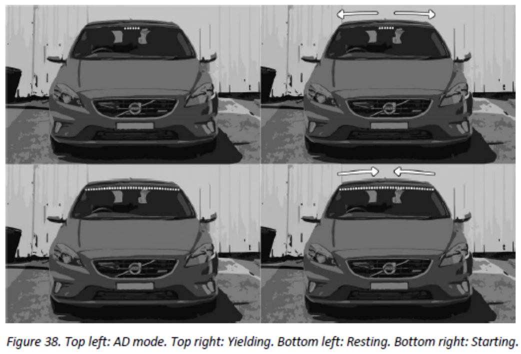


Figure 2.4: AVIP – Driving modes (Lagström and Malmsten Lundgren, 2015, Figure 38).

Semcon – Smiling Car

Semcon created together with Rise Viktoria the concept Smiling Car[5] which is a vehicle concept with the goal to communicate the message, when it is safe/not safe to cross the street, towards pedestrians. As named Smiling Car, the vehicle is showing a curved line that represents a smiley when the car is waiting for the pedestrian to cross. It is displayed on a LED matrix, built into the front grill. A horizontal line indicates that the vehicle is about to start moving again and the pedestrian must wait (*see* Figure 2.5).

Figure 2.5: Semcon – Smiling Car. Photo by Semcon.

[5]Source accessed on 10.March 2017 from: `https://semcon.com/smilingcar`

2.2.2 MIT – AEVITA

AEVITA is a research system investigating the vehicle-pedestrian communication by the Massachusetts Institute of Technology (MIT). The concept vehicle is a 1/2-scale vehicle, featuring advanced mixed-materials (CFRP and Aluminum) and has a significantly modularized architecture. The vehicle reacts depending on the environmental sensed data (Pennycooke, 2012). It uses light and sound to communicate with pedestrians. A color change of the wheels indicates the proximity of the pedestrian and the headlights move according to the pedestrians' movement to establish an "eye-contact" (Pennycooke 2012, p.84). The vehicle can transform its appearance with a folding joint mechanism and is able to communicate in different body language system combinations such as e.g. an aggressive, in which some mechanical parts of the vehicle move quickly, or a submissive mode. The vehicle is displayed in Figure 2.6.

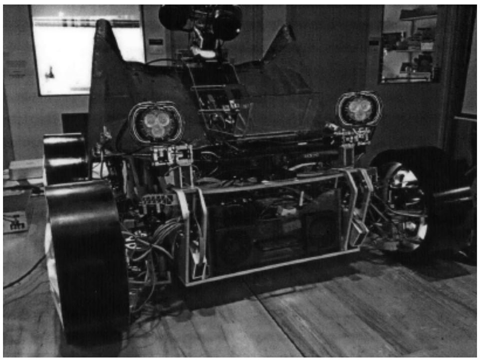


Figure 2.6: MIT – AEVITA concept vehicle. Photo by Pennycooke, 2012).

2.2.3 Design concepts

Design concepts include concepts from Mercedes Benz, Audi, Royal College of Art and Imperial College London and Leonardo Graziano.

Mercedes Benz – Luxury in Motion

Mercedes Benz developed the concept vehicle called Luxury in Motion – F015 (Mercedes Benz, 2015). The vehicle is part of the CASE strategy of Mercedes; CASE stands for: connected, autonomous, shared & service and electric drive. The vehicle shows several different ideas of how an AV could communicate with their surroundings with a focus on pedestrians. As Mercedes wants the owner (private owned) to decide if he/she wants to drive manually, there is a steering wheel on board that can swing out. In automated driving mode, the vehicle's LEDs light up in blue (see left image in Figure 2.7), and in white when the vehicle is driven manually.

In the case of a pedestrian that wants to cross the street, the concept vehicle shows an undulating light sequence on the LED communication display that is embedded into the front grill, to indicate that the vehicle is waiting for the pedestrian to cross, illustrated in the center picture in Figure 2.7. The LEDs move together with the pedestrians' position and more or less LEDs light up depending on the distance between vehicle and pedestrian. Meanwhile, on

Figure 2.7: Mercedes F015 – Pedestrian communication (1). Photos by Mercedes Benz.

the rear side of the F015 vehicle, the lower LED display indicates for the road users behind the vehicle that on the side where the pedestrian is crossing to, should not be overtaken. Additionally, a graphical representation of the pedestrian with her/his current position in front of the vehicle is displayed with red dots (*see right picture in* Figure 2.7).

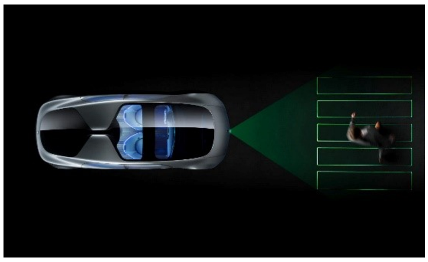


Figure 2.8: Mercedes F015 – Pedestrian communication (2). Photo by Mercedes Benz.

Furthermore, the concept vehicle can project laser messages, likewise an animated zebra crossing on the road surface (see Figure 2.8) and provides verbal communication to the pedestrian via audio signals. (researcher of Mercedes Benz, personal communication, March 3, 2017).

Audi – Light concept the swarm

Audi shows in the rear light concept the swarm[6] with the help of an OLED screen stretching over the whole rear side of the vehicle (see Figure 2.9), different visualizations for the cars' actions. Tiny points of light flicker on the OLED like a swarm of bees indicating the velocity of the vehicle and white lines showing in which direction the steering wheel is pointing towards.

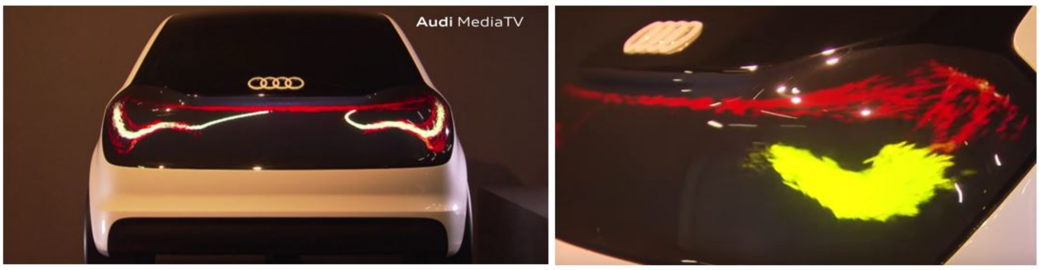


Figure 2.9: Audi – Light concept the swarm.

[6]Source accessed on 10.March 2017 from: `https://www.audi-mediacenter.com/en/audimediatv/video/audi-future-lab-footage-the-swarm-2283`

Leonardo Graziano – AutonoMI

AutonoMI[7] is an interface developed for AVs by Leonardo Graziano at the ISIA Roma Design Institute. The concept compounds the outside communication between vehicle and pedestrian. It uses a light indication that is moving in conjoint with the pedestrians' movement in front of the vehicle to communicate that the vehicle noticed the pedestrian, displayed in Figure 2.10.

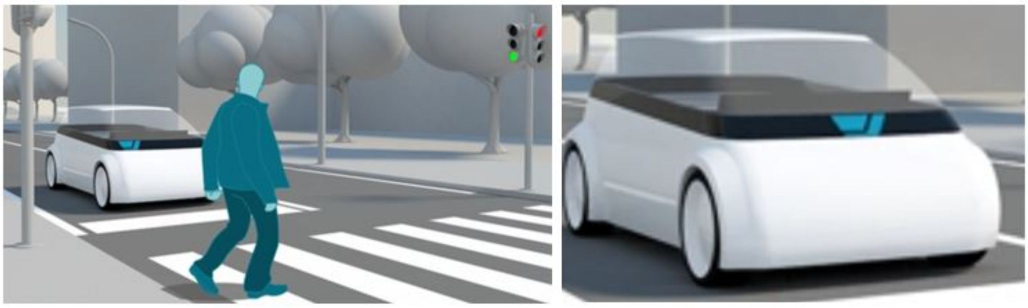


Figure 2.10: AutonoMI – An AV interface for passenger and pedestrian communication.

Blink – A language for autonomous vehicles

Blink[8] is the vision of a communication language for AVs created by researchers at the Royal College of Art and Imperial College London. The concept integrates four OLED displays, two into the windshield and two in the rear window at each corner of the vehicle, using different light signals to show pedestrians when the car recognized them and is aware of their presence. When a pedestrian is detected, a silhouette of a person is projected that mirrors the movements of a pedestrian, accompanied by short sounds. To interact with the vehicle, the pedestrians can raise their hand to communicate a stop sign towards the vehicle, see left side in Figure 2.11. After that, the silhouette turns green, and the car is stopping. To let the car continue driving, the pedestrian moves one hand out to the side, the silhouette displayed on the OLEDs turns red and the vehicle continues moving again, illustrated in the right part in 2.11).

[7]Source accessed on 10.March 2017 from: `http://www.leonardograziano.com/pro_05.html`
[8]Source accessed on 10.March 2017 from: `https://www.humanisingautonomy.com/`

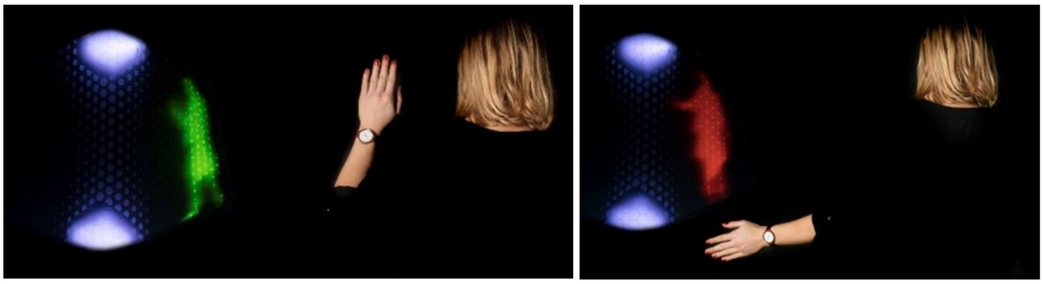


Figure 2.11: Blink – A language for autonomous vehicles.

2.3 Interacting with AVs

HCI research in the field of AVs has been in an interest in the research community and stays an important topic as technology advances (Ohn-Bar and Trivedi, 2016). Ohn-Bar (ibid.) is giving an overview of human centric related research studies including humans in the vehicle, humans around the vehicle and humans in surrounding vehicles. This research project focuses on HCI between SAV and pedestrian. However, research conducted in the field of HCI for VRUs that includes pedestrians is mainly focused on the further development of technology on automated driving (e.g.: recognition of pedestrians' intention, path prediction, behavior analysis and pattern classification) than on the perception of the pedestrian to interact with the SAV.

There are different research approaches to study the communication between AVs and pedestrians. In their master thesis on autonomous vehicles' interaction with pedestrians, AVIP (Lagström and Malmsten Lundgren, 2015), a real environment experiment, using a prototype that consists out of a LED strip, showing the intent of the vehicle, was setup. Matthews (Matthews, 2016) also created an interface, calling it Intent Communication Interface (ICS) using LEDs, an LED matrix and speakers on a golf cart to study the behavior of AVs and pedestrians. Additionally, a Markov Decision Process (MDP), was used to simulate the behavior of pedestrians interacting with an AV in a first experiment.

2.4 Implications for the work

To conclude, the gap between SAV and pedestrian research has to be closed in shifting the focus of HCI research on studying the communication behavior and interactions between SAV and pedestrians. All concepts, research as well as design concepts, presented in this chapter, facilitate a base for the state of the art research in phase I (see Chapter 4.1) and are used as an input for the concept design and creation of an interaction concept (see Chapter 5).

Chapter 3

Research methodology

In this chapter, the underlying research methodology is described. This includes the overall research process, the ethical point of view, the used data collection methods and the data analysis tools. Last, the used methods for the evaluation of the gathered data are pointed out.

3.1 Research process

This project takes an exploratory research approach. An overview of the research process is illustrated in Figure 3.1. The different phases are representing the *main part* of this thesis (see Chapter 1.7 for the whole document outline). The detailed research process is described in the subsequent text.

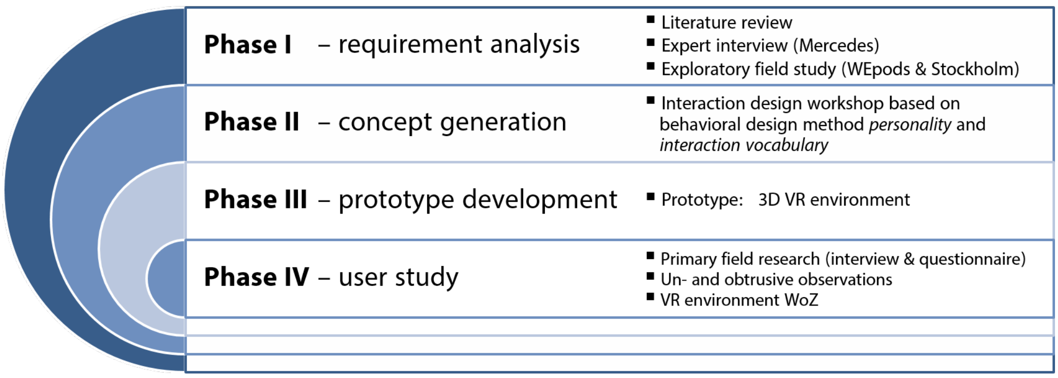


Figure 3.1: Research methodology – Research process overview.

The first research sub-question, *a) How does an SAV2P interaction concept look like?* will be answered in **Phases I-III**, the second sub-question, *b) Does the introduction of an interaction concept increases the level of comfort for the pedestrian in a crossing situation?* will be addressed in the main user study, in **Phase IV**.

Phase I – requirement analysis. First, a literature review is performed to obtain the state-of-art and known research challenges that is translated into first requirements for the conceptualization. This included to find out parameters which are involved in the communication process between SAV2P. Through interviews with experts and users, as well as observations in field studies, further requirements are gathered. One interview and exploratory field study is performed in Wageningen (Netherlands) within the scope of the WEPods project to receive insights from a real SAV2P environment.

Phase II – concept generation. To answer the first research question, a concept is designed based on the requirement analysis. In an iterative process, the basis concept is built together with input from other HCI students and design experts in two interaction design workshops. This process encompassed the behavioral HCI design method *Personality* by Spadafora *et al.* (2016).

Phase III – prototype development. Based on the requirement analysis and the created concept, a VR 3D environment for the traffic situation as well as the interface itself is developed, tested and iterated.

Phase IV – user study. To evaluate the prototype and answer both research questions, a user study is performed in a simulated street environment. The data collection methods of unobtrusive and obtrusive observations as well as a semi-structured interview and questionnaire are used in the study. In the VR test environment, the whole interaction concept can be tested.

3.2 Research ethics

Having a human subject in the center of this research, it is essential to put the interests and health of the participant at first. The participant has to be informed about the background information of the research and be informed about all possible risks (Lazar, 2017). In this research project personal data of participants as well as behavioral data is collected. However, only the data which is needed for the research purpose will be gathered, this fulfills the *collection limitation principle* by the OECD (1980) recommendation for privacy. Furthermore, personal data is anonymized and not linked with any personal contact information. All participants volunteered on their free will without any incentive and were able to stop the experiment at any point of time. Last, the purpose and which data will be collected was communicated towards each participant as "the voluntary consent of the human subject is absolutely essential” (U. Government., 1949).

3.3 Data collection methods

This master thesis used various data collection methods for the different phases of the research project, which are detailed in the following. Besides, the data collection methods are related to the overall research process and it is pointed out in which part of this thesis they have been utilized.

3.3.1 Literature review

The data collection method *literature review* is one of the first methods used in the whole research process and allowed to gather existing ideas, concepts and research results as well as receive open challenges from other related work that can be used as an input for this research project.

Literature review is one essential data collection method that was used in this thesis to explore on existing vehicle concepts and interaction concepts in Phase I. It was also used throughout the whole research process to validate and verify the thesis work at each stage.

3.3.2 Unobtrusive & obtrusive observations

Observational methods are used to gather data directly from the execution of a specific task or scenario (Stanton, 2013). These include observations of the tasks by system perspective, participants performing tasks, focusing the observations on task steps, sequences, errors and the human to machine -, as well as the human to human communication. Furthermore, the system environment, used interface modalities and technologies (input and output) and organisational environment can be examined.

Several different types of observations exist. A direct/remote observation can be made to either directly or remotely observe a participant performing a task. Furthermore, it has to be decided if an unobtrusive or an obtrusive setup should be chosen. Unobtrusive observation methods result in the case that the participant is observed without directly interacting with him/her, while an obtrusive observation encompasses the direct interaction with the test participant.

There are five different types of information that can be gathered from observational methods: *sequence of activities*, *duration of activities*, *frequency of activities*, *fraction of time spent in states* and *spatial movement*.

The use of observational methods is at any step of the research work possible to either find out existing phenomena, test prototypes or evaluate designs.

Observation studies were made in the field studies of Phase I (see Chapter 4.2) and the conduction of the user study in Phase IV to study the behavior of pedestrians.

3.3.3 Interview

Interviewing is a flexible and direct method to gather a high volume of specific information (Stanton, 2013). They are extensively used in a user-centered design approach as the designer wants to get insights directly from the user of a system. System usability, user perception, user reaction and -attitude, a job analysis, a cognitive task analysis or errors are only some of the possible aspects which can be examined.

There are three different main types of interviews which allow to collect more specifc or broad data from the participant, which are listed in the following.

1. **Structured interview.** This interview type allows to probe the participant in using a set of pre-defined questions to gather specific information. The content of the interview is fixed and therefore does not allow another order or follow-up questions.

2. **Semi structured interview** The interviewer has a pre-determined set of questions to ask the participant. However, the questions can be adapted and additional follow-up or new questions can be asked.

3. **Unstructured interview.** The unstructured interview is used to explore different aspects of the subject.

Semi structured and unstructured interviews were used in the field studies in Phase I (see Chapter 4.2) to gain first hand insights on the behavior of pedestrians and filtered information by experts. Semi structured interviews were used in the user study in Phase IV (see Chapter 7) to gain direct inputs from participants, to verify the observed behavior of them, and last, to receive their motivation on the behavior.

3.3.4 Questionnaire

Compared to interviews, *questionnaires* allow to fastly collect large amount of data from a large participant population. They can be used in almost any kind of topic, both for qualitative and quantitative data. However, they are mostly used for quantitative studies as they allow to collect a large amount of data in a short time. Compared to the interview the participants are not directly in contact with the researcher. There are a number of established human factors questionaire methods: Software Usability Measurement Inventory (SUMI), Questionnaire for User Interface Satisfaction (QUIS) and system usability scale (SUS) (Stanton, 2013). Those questionnaire methods have their focus on the evaluation of software and hardware and are extensive.

These methods were used as input in the design of the questionnaires in this study.

3.4 Data analysis tools

The data analysis tools of thematic content analysis, descriptive- and inferential statistics are used in this thesis and are detailed in the subsequent section.

3.4.1 Thematic content analysis

To analyze the qualitative data collected in the project thematic content analysis was used. A content analysis is commonly used to analyze interview data and is a systematic and replicable technique to translate many words into a small number of different content categories, themes and patterns based on rules of coding. There are two different approaches to perform an analyis of the data: *emergent coding* and *priori coding. Emergent coding* represents the technique to analyze the qualitative data without having any related theory or model that serves as a basis for the analysis. Therefore, it is built up by noting down concepts and ideas that are continually refined until a coherent model that encompasses the needed details. In contrast, *priori coding* describes the coding based on related work and established theory or hypothesis to guide the definition of coding categoreis (Lazar, 2017).

The method was used in Phase I to analyze the gathered data of the observational studies and the interviews in the field studies. Furthermore, it was used to analyze the data gathered in Phase IV. In both times, the *priori coding* method was used as already related work and hypothesis were worked out and the themes are set around the topics of *comfort, safety, confidence, immersiveness, understanding, efficiency* and *design*.

3.4.2 Descriptive statistics

Descriptive statistics is used to understand the nature of the collected data set and find out the range into which most of the data points fall; and how the data points are distributed. Common used descriptive measures are: means, medians, modes, variances, standard deviations, and ranges. Accompanied by performing descriptive statistics are the pre-steps: *cleaning*, *coding* and *organizing*. *Cleaning* is the process of testing the collected data for errors and validity and to skip the data records with invalid data. *Coding* is the step of translating the data set into one consistent for the statistical method appropriate format. The last step,*organizing*, is to organize the data in a format that all predefined requirements of the data-processing software are met (Lazar, 2017).

Descriptive statistics was used in Phase IV, Chapter 7 to show trends on the gathered data.

3.4.3 Inferential statistics

The statistical hypothesis test used in this work was the non-parametric equivalent of the paired samples t-test, the Wilcoxon Signed Rank Test. Accompanied by performing inferential statistics are the same pre-steps as for descriptive statistics (see Chapter 3.4.2).

This method was used in Chapter 7 to help testing the hypothesis of the second research sub-question (see *question b* in Chapter 1.4).

3.5 Creativity methods

Creativity methods were used mainly in the conceptualization phase. First, a method to design the behavior of interactive objects is presented which was used to design the different interactions incorporated in the interaction concept.

3.5.1 Interaction design & designing the behavior of interactive objects

Interaction design has become "a vital concept within the design process of interactive systems. It is primarily concerned with the design of sociotechnical systems that take into account not only their users, but also the use of technologies in users' everyday activities, it can be thought of as the design of spaces for human communications and interaction" (DePaula, 2003)

One method of interaction design is the recent developed framework *designing the behavior of interactive objects* from Spadafora *et al.* (2016). The method enables to design proactive and autonomous interactive objects with a focus on aesthetics of the interaction. It uses a set of personalities and an interaction vocabulary by Lenz *et al.* (2013) to describe the specifics of an interaction without already limiting it to a specific implemented technology.

This method was used as a basis for the interaction design workshop in Phase III (see Chapter 5.2 for more details).

3.6 Evaluation tools

3.6.1 Research using VR & virtual environments

VR and virtual environments are used in the context of research and production of vehicles.[1] Mostly, research is focused on the inside of a vehicle from a driver's or passenger's perspective (researcher of Mercedes Benz, personal communication, March 3, 2017). In one study, for instance, the effects of advanced safety driving systems was evaluated in VR (Kwon *et al.*, 2006).

Besides, VR environments are successfully used in studying crossing behavior and risk acceptance in traffic with manually driven vehicles (Doric *et al.*, 2016; Morrongiello *et al.*, 2015). As this is one of the first research prototypes in that direction and technology advanced, it is still a new technique for studying the interaction between AVs and pedestrians.

VR facilitates a controlled test environment that allows to easily repeat experiments and track the persons' motion, eyes' sight and behavior (Fox *et al.*, 2009).

VR was used as an evaluation method in Phase IV (Chapter 7) to facilitate testing the SAV2P interface in a close to realistic scenario.

[1] Source accessed on 10.March 2017 from: `http://www.triplepundit.com/2017/01/ford-virtual-reality-labs/`

Chapter 4

Phase I: requirement analysis

In Phase I, the requirements on the communication concept are collected through different collection methods. First, a literature study of the state of the art is performed. Furthermore, field studies and expert interviews are conducted to gain first hand insights as well as to complement details on literature gaps.

4.1 Literature review

As a first step in the requirement analysis, a literature review was conducted.

4.1.1 Purpose & Goal

The purpose of the literature review was to gain an overview of the state of the art research in the field of vehicle-to-pedestrian communication.

The goal of the literature review was to gain insights of the current problems that can be tackled in an interaction concept and thereby gather the first requirements for a concept. Last, to collect requirements for the conduction of the user study.

4.1.2 Method

To find research about state of the art, a key word search was performed with the following words and combinations of them (ordered alphabetically): *acceptance, automated, autonomous, behavior, car, communication, drive, intention, interaction, pedestrians, perception, safety, state of the art, trust, vehicle, vulnerable road user*. The search engines Elsevier (Scopus/Science direct), Google Scholar, ResearchGate and Transport Research International Documentation (TRID) were used for the key word search. Furthermore, an overview paper by Ohn-Bar and Trivedi (2016) was identified with the same key words, which led to additional research papers.

4.1.3 Results

The research of Lagström and Malmsten Lundgren (2015), presented in Chapter 2.2.1, shows that pedestrians were less willing to cross the street in case of the driver was inattentive or showing uncommon driver behaviour such as actively reading a newspaper. Furthermore, they conducted field experiments with a Wizard of Oz (WoZ) vehicle as an AV.

Doric *et al.* (2016) tested crossing behavior in VR with normal vehicles. They came to the result that the crossing behavior of pedestrians is among others depending on the speed of the approaching vehicles and the gaps between vehicles in the traffic. In addition, the street design has an impact on the behavior and feeling of the pedestrians. Depending on if the crossing is signed, or wide open spaces are available for the pedestrian, the feeling of the personal priority as a road user in the traffic situation changes (Parkin *et al.*, 2016).

Katz *et al.* (1975) studied 960 crossing situations and came to the result that the speed, the place and the distance between the vehicle and the pedestrian's point of entry to the road are factors to consider in the behavior of the road users. In case of an individual pedestrian crosses or a group, as well as if the pedestrian is not looking at the approaching vehicle at all, has an impact on the crossing situation that has to be considered.

Keferböck, F. & Riener, A. (2015) studied trust and confidence of pedestrians for different levels of automation and do highlight the importance of an active communication by AVs. This is confirmed by the results of Habibovic *et al.* (2016) concluding that pedestrians must get feedback from the vehicle itself to improve the understanding of the vehicles' intentions. They indicate that if eye contact is discarded due to vehicle automation, the perceived safety could be sustained given that pedestrians are provided with the corresponding information, for instance with an external vehicle interface.

Hoff and Bashir (2015) give recommendations to maximize the trust into automated systems, pointing out that usability of a system is co-related to how much a system is trusted. Therefore, the automated system has to behave in a manner that is expected. In addition to that, accurate, continuous feedback on the reliability and situational factors of the SAV can facilitate the trust of pedestrians (Merat *et al.*, December 2016). The balance of amount of information that is communicated towards the pedestrian versus updates that are triggered in a moment in time has to be right and helpful (Lees and Lee, 2007).

Merat *et al.* (December 2016) mention that the appearance and communication style of an AV has an impact on the level of safety and trust. Therefore, the communicated message has to represent the state or function that is intended to be communicated towards the pedestrian.

As SAVs will become a novel vehicle on the shared road space, VRUs who are not familiar with the technology might not recognize the vehicle as automated in the initial phase and do not understand or know how the vehicles can behave (Vissers *et al.*, 2016).

4.1.4 Implications & requirements for the concept and the user study

The following factors were identified that influence the pedestrian's behavior and willingness to cross the street:

- Speed of the vehicle
- Location and distance of the vehicle
- Vehicle acc-/deceleration
- Eye contact with the driver
- Familiarity of the pedestrian with the environment
- Weather and view conditions
- The traffic situation (Signed or unsigned intersection, amount of vehicles, traffic rules and amount as well as behavior of other VRUs)

The prior listed factors have to be taken into account for the conduction of the research study and must be set to a value that can be recorded to build validity and reproducible research. As an eye contact is seen as a means of communication towards drivers of manually driven cars, a replacement through an interface might help to make the pedestrian feel comfortable in a crossing situation. An active communication by the SAV may thereby make the pedestrians feel safe in the crossing situation encountering an SAV.

For the interface itself the following requirements were identified:

- Requirement 1: The interface should provide information on the driving state: SAV is *start driving, stop driving* or *waiting.*
- Requirement 2: The interface should communicate accurately, timely and continuous.
- Requirement 3: The interface has to be simple and easy to understand because a high usability of the system facilitates the pedestrians trust and comfort, moreover, it has to be interpretable fast as the traffic situation might be short in it's duration.
- Requirement 4: The interface should be visually appealing and has to represent the function or state that should be communicated.
- Requirement 5: The interface should be present as long as possible, meaning that the pedestrian can always get information.
- Requirement 6: The interface should show or underline that the vehicle is an SAV.

4.2 Field studies

4.2.1 Observations & interviews in the Netherlands (WEPods)

At Wageningen University in the Netherlands, two modified EasyMile EZ10 are used for research purposes in different fields. The SAVs, called WEpods, are driving on a pre-determined route (around 2km) within the campus area on public roads and have been running since November 2015. The current research goal is the technical feasibility, incorporating ghost object detection. Every Tuesday between 11:00 and 13:00, the public can take free rides on the campus route with the SAVs. The route driven can be found in the Appendix A.1. Within the scope of this thesis, Wageningen was visited in end of February 2017.

Purpose & Goal

The purpose of this field study was to get familiar with one current implementation of an SAV and gather some first hand observations and information on the communication between SAV2P.

The goal was to gather requirements for the interaction concept. Furthermore, to validate the results by Rodriguez *et al.* (2016) who studied the perceived safety of VRUs in a case study within the WEPods project.

Method

At the Plus Ultra building at the Wageningen university campus, first, the project manager of the WEPods project gave a presentation on the current status of the WEpods project and answered questions in a semi structured interview. Then, a test ride on the 2 kilometeres route was executed in around 15 minutes and the steward was interviewed (unstructured). The prepared leading observational and interview questions can be gather in the Appendix A.1.2.

Results

The presentation highlighted that the two SAVs (see Figure 4.1) are well-known around the city, as there are active media publications in the local newspapers. The local inhabitants were able to suggest names for the vehicles. Furthermore, according to the statement of an interviewed researcher, people call the vehicles cute. Those aspects show that the vehicle is well integrated into the community.

Before the test ride it was observed by the author that an LED-matrix ticker with the text "Autonomous Car, keep distance" is mounted both in the front-

Figure 4.1: SAV – Easymile EZ10 (WEPods – Wageningen). Photo by author.

and rear-window of the vehicle. The interview relieved that apart from the ticker, and a bell sound that is indicating that the vehicle is start moving after it has been standing still, no other direct communications are made towards VRUs.

During the author's test ride, it was observed that the car drivers followed the instructions on the LED ticker and kept more distance compared to the distance to other vehicles and VRUs. VRUs, especially cyclists, were not stopping at busy crossings. This resulted in a very long waiting time for the SAV to continue driving and the steward had to intervene into the driving process to manually start and stop the vehicle to move again.

The steward mentioned that, especially in the beginning of the project, a lot of people were trying to step in front of the vehicle to see if it is going to stop for them and took pictures because of the SAV's novelty factor. Moreover, cyclists overtake often so close that the vehicle executes an emergency brake.

It was observed that from the outside, the steward is not easily identifiable as a person who can intervene into the SAV's driving activities, this is also confirmed by studies of Rodriguez *et al.* (2016).

Implications & requirements for the concept and the user study

The novelty factor of the vehicle might affect the participants in the user study of this thesis project as they probably have not seen any comparable vehicle at the moment of the experiment conduction. Therefore, in the user study it has to be first explained, what an SAV is and what it is in general capable of. Furthermore, a question in terms of trust after having experienced the SAV in the user study could give more insights on that note. The list of requirements (see Chapter 4.1.4) was complemented with additional derived requirements, mentioned subsequently:

- Requirement 6: The SAV should get enough attention with the interface, as VRUs felt to have priority at all times.
- Requirement 7: The interface should use sound to indicate it's intentions, e.g. a bell sound creates a mental model for a tram start moving.

4.2.2 Interaction between pedestrians & manually driven buses in Stockholm

To gain further insights in the communication between pedestrians and drivers, as public SAVs can be also seen as small buses, a field study was conducted around Stockholm.

Purpose & Goal

The purpose of the field study was to find out, how the communication between bus driver and pedestrians are currently performed.

The set target was to learn what are current interaction behaviors and if there are any communication issues between bus drivers and pedestrians.

Method

14 bus drivers (8 female, 6 males between 30 and 50) and 25 passengers (12 female, 13 male between 18 and 65) were interviewed. In total, 15 bus rides where performed to find out, how the communication between bus driver and pedestrian is currently performed to learn what are current behaviors and occurring issues. The bus route 50 was selected as it is a route for the daily commute between the living area Lappkärrsberget and the city center of Stockholm (see route in Appendix A.2.1). The observations and interviews were mainly performed at three different time frames: in the morning between 7:30 and 8:30, in the afternoon between 13:00 and 16:00 and in the evening between 17:00 and 20:00.

A set of questions was defined for observation and interviews, see Appendix A.2.2. Observations at bus stops, as well as inside of buses were made. Besides, semi-structured interviews were performed individually with pedestrians and bus drivers.

Results from the observations of bus driver and pedestrian interaction
The indication that pedestrians know that the bus stops or does not stop are that it slows down, there is a brake sound and the lane indication light is on/off.

To indicate that the pedestrians want to enter a bus they move towards the curb, or more precisely close to the point where the bus is going to stop (mostly at the corner of the tactile pavement). Passengers with strollers stay behind the main queue of people as the bus is opening the second or third door to let them enter. Apart from passengers with strollers, the passengers always get into the bus at the front and queue up. At the station Odenplan, there are during rush hour times additional staff checking bus tickets, letting people enter directly at the second and third door of the bus. To indicate that they want to enter, passengers get their wallet / travel card out of their pocket (often with an active use of gestures) or they wave towards the bus driver (mostly in situations in which are not many people standing at a bus stop).

Results of interviews with pedestrians
The results of the interviews with the pedestrians mainly confirm the gathered data from the observations. Most people stated that they use gestures (waving, get the bus ticket out of their pocket and show it actively or stand/walk towards the curb) to indicate that they want to enter a bus in situations of less than three persons waiting at a bus stop.

They mentioned that they see if a bus stops when it slows down (N=17), the lane indication is on (N=14), it moves to the side of the street (N=7) and there is an eye contact with the bus driver (N=9).

On the question, if it is always understandable that the bus will stop for them, they mostly agreed (see appendix).

In situations where one person is waiting alone at a bus stop (N=4), it is sometimes unclear if the bus will stop. Also, when the bus started driving after passing a bus stop which is close to a zebra crossing (N=1), the indication lights are not turned on (N=8), or there is no eye contact with the bus driver (N=5) and the bus is not slowing down (N=9), it is hard to see if the bus will stop.

To cross a street in front of a bus at a zebra crossing, the interviewed pedestrians mentioned that they see that the bus is stopping for them, when it slows down (N=20), there are gestures from the bus driver (N=7) or facial expressions (N=6). When they were asked to elaborate on the difference compared to other vehicles, they said that a bus is slower, larger, less agile and usually brakes more comfortable for pedestrians.

Results of interviews with bus driver (semi structured)
When there are only one to three persons standing at a bus stop, bus drivers mention to see if the persons want to enter with checking: if the persons are turned towards the bus (N=10), there is an active eye-contact (N=7), they wave (N=6), smile at the bus (N=2), the persons are standing close to the curb (N=12) or standing up from the bench when the bus approaches (N=8).

To see that persons do not want to enter the bus ride, bus drivers answered that persons turn with the back towards the bus (N=10), do some other activity like reading, sitting, using the smartphone (N=8), or are not standing up (N=8).

On the question, how do you signalize to give pedestrians way, if they want to cross the street?, they answered: to slow down (N=14), make eye-contact (N=10), wave or use lights, however, only when the bus is on a one-way, as they are liable if another vehicle overtakes in that moment (N=4).

Implications and requirements for the concept

Four bus drivers mentioned to only give active signals to pedestrians when they are driving on a one-way, caused by liability reasons. Hence, the requirement of not actively giving signs to show the pedestrian that he/she should cross but showing own driving intentions towards the pedestrian, can be formulated.

Both, pedestrians and bus drivers agreed on the fact of using eye contact in moments of crossing. Additionally, pedestrians also said they use eye contact to show their willingness to enter the vehicle. This confirms the literature findings (see Chapter 4.1.3) that is stating that an active use of eye contact is present between vehicle-to-pedestrian communication.

4.3 Concluding requirements for the concept

Summarizing the results of the literature review, the observations and interviews from the field studies, the following requirements are identified for the concept generation and development of the prototype. Furthermore, the related research questions are connected to them.

4.3.1 Functional requirements

A priority on a scale (low, middle, high) was given to each requirement individually based on the author's evaluation. The abbreviations LR for literature review (see Chapter 4.1) and FS for field study (see Chapter 4.2) are used.

Table 4.1: Functional requirements.

Requirement F-01	Indicate future driving state of SAV
Description	The driving states start driving, stop driving and waiting should be communicated towards the pedestrian.
Rationale	If the SAV communicates the future driving state pedestrians feel more comfortable in crossing the street in front of an SAV and are interacting with it.
Originator	LR (Lagström and Malmsten Lundgren, 2015)
Fit criterion	The pedestrians can determine which will be the next driving state of the SAV.
Priority	HIGH
Requirement F-02	Active indication of SAV
Description	The SAV actively indicates towards its surrounding that it is an SAV.
Rationale	The user may be confused by the fact that the vehicle has no human driver and wheel behind the windshield.
Originator	LR (Lagström and Malmsten Lundgren, 2015), FS (WEPods)
Fit criterion	When the user can determine only from the vehicle approaching that it is an SAV.
Priority	Low (Form factor / appearance of the SAV already helps)
Requirement F-03	Acknowledgement of multiple individual pedestrians
Description	The SAV can acknowledge individual pedestrians.
Rationale	If the SAV does not show the pedestrians that it sees them, pedestrians might get anxious in crossing the street.
Originator	LR (Lagström and Malmsten Lundgren, 2015), FS (WEPods)
Fit criterion	The pedestrians feel comfortable in the SAV noticed them individually.
Priority	Low (Priority to first test with one pedestrian)
Requirement F-04	Eye-contact replacement (acknowledgement)
Description	The SAV acknowledges pedestrians.
Rationale	If the SAV does not show the pedestrians that it sees them, pedestrians get anxious in crossing the street.
Originator	LR (Lagström and Malmsten Lundgren, 2015), FS (WEPods)

Fit criterion	The pedestrians feel comfortable in the SAV noticed them.
Priority	HIGH
Requirement F-05	Information on destination / next stop / direction
Description	The SAV provides a visual information on the next destination / stop or direction the SAV is heading to.
Rationale	This enables the pedestrians to see if they could use the specific SAV for their travel route / commute.
Originator	FS (Stockholm)
Fit criterion	The pedestrians can evaluate where the SAV is heading to and know if they could take the SAV for their next destination by just looking at the vehicle.
Priority	LOW (not part of the pedestrian interactions at this stage)
Requirement F-06	Warning pedestrian for hazardous road situations
Description	The SAV can warn pedestrians for hazardous road situations such as cars overtaking in a blind spot.
Rationale	This enables to improve the safety on streets
Originator	FS (Stockholm), Mercedes Benz expert interview
Fit criterion	The pedestrians understand the signal by the SAV that it warns them and therefore, they are not stepping into the situation of being harmed or injured by any road user.
Priority	MIDDLE (high complexity caused by variety of situations)

4.3.2 Non-functional requirements

Usability requirements like learnability, efficiency, memorability, errors, satisfaction are non-functional requirements that also must be taken into account. Obtained non-functional requirements are described in the following:

Table 4.2: Non-functional requirements.

Requirement NF-01	The interface should communicate accurately, timely and continuous.
Description	The interface should give the interacting people at each point of time the right information of, for instance, the current driving state. The communicated information should be observable at all times for the pedestrian (continuous and timely) and should be correct.

Rationale	This enables a fluent and accurate communication to facilitate safety and comfort for the pedestrian.
Originator	LR (Hoff and Bashir, 2015), FS (WEPods)
Fit criterion	The pedestrian is informed about the driving state at the right time, continuously and the driving state is correct.
Priority	HIGH
Requirement NF-02	The interface has to be simple and easy to understand
Description	An easy and simple system allows to fastly receive the communicated message in a short amount of time.
Rationale	An interface that is simple and easy to understand enables a good communication between SAV2P and includes a big number of users that can understand the system. Furthermore, it is vital for a fast communication.
Originator	LR (Hoff and Bashir, 2015)
Fit criterion	All pedestrians can understand the message by the SAV in a fast way.
Priority	MIDDLE-HIGH
Requirement NF-03	The interface should be visually appealing.
Description	The interface should give the interacting people at each point of time the right information of, for instance, the current driving state. The communicated information should be observable at all times for the pedestrian (continuous and timely) and should be correct.
Rationale	This enables a fluent and accurate communication to facilitate safety and comfort for the pedestrian.
Originator	LR (Lagström and Malmsten Lundgren, 2015; Hoff and Bashir, 2015)
Fit criterion	The pedestrian is informed about the driving state at the right time, continuously and the driving state is correct.
Priority	LOW (not measured in the scope, future work)
Requirement NF-04	Make pedestrian feel calm
Description	The pedestrian feels calm in crossing the street without thinking too much about how he/she should behave in a specific situation.

Rationale	The interface should be easy understandable (NF-02) and therefore not overstrain the pedestrian's mind. Furthermore it should communicate accurately, timely and continuous (NF-01) to facilitate a calm feeling.
Originator	author & LR (Lagström and Malmsten Lundgren, 2015; Merat *et al.*, December 2016)
Fit criterion	The pedestrian behaves like on another zebra crossing and feels not negatively influenced.
Priority	HIGH

Requirement NF-05	Make pedestrian feel comfortable in crossing the street in front of the SAV
Description	The pedestrian feels comfortable in crossing the street like in another crossing situation.
Rationale	The interface should be easy understandable (NF-02) and therefore not overstrain the pedestrian's mind. Furthermore it should communicate accurately, timely and continuous (NF-01) to facilitate a comfortable crossing experience.
Originator	author & LR (Vissers *et al.*, 2016; Merat *et al.*, December 2016)
Fit criterion	The pedestrian behaves like on another zebra crossing and feels not negatively influenced in his/her comfort.
Priority	HIGH

Chapter 5

Phase II: concept generation

Phase II is based on the requirements and results given by the requirement analysis (Chapter 4). First, an overview of derived interaction scenarios is described, after that, a design work shop is outlined that served as an input for the interaction concept. Last, the generated interaction concept is illustrated. This answers also the research question a (Chapter 1.4): *How can an SAV2P interaction concept look like?*.

5.1 Interaction scenarios

The key questions for the creation of an interaction concept for the SAV's interface are derived from the requirements that are prioritized with middle and above:

(a) How can an SAV acknowledge a pedestrian? (Requirement: F-04, Table 4.1)

(b) How can an SAV communicate its intentions and the current driving state? (Requirement: F-01, Table 4.1)

(c) How can a SAV communicate that it will stop or not stop for pedestrians? (Requirement: F-01, Table 4.1)

(d) How can an SAV warn pedestrians for hazardous road situations? (Requirement: F-06, Table 4.1)

(e) Which auditory and visual modalities and its combination is perceived as the most fitting for each driving scenario? How should the communication be timed and which representations can be used for the communicated information? (Requirement: NF01-NF05, Table 4.2).

As a delimitation, only crossing situations at unsigned zebra crossings were considered as traffic situations where the pedestrian wants to cross the street. The following four main interactions were identified for the concept:

1. **Giving way.** The SAV signalizes to the pedestrian that it is giving way and will either *stop and wait* or is *already standing and waiting* for the pedestrian to cross the street.

2. **Not giving way.** The SAV cannot or "does not want to" give way for the pedestrian to cross the street. This interaction may, for instance, occur in the situation, when the SAV is not capable of physically breaking in time for the pedestrian.

3. **Acknowledgement.** An acknowledgement of the SAV towards the pedestrian is performed by signalizing the pedestrian that the SAV sees the pedestrian.

4. **Warning of hazardous situation.** In case of the SAV wants to warn the pedestrian of a hazardous situation such as another vehicle is approaching from a blind spot, the SAV needs to gain attention and communicate this warning information towards the pedestrian.

Out of the latter described interactions, five interaction scenarios were created, detailed in the following and visually related in Figure 5.1.

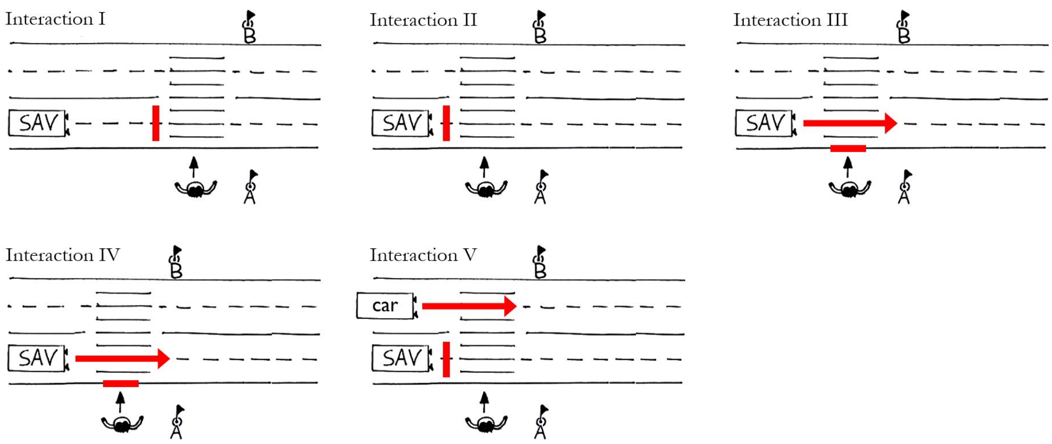


Figure 5.1: Interaction scenarios.

Interaction I – Giving way (stopping)

- The SAV is 50 meters away. SAV signalizes to the pedestrian that it is giving way and will stop and wait for the pedestrian to cross.

Interaction II – Giving way (standing)

- The SAV wants signalizes to the pedestrian that it is giving way and is already standing and waits for the pedestrian to cross.

Interaction III – Not giving way (start driving)

- The SAV was standing and wants to indicate that it is start driving and therefore not giving way for the pedestrian anymore.

Interaction IV – Not giving way (driving)

- The SAV cannot or "does not want to" give way for the pedestrian to cross. This interaction occurs when the SAV simply is not capable of physically breaking in time for the pedestrian.

Interaction V – Warning

- The SAV is standing and waiting for the pedestrian to cross. A moving object such as a manual driven car or a cyclist is approaching in the blind spot of the pedestrian. The SAV wants to warn the pedestrian to stop further continue crossing the street.

In general, there are two different approaches to design the SAV2P communication. One is that the SAV communicates its own intentions to the pedestrian. In contrast, a command based communication style means that the SAV communicates to the pedestrian what the SAV wants the pedestrian to do (e.g. please cross / wait / do not cross). In this thesis project, an intention based approach is chosen.

5.2 Design the interaction – A design workshop

To develop the interaction design concept, two design workshop with a duration of about three hours were performed with interaction designers. Methodology from both Spadafora *et al.* (2016) and Lenz *et al.* (2013) were used as an input for the workshop.

Purpose
The purpose of the design workshops were to translate the gathered requirements from Phase I into an interaction concept that can be used to prototype a matching interface for the SAV in the next step. Furthermore, to receive insights before the start of the prototype development and get a feeling in how the system might work in a real scenario and which are open issues and problems to tackle.

Goal
The goal of the workshop was to receive in a first step, a set of parameters for each interaction, combined with ways of how the SAV2P interactions could be designed. Secondly, the target for the workshop was set to work out all the interactions of the interaction scenarios (see previous Chapter 5.1) for the interaction concept that can be used and implemented in a prototype.

Participants

The workshops consisted of 4 and 3 participants, all students of human computer interaction and design at the KTH Stockholm (Sweden) with a age range from 23 to 29 with different ethnic backgrounds (Asian/European).

Method

First, the workshop organizer introduced himself to the group and the participants introduced themselves to each other. After that, a brief introduction into the topic of SAVs was given. The introduction included a definition of the autonomy level (at least level 4, see Chapter 2.1) and how an SAV can physically look like. For the latter, a photo of the EasyMile EZ10 vehicle was shown to the participants (see Figure 2.1). In the next step, the organizer introduced the interaction vocabulary by Lenz *et al.* (2013), split the participants into two groups and explained the first interaction scenario. After that, the following iterative process was performed for each of the five detailed interaction scenarios (Figure 5.1):

(a) 10 minutes of individual brainstorming on the behavior of the interaction based on the interaction vocabulary by Lenz *et al.* (2013).

(b) 10 minutes of individual sketching of the interaction and interface of the SAV.

(c) 5 minutes of group discussion on the interaction with the use of the interaction vocabulary.

(d) 10-15 minutes sketching, and filming in short clips the whole interaction, pinpointing which are important behavioral parameters.

Last, all the video clips were watched and analyzed, constructive feedback was given by the participants and pros and cons of each interface interaction discussed. In Figure 5.2 the brainstorming session and the step of sketching in groups is displayed in the left part of the image, on the right side of the image, the preparation of one interaction video clip is illustrated. Figure 5.3 shows a whiteboard being used in the workshop, to talk about the interactions and having an overview of the interaction vocabulary (see on the right part of the image) in mind.

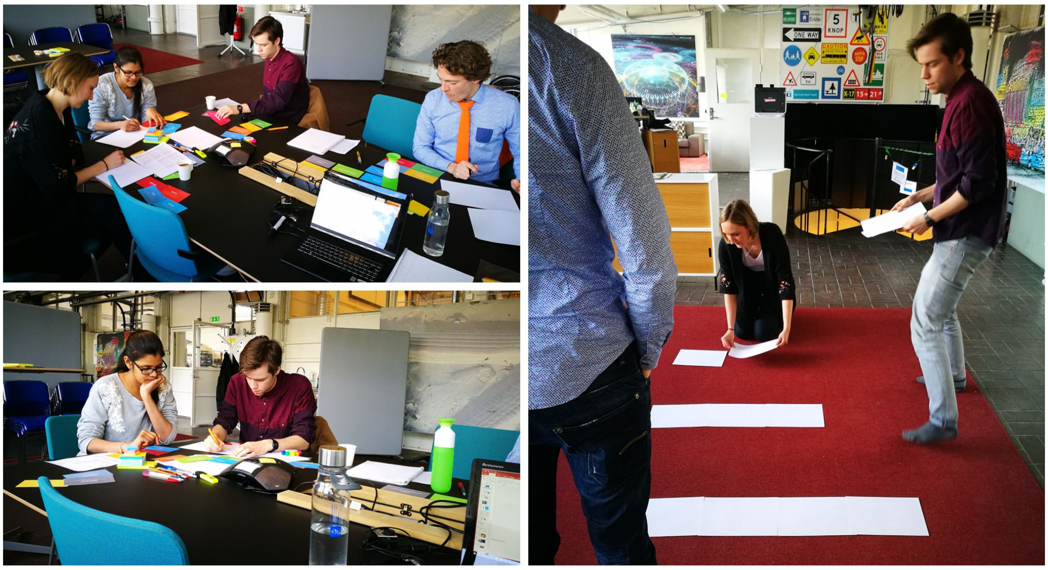


Figure 5.2: First interaction design workshop.

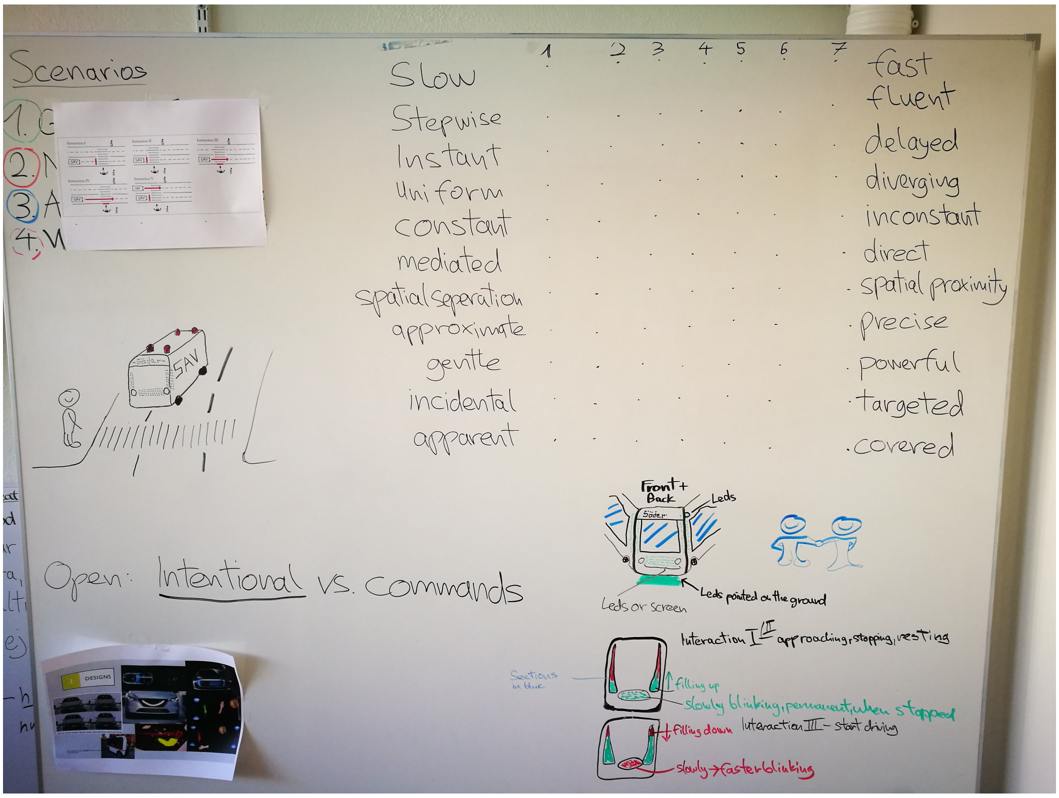


Figure 5.3: Second interaction design workshop – Parameters whiteboard.

5.2.1 Results & discussion

The results of this workshop show that, in general, the following key points are valid for the design of the interaction design:

- Fast and efficient communication is key, long negotiations between both communication partners SAV and pedestrian are not wished. This means fast transitions between the communication of messages and repetitively, short timed visual animations. (Requirement: NF-01/02, Table 4.2)
- The phase of the pedestrian acknowledgement is possible with a change of light color more preferably, compared to a representation of small dots as it can be interpreted more ambiguous. The same is valid for warning situations. (Requirement: F-04/F-06, Table 4.1)
- Sound should be used carefully and can also confuse in some interaction scenarios.

The used methodology enabled the workshop participants to have a common discussion ground on the behavior of the interaction and the description of it. Furthermore, it allowed the designers to compare the different interactions from each other and first think through, how the interaction behavior should be designed before to start thinking of a concrete visual and audio representation of the interaction.

However, at some points of the workshop process, the designers agreed on the fact that the interaction vocabulary was too vague and could be more specific, this however did not limit or negatively affected the design of the interaction concept.

5.3 Resulting interaction concept

In this section the resulting interaction concept is described. First the use of visual & auditory modalities and the placement of the interface prototype is outlined, then the resulting interaction design for each interaction scenario is detailed.

5.3.1 Use of visual & auditory modalities

The interaction concept includes visual and auditory communication modalities. However, a full multimodal interaction concept which comprises all road users is due to the duration of this project not in the scope.

Auditory signals enable more VRUs to effectively receive a communicated message from the vehicle as it increases the accessibility for people with a bad sight or blindness as well as people who are not paying attention or are not directly looking at the vehicle. Furthermore, auditory signals are attention grabbing.

Visual modalities have the advantage of a long range and are not affected by pedestrians wearing headphones.

5.3.2 Placement of the interface prototype

The interface should be placed close to where the driver of a vehicle is usually situated in the vehicle as the mental model of pedestrians associates that information is seeked from around this area (Lundgren *et al.*, 2016). With SAVs however, this might shift as an SAV is a novel vehicle type with another form factor compared to a well-known car. Furthermore, a placement on the corners like in the interface Blink (see Chapter 2.2.3) allows to enrich the area of visibility (see Figure 5.4). This enables for the pedestrians to get the communicated information at all times (Requirement: NF-01, Table 4.2).

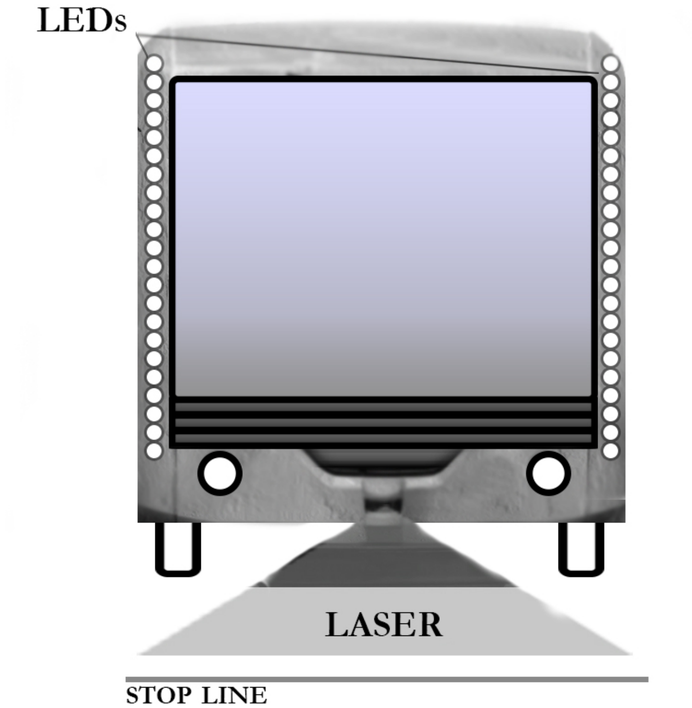


Figure 5.4: Interface – LEDs at the side of the SAV at the front and back.

5.3.3 Resulting interaction design for each interaction scenario

There were several different approaches and communication possibilities identified during the design workshops. Out of the generated interaction ideas, one resulting interaction design for each interaction scenario was created. See Chapter 5.1 for all interaction scenarios.

Interaction I, II & III	**Giving way (stopping, waiting, start moving)**
Description	The SAV is 50 meters away. SAV signalizes to the pedestrian that it is giving way and will stop and wait for the pedestrian to cross, then after waiting it starts moving again.
Signal stopping	LEDs are moving from top to bottom in blue, adding one more constantly active LED after each round of top to bottom movement (filling up the whole LED bar till the vehicle is stopped). A laser projects a horizontal line on the road surface to show at which location the SAV is going to stop.
Signal waiting	LEDs slowly (low frequency) pulsating on/off in blue.
Signal start moving	Just before the SAV starts moving again, a bell sound in conjoint with fast (high frequency) blinking blue lights is indicating that the vehicle will move again. The laser projected line will blink fast before the vehicle moves and then disappears.
Signal started moving	The vehicle stays in the mode of fast (high frequency) blinking blue lights.

Table 5.1: Resulting interaction concept – Interaction I, II & III.

Interaction IV	**Not giving way (driving)**
Description	The SAV cannot or "does not want to" give way for the pedestrian to cross. This interaction occurs when the SAV simply is not capable of physically breaking in time for the pedestrian.
Signal not stopping	The SAV interface shows fast (high frequency) blinking blue lights indicating that the vehicle will not stop. If the pedestrian is close to the curb and not paying attention, the vehicle is giving a bell/honk sound. Additionally, a laser projected warning triangle is displayed on the road surface next to the pedestrian.

Table 5.2: Resulting interaction concept – Interaction IV.

Interaction V	**Warning**
Description	The SAV is standing and waiting for the pedestrian to cross. A moving object such as a manual driven car or a cyclist is approaching in the blind spot of the pedestrian. The SAV wants to warn the pedestrian to stop further continue crossing the street.
Signal warning	The SAV is fast red blinking on the side of the object overtaking and using active sound signals such as a bell or a honk to warn the pedestrian and grab attention. Additionally, a laser projected warning triangle is displayed on the road surface next to the pedestrian.

Table 5.3: Resulting interaction concept – Interaction V.

Chapter 6

Phase III: prototype development

In the third phase of the project, the VR prototype is developed. The prototype encompasses the development of a VR environment and the SAV2P interface. The SAV2P interface is developed based on the created interaction concept in Phase II (Chapter 5). The VR prototype is iterated in several steps. The goal of the prototype is to gain a platform that allows to perform tests with users and answer the research question b (Chapter 1.4): *Does the introduction of an interaction concept increase the level of comfort for the pedestrian in a crossing situation?*.

6.1 SAV2P – Development of a VR environment & an interface prototype

6.1.1 Software & hardware architecture

For the development of the VR environment and SAV2P interface prototype, a computer, an VR HMD (HTC Vive[1]), headphones, a hand-held controller, and two base stations that enable motion tracking for the person in VR and for the controller. The computer fulfills the specifications for a VR setup (VR-ready) that is needed to process the graphic intense VR environment. The HMD provides a total resolution of 2160×1200 pixels (1080×1200 pixels per eye), a refresh rate of 90 Hz and a nominal field of view of about 110 degrees.

The VR environment was built in the game engine Unity3D[2]. The developed software consists mainly out of three components: the *control interface* – it allows the test leader to control the behavior of the VR environment and manipulate different parameters, the *main application* – the application which is running all the graphical and logic part, and the *Steam VR library* – that is a library providing a Unity3D interface which enables an easy use and control of the VR equipment in the built VR environment. An overview of the whole architecture is displayed in Figure 6.1.

[1]HTC Vive manufacturer website. Accessed on 8.May 2017: `https://www.vive.com/eu/`

[2]Source accessed on 3.April 2017 from: `https://unity3d.com/`

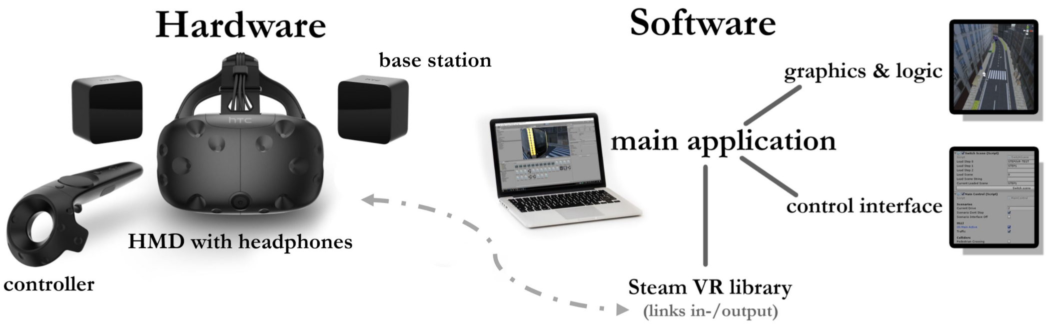


Figure 6.1: SAV2P VR prototype – Software & hardware architecture. Images of the HMD equipment by HTC, Press Kit, retrieved on 10.July 2017 from: `https://www.htc.com/us/about/newsroom/htc-vive-press-kit/`

6.1.2 First iteration

The first VR prototype environment consisted of two SAVs, one being able to move, the other one permanently standing at the pedestrian walk. Furthermore, two houses at the road were part of the environment. This setup allowed to get a feeling of how the sizes of the VR environment are compared to a real life setup and were adjusted to real life sizes. Furthermore, tests with the velocity of the SAV were performed to get a feeling of how fast the vehicle is approaching to the pedestrian walk. However, in this stage, only linear movements of the vehicles that are not physically correct were tested. Besides, the first tests with different light sources were made. An impression of the first prototype is given in Figure 6.2.

Figure 6.2: SAV2P VR prototype – First iteration.

6.1.3 Second iteration

The second iteration focused on the development of the interface itself, starting with adding all LED light sources around the vehicle. Secondly, to write a script that can individually address the light sources and thirdly, to create the different animation parts for the interaction.

Above that, the physical engine of Unity was used to give the vehicle a realistic movement with forces that result in a realistic torque of the SAV. Way points were placed in the environment to let all vehicles move on a certain path.

Last, the street environment was enhanced with several buildings and a manually driven car was introduced as another road user.

6.1.4 Final iteration

Interface design

The design of the SAV2P interface was based on a user-centric design approach involving students and experts in the field of HCI. It was iterated using the HCI interaction vocabulary by Spadafora *et al.* (2016); Lenz *et al.* (2013). The focus was on designing an interface that uses audio and visual modalities to communicate intentions of an SAV to pedestrians. As shown in Figure 6.3, the final interface consists of four LED columns, positioned at each corner of the SAV, that communicate the following messages: not stopping (flashing yellow), stopping (blue light movement from top to bottom), waiting (slowly fading blue) and start driving (bell sound, flashing yellow light).

As the LEDs are also placed at the side of the vehicle the visual communication of the SAV is observable around 360 degrees of the vehicle (Figure 6.4).

Figure 6.3: SAV2P interface – Different interface states in VR.

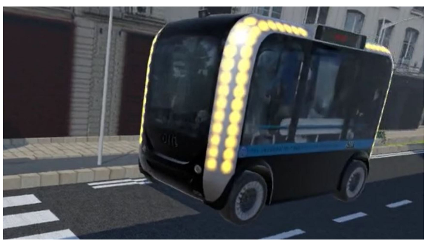


Figure 6.4: SAV2P interface – View from the side.

VR environment

The VR street environment was improved with several additional objects such as boxes, trash bins, a bench, street lights and a bus stop to make the scenery appeal more realistic. Additionally, background sound of a slightly busy street environment was added. An overview of the scene is illustrated in Figure 6.5.

Additionally, the skin of the HTC Vive controller was replaced by a small box that is used in the user study.

Figure 6.5: VR environment – Final iteration bird view.

6.2 Differences between interaction concept & interface prototype

Compared to the conceptualized interface in the previous Phase II (Chapter 5), there are some changes made to the interaction design. The interface is switched off, when the vehicle is not close to the zebra crossing (further than 50 meters) as the activation of the light sequence creates a feeling of acknowledgment towards the pedestrian. The interface is also switches off faster, after the SAV passed the pedestrian walk. Furthermore, the interface light color switches to yellow to indicate that the SAV will soon start moving or is not going to stop (Interaction III, Chapter 5.1) as a warning sign. It was pivoted as the same color for the whole interaction was too calm for the communication.

Given the limited amount of time, the laser projection was left out of the interface, as the first tests showed that it is a lot of fine tuning needed to make the laser appear in a non artificial way.

Chapter 7

Phase IV: user study

In this chapter, the details of the setup of the conducted user study and the related test procedure are detailed. Last, the results of the user study are presented.

7.1 Purpose & goal

In this user study, a VR setup was utilized to investigate the communication between pedestrians and SAVs. Thereby, the formerly created interaction concept that was built in Phase II, could be tested in a VR environment. This allowed to study the behavior of the pedestrians encountering an SAV with the use of the developed SAV2P interface versus no interface.

The goal of this user study was to answer the second research question: *b)Does the introduction of an interaction concept increase the level of comfort for the pedestrian in a crossing situation?* and test the null hypothesis H_o*: There is no difference in the comfort of crossing the street.* Related to that, the goal was to study and answer the following questions:

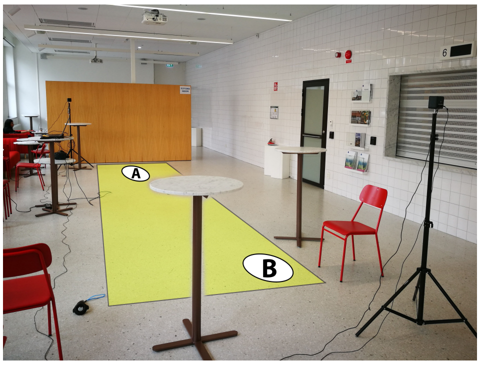
- Are test subjects able to decode the interface output?
- How high is the level of confidence to interpret the intention shown by the interface?
- How does the test subjects emotionally respond to the system? Are they feeling comfortable?
- Do test subjects feel safe/comfortable to act on the signal given by the interface and cross the street?
- How immersed did they feel in the VR environment?

7.2 Setup of the user study

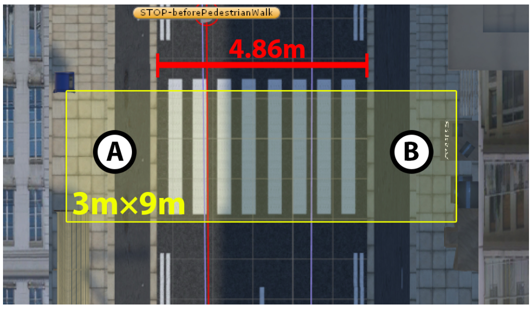
The experiment was conducted in the VR environment developed in Phase III (Chapter 6) in which each pedestrian encountered SAVs with and without the SAV2P interface (i.e. within subject design). In the following, the hardware setup and the test procedure is detailed.

7.2.1 Hardware setup

The same hardware setup as for the development of the VR environment and SAV2P interface prototype was used (see Chapter 6.1.1). The experiment was setup at two different test locations. Both test locations allowed the participants to freely move within an total area of 9×3 meters that is capturing a 4.86 meters wide zebra crossing in the VR environment. The first test location is illustrated in Figure 7.1a. The matching top view, showing the dimensions of the zebra crossing and the area in which the participant can freely move in the VR environment, is displayed in Figure Figure 7.1b.



(a) Test location I.



(b) Top view of VR scene.

Figure 7.1: Test location I & matching top view in VR scene.

7.2.2 Test procedure

Two researchers conducted the experiment, a test leader (the author) and a research assistant. The test leader had the view of what the subject is seeing at all times (Figure 7.2a) as well as an overview of the whole VR scene (Figure 7.2b). Furthermore, the test leader controlled the VR environment with a control interface that allows to change parameters (e.g. SAV2P interface switched on/off, traffic turned on/off, etc.) and switch between scenes (e.g. test scene and street environment).

(a) First-person perspective of test subjects observing the traffic.

(b) Bird view of VR test environment.

Figure 7.2: First-person perspective & bird view of VR environment

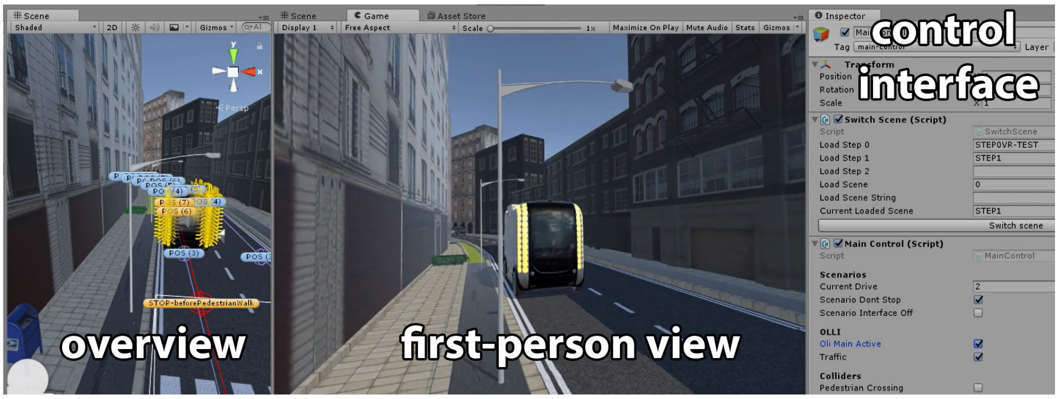


Figure 7.3: Test leader overview.

The whole view of the test leader is displayed in Figure 7.3. The research assistant assessed the participant, helped in recording the answers from the participants and guided them together with the test leader through the following five main steps:

1. **Introduction to the test**

    - *Goal:* Assessment of participant's level of experience as pedestrian and knowledge of SAVs. A test scene, in which the subject is free to move around in space, verifies if he/she feels comfortable in the VR environment.
    - *Procedure:* The test leader introduces him/herself to the participant and gives brief description about the project, stating the title, a description and the goal of the project: to study pedestrians' communication with SAVs.

      After that, the participant's prior knowledge about SAVs, the amount of experience as a pedestrian and the usage of public transport systems is assessed (Appendix B.1.1).

The participant is asked to sign a consent that he/she agrees on to be recorded during the experiment. The information that is gathered in the experiment, including the recorded video, is solely used for research purpose. The participant is able to quit the experiment with no reason at any time of the user study which is stated as a part of the consent.

Before the participant is presented with the virtual scene including the SAV, another test scene is played to make the user familiar with the VR environment. The user is shown a basic scene that is illustrated in Figure B.1 in that he/she can walk around to gain a feeling of comfort in wearing an HMD and being placed in a VR environment. During that test time, the test leader asks the participant, if the HMD is positioned correctly – makes adjustments if necessary – and asks the participant, if he/she is feeling well in the VR environment.

2. **Interface introduction and first encounter**

   - *Goal:* Getting familiar with SAV as a novel vehicle type and the SAV2P interface. Test the understanding of the participant in a first encounter of the SAV and the interface.
   - *Procedure:* The participant is not familiar with the interface and encounters it for the first time without being informed about it. He/she has the task to wait on the curb at the zebra crossing and observe the traffic. The SAV is stopping at the zebra crossing and after 5 seconds passing by. The participant is asked to describe the scene and what the SAV wanted to indicate (Appendix B.1.2).

3. **Interface understanding, level of confidence and understanding**

   - *Goal:* Explain all the functions of the system to the participant and measure the participant's level of understanding and confidence.
   - *Procedure:* Outside of VR, a video explains the details of the interface. The participant is asked if he/she understood the interface and can ask questions. Back in VR, the participant observes an SAV passing and answers questions about the understanding of the interface (Appendix B.2). Then he/she is asked to cross the street twice and read a note on a box. Each time, the participant is asked to rate her/his understanding of the interface and the confidence on a 6-point Likert-scale (Appendix B.2.1).

4. **Test & measurement of perceived safety and comfort**

   - *Goal:* Assess the pedestrian's perceived level of safety and comfort in crossing the street.
   - *Procedure:* The participant experiences the SAV yielding and waiting for the pedestrian to cross, once with the interface on and once with the interface off (in a randomized order). The participant is given the task to

get a box (a VR hand-held controller) and bring it on the other side of the street. After each encounter, the participant is asked to asses safety, comfort and expectations on a 6 grade Likert-scale as well as to motivate the answer (Appendix B.2.2).

5. **Interview on general impression and differences for verification**
   - *Goal:* Verify the answers and results found in the previous steps and get a self assessed insight on the participant's level of immersiveness within the VR environment. Additionally, to obtain design suggestions and improvements as well as the hypothetical acceptance of an SAV with the interface on the street.
   - *Procedure:* A semi-structured interview is performed outside of the VR environment. Questions related to how the participant experienced the differences in safety and comfort with the SAV2P interface on and off and about the level of immersiveness the participant felt in the VR environment are asked. The questions can be found in Appendix B.2.3.

7.2.3 Participants

N = 34 persons participated in the research experiment. From this sample, 22 were male and 12 female. The mean age was 24.6 with a 2.9 year standard deviation and a age range from 19 to 32 years old. All participants were students and recruited by asking them in a public area in the same university building where the experiment was conducted. 26 persons came from European countries, 8 persons were from Asia and 1 person from South America.

Figure 7.4: User study conduction – Participant in VR.

The knowledge for SAVs was assessed on a scale from 0 to 5 where 0 until 3 stands for the participant only read about the topic of AVs and SAVs or saw video material, 4 meaning that they saw an SAV on the road and 5 that they took a ride with an SAV. 31 participants stated a knowledge of 0 to 3, 1 a knowledge of 4 and 2 participants already drove with an SAV (Easymile EZ10 in Kista, Sweden).

The participants' experience as a pedestrian was high. The participants stated that they use public transport on a daily (31 participants) or weekly (3 participants) basis and walk as a pedestrian in the inner city on a regular basis (22 participants daily, 11 weekly and 1 participant monthly).

7.3 Results

A behavioral analysis was performed on the recorded combination of audio and video data and has been triangulated with the responses of the semi-structured interview. An initial analysis is presented including descriptive statistics to show trends and a significance test.

7.3.1 Understanding and preference of SAV2P

A significant majority (32 participants) indicated that they preferred the SAV2P interface after having learned how to interpret the signals. This result is confirmed by statements of the test participants such as without the SAV2P interface "it felt like a normal bus without a driver is approaching, that was scary." or "I was unsure if it will wait and not run me over, I had to constantly check [the SAV]."

The level of confidence in understanding how the SAV2P interface works was measured in two rounds, see Figure 7.5. A first measurement (a), after two encounters of the SAV that were observed without crossing the street and the explanation of the system with a video clip. A second measurement (b), after the first crossing interaction in the VR environment. The results show that the self-assessed level of confidence in interpreting the intention shown by the SAV2P interface was high. Around 85% (29) of the participants self-assessed their understanding with a 4 (8) or a 5 (21) on a scale from 0 to 5.

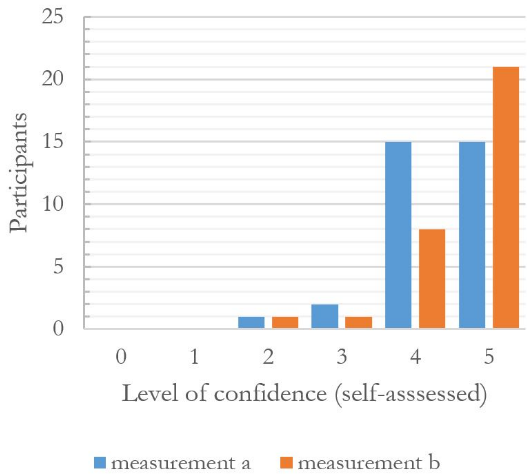


Figure 7.5: Results – Understanding of the system (Level of confidence).

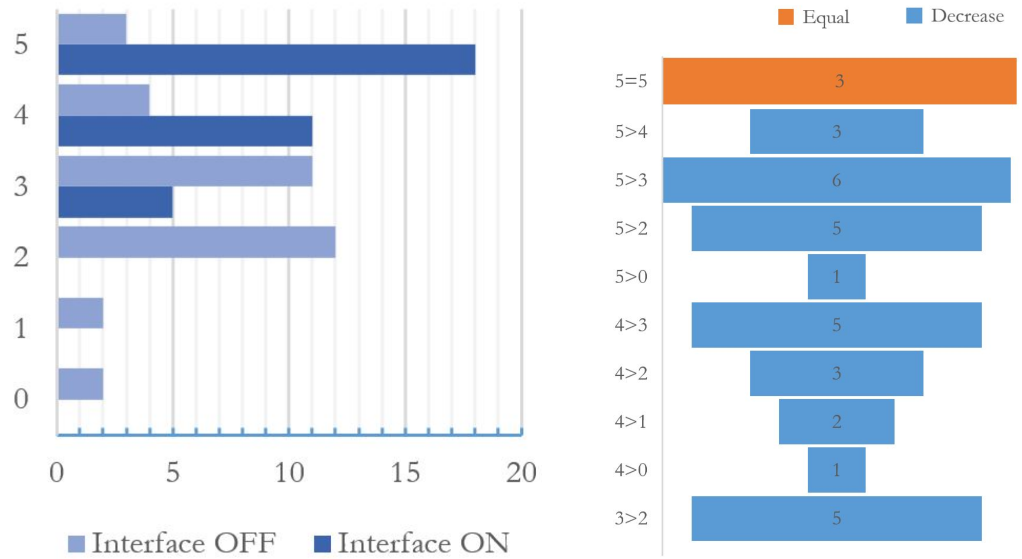
The thematic analysis on the topic of *understanding* shows that the participants felt more confident with an SAV2P interface. Additionally, both was mentioned by different participants: to be able to act faster or slower with the SAV2P interface. However, slower was motivated with the novelty of the interface.

- Higher confidence with SAV2P interface
  - "With the interface, I have more confidence in its behavior because I knew that [the SAV] will stop."
- Faster acting with SAV2P interface
  - "I felt a hesitation myself when I wanted to cross and checked if the vehicle will move" (SAV2P interface off)
  - "I had to assume the SAV stays, I shortly waited." (SAV2P interface off)

- Slower acting with SAV2P interface
  - "The lights helped the most, but I was checking them always, waited to check if it is the right signal then walked over"
  - "I think I need more time to train to really act on the signal"

7.3.2 Pedestrian's perceived safety in crossing the street

The total distribution of the gathered answers on the pedestrians' perceived safety is illustrated in 7.6a. Only three participants felt the same level of safety both when encountering an SAV with and without the SAV2P interface. The relative change from having the SAV2P interface on to off is displayed in 7.6b.



(a) Distribution of pedestrian's perceived safety in total.

(b) Relative change of pedestrian's perceived safety.

Figure 7.6: Results – Total distribution & relative change of pedestrian's perceived safety.

To test if there is a statistically significant difference in perceived safety depending on if the interface was off or on, a Wilcoxon Signed Rank Test was performed. Given that a within-subject design was used, the significance test involves data from 2 related samples from the two encounters exploring the perceived safety (see step 4 in the test procedure, Chapter 7.2.2). The results show with a significance level of $\alpha = 0.05$ that the null hypothesis *H0: There is no difference in perceived safety of crossing the street* is rejected.

Ranks

		N	Mean Rank	Sum of Ranks
Interface off - Interface on	Negative Ranks	30[a]	16.30	489.00
	Positive Ranks	1[b]	7.00	7.00
	Ties	3[c]		
	Total	34		

a. Interface off < Interface on

b. Interface off > Interface on

c. Interface off = Interface on

Test Statistics[a]

	Interface off - Interface on
Z	-4.785[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

The thematic analysis on the theme of *safety* shows that the participants felt more safe in crossing the street with an SAV2P interface:

- Feeling of not secure without the SAV2P interface
  - “It felt like a normal bus without a driver is approaching, that was scary.”
  - “I was unsure if it will wait and not run me over, I had to constantly check [the SAV].”
  - “I felt nervous about crossing the street”.
  - "The difference is that I don’t know what will happen."
- Feeling of more safe with SAV2P interface
  - "It felt much safer with the lights on."
  - "Yes, more safe with signalizing."
  - "I am trusting it more" (SAV2P interface on)

7.3.3 Pedestrian's perceived comfort in crossing the street

The level of comfort in crossing the street was perceived as significantly higher while the interface was switched on (29 participants felt comfortable) compared to when the interface was switched off (13 participants felt comfortable), see Figure 7.7. This was motivated by statements such as “I feel unsure when the vehicle will start moving again” and “I don't trust this vehicle”. This result was confirmed by the behavioral analysis in which a hesitation was observed in several cases where the participants waited until the vehicle was standing still and checked if it will remain in its position, before they started crossing the street.

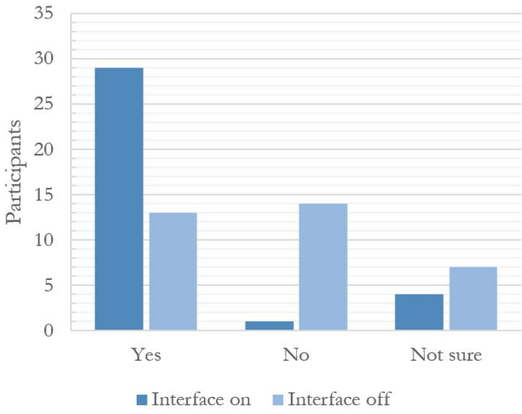


Figure 7.7: Results – Level of comfort (SAV2P interface on vs. off).

In contrast, the SAV2P interface facilitated at least 50% of the participants to start crossing the street earlier compared to when the SAV had no interface. This is the outcome of the behavioral analysis on the participants' behavior of start crossing the street encountering the SAV. The details are illustrated in Table 7.1. One column represents the combination of the subjects behavior encountering the SAV with the interface on and off. However, not all participants (10 participants) could be analyzed on that note as crossing situations occurred where the participant was not able to start crossing earlier caused by other ongoing traffic. Related to the level of comfort to cross, 32 participants stated that the communication of the SAV helped them in crossing the street when the interface was on, compared to, only 4, when the interface was off, see Figure 7.8.

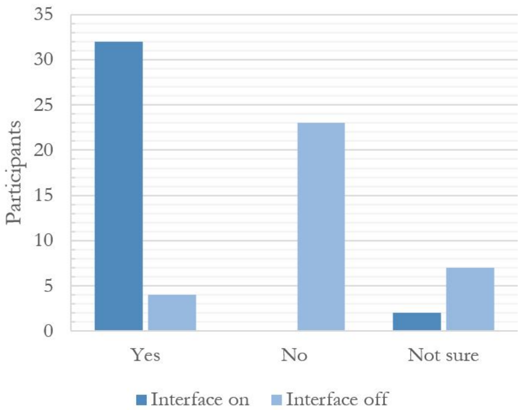


Figure 7.8: Results – Communication helped (SAV2P interface on vs. off).

	Pedestrian starts crossing the street encountering the SAV					
Interface on	afterSAVpassed	0m	0m	1-2m	2-5m	5m>
Interface off	afterSAVpassed	afterSAVpassed	0m	0m	0m	0m
Subjects	1	1	6	10	4	2

Table 7.1: Behavioral analysis on pedestrians start crossing the street.

7.3.4 Immersiveness in the VR environment

Two third of 34 participants had previous experience of VR. As the level of VR experience was not measured on a scale this result includes participants with different levels of VR experience - from simple HMD like the Google Cardboard to the HTC Vive. The participants felt immersed in the VR environment and mentioned that they tried to step on the curb although they knew it was just a height difference in VR. They motivated the high immersiveness by the combination of audio and visual information. On a scale from 0 to 5 with 5 as very immersed, they rated the VR experience: 5 (7%), 4(63%), 3(30%) and none below, see Figure 7.9. As a motivation one participant stated: "I really felt a hesitation on passing to the other side of the street because it felt so real".

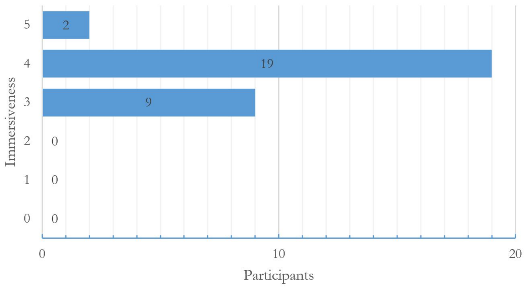


Figure 7.9: Results – Distribution level of immersiveness.

In general, it was observed that the participants were stepping sometimes more careful and moved slower than on a zebra crossing in a real environment, such as observed in the conducted field studies (Chapter 4.2). When they were asked if they think they moved slow or fast in VR, they mostly agreed on slower than in reality. During the test phase and at the conduction of the user study there were occasions where persons were hit by vehicles in the VR environment. In those situations the persons were trying to step aside in the last moment to avoid getting hit by a vehicle. One participant yelled in the moment of the crash in VR. On the aspect of immersiveness, the observed behavior of stepping aside and the use of an active expression shows that the persons in VR were also emotionally immersed. Additionally, the occurred crash situations point out that the VR environment can be still more improved in terms of quality and robustness as the vehicles should have stopped for the pedestrian.

Four participants additionally experienced the prototype of the SAV2P interface on a flat computer screen and were asked to cross four times to the other side of the street, using the zebra crossing. They were using the arrow keys and the mouse to move and navigate the camera in the environment. After that they were asked about how immersed they felt compared to wearing the HMD to interact with the VR environment. Three participants who rated a 4 for the VR experience with HMD, gave a 2 for the flat screen. One participant assessed the immersiveness of the flat screen experience with 1, in contrast to, 4 with the HMD. All the four participants were changing their behavior of being a pedestrian and tried to see what happens if they step in front of the SAV when it is indicating to not stop, respectively, to start driving. When they were asked to motivate their lower rating of the flat screen experience, they stated that "it feels more like a third person in a game" or "now as I know that I am just controlling this player, I want to see if the [SAV] is going to run over me. I wanted to check that in the VR [environment with HMD] as well but I was too afraid of that the vehicle will crash into me".

7.3.5 Design suggestions for the SAV2P interface and the VR environment

In the end of the user study, most of the participants were asking questions and giving comments on the design of the SAV2P interface and the VR environment they experienced. Six participants were asking about the color choice of the SAV2P interface and stated to naturally prefer green and red. However, they also came to the conclusion that especially in a transition phase of mixed traffic, another color choice might be a better choice as red and green might confuse with existing traffic- and break light systems.

To higher the level of immersiveness for the VR environment, participants gave feedback and stated things that could be enhanced in the VR environment to make it more realistic: "other pedestrians are missing (kids playing, older people walking with sticks)", as well as people with phones talking with each other, a higher amount of more diverse traffic including trucks and cyclists could be added.

Chapter 8

Discussion

This chapter presents a discussion on the results, a reflection on the research process and the used research methods. Moreover a sustainability and ethical perspective is pointed out. The chapter concludes with recommendations for future research work.

8.1 Results

The goal of this thesis was to answer the research question: *How will pedestrians be affected by the introduction of an interaction concept within the context of SAV2P?*.

First, a literature review and two field studies were conducted (Phase I) to find out how the communication between pedestrian and vehicles is performed. The results from the literature review and the field studies were translated into functional- and non-functional requirements. The outcomes of the literature review were congruent with the ones of the field studies and show that an active use of eye contact is present between vehicle-to-pedestrian communication.

The findings from the conceptualization phase (PHASE II) present five different interaction scenarios that can be designed in many different ways. In this project one SAV2P interface was developed based on the found functional- and non-functional requirements from conducted literature review and field studies. This allowed to evaluate and answer the first sub-question *a) How can an SAV2P interaction concept look like?*. The results of Phase II show that the SAV2P interface should use both visual and auditory modalities to communicate with pedestrians.

In the user study (Phase IV), participants indicated that they liked the combination of audio and visual communication modalities. The understanding as well as the related level of confidence on the SAV2P interface was rated high. Furthermore, both a faster and slower acting with the SAV2P interface was mentioned. As at least 50% of the participants started crossing the street earlier while encountering the SAV with the SAV2P interface, the statements for a slower reaction time might also be connected to the novelty factor of the interface. This means that pedestrians may be able to interpret the signal of the SAV and act faster on it with a higher level of experience. This was also one finding in the work of Lagström and Malmsten

Lundgren (2015). Additionally, the majority of the participants stated to prefer encountering an SAV equipped with such an SAV2P interface compared to an SAV without one.

Nevertheless, participants had different opinions on the design of the SAV2P interface, especially in terms of coloration, the opinions were drifting apart. Therefore, further different designs of an interface as well as new standards have to be researched and examined.

Having answered the first research sub-question, the basis for the evaluation on the second sub-question *b) Does the introduction of an interaction concept increase the level of comfort for the pedestrian in a crossing situation?* is given. The outcomes from the user study (Phase IV) indicate that the devloped SAV2P interface has the potential to improve pedestrians' perceived safety and comfort in crossing the street, encountering SAVs. The test procedure of the user study was setup as a within subject design. This allowed to gain a relative comparison on the perceived safety and comfort for each individual. The related hypothesis *H0: There is no difference in the level of comfort of crossing the street* (Chapter 1.4) was statistically tested with the Wilcoxon Signed Rank Test and thereby rejected. This result was also confirmed with the conduction of a thematic content analysis of the interview answers on the differences between an SAV2P interface on or off. Furthermore, the results are giving the same indication as related work on AV-to-pedestrian communication by Lundgren *et al.* (2016).

The participants felt more comfortable in crossing the street when the encountering SAV was showing it's intention respectively driving state with the SAV2P interface compared to not having an interface. This was confirmed by a behavioral analysis on the crossing behavior that showed that at least 50% of the participants started to cross the street earlier compared to when the SAV2P interface was off and were often start crossing when the SAV was not standing yet. This shows that the SAV2P interface also has the potential to make crossing decisions faster for the pedestrian.

The participants felt immersed in the VR environment. The user study of four participants that also interacted with the SAV on a flat computer screen indicates that this setup has a direct influence on the behavior of how participant's interact with the VR world. To reason from that, a user study using the full VR experience with an HMD and the possibility for the participants to move in the world, results in a more realistic behavior and interaction of the subjects. Nevertheless, also the conduction of user studies in VR environments with HMD have effects on the results, like the partly observed slower walking speed, compared to in a real environment.

To sum up, from the user study it can be concluded that an SAV2P interface is an external device that is able to successfully communicate the driving intentions of an SAV. Thereby it facilitates the level of comfort and the perceived safety of pedestrians and makes faster and safer reactions by the pedestrians possible.

Both, the level of comfort and the perceived safety were higher with an SAV having an interface communicating it's intention and driving state to the pedestrian. All participants were able to decode the signal conveyed through the SAV2P interface.

8.2 Reflection on research process & methods

This research project followed the four phases: **Phase I** – requirement analysis, **Phase II** – concept generation, **Phase III** – prototype development and **Phase IV** – user study, described in detail in section *research process* (Chapter 3.1).

In **Phase II**, the methodology of Spadafora *et al.* (2016) was used. The related interaction vocabulary by Lenz *et al.* (2013) were seen as helpful by the participants of the interaction design workshops. They facilitate a common ground to discuss and compare different interactions based on behavioral parameters and interaction styles. However, as briefly mentioned in Chapter 5.2.1, the interaction vocabulary could have been more specified to the topic of automated driving.

In **Phase II & III**, a deeper investigation towards the prototype realization and test of several different designs to decide on a final interface design was missing. Only some small adjustments were made after a small number of user tests, for instance, the change of colors and the timing of the communicated intentions by the interface were made. Moreover, the involvement of HCI experts and designers from the automotive domain could have further improved the perspective and design of the interaction concept.

In **Phase IV**, the test procedure of the user study was setup as a within subject design. This allowed to gain a relative comparison on the perceived safety and comfort for each individual. However, this might have also affected the expectations of the participants as they first learned how the SAV2P interface works and after that were asked to give an indication on safety and comfort with the interface on or off. An additional study with a between subject design would now help to draw further conclusions.

The studied user group consisted only of students what strengths to make assumptions for this specific user group. In spite of that, the open question stays, if another target group such as children or elderly would interact in the same way or differently. In case of setting up user studies with different participant groups (e.g. elderly), it must be considered that two third of the participants in the conducted user study in this work had previous experience with VR. This is a factor to consider for a low impact of VR novelty effects, for instance, being distracted by the VR experience itself. This effect might occur with other target groups that are less familiar with VR environments. Therefore, the used method to study the impact of an SAV2P interface on pedestrians might not be the most fitting for all different kind of target users. For this reason, it has to be further researched in which situations and with which participants VR environments are an appropriate way for evaluation.

The number of participants who experienced an SAV in reality is with 3 participants very low. More participants with a higher knowledge and experience of SAVs could have more extensively explored the users needs.

As mentioned in the discussion of the results (Chapter 8.1), comfort and perceived safety were not individually valued and defined by participants. Moreover, these parameters were not further defined in the context of the user study. Wasser J. *et al.* (2018) introduces a conceptual comfort framework for the design of SAVs that has it's focus on the users, respectively passengers of SAVs, however, a derived set of factors for the interaction between pedestrians (VRUs) and SAVs may be useful to consider to be used in future research.

8.3 Sustainability & ethics

Some sustainability aspects for the promotion of SAVs were already mentioned in section *Background & motivation* (Chapter 1.1). To summarize the pros and the cons, SAVs have the potential to have a positive environmental and social impact. A change of the whole design of urban areas to better meet the needs and wishes of VRUs is one convincing argument. This means: less parking spaces, more efficient and less traffic running in the inner cities, if the inhabitants use SAVs instead of private owned cars. Furthermore, SAVs enable a higher level of mobility for new user groups such as elderly, young- and disabled people (Frisoni *et al.*, 2016; van Nes and Duivenvoorden, 2017).

In this research project an SAV2P interface that aims to improve the pedestrian's perceived safety and comfort in crossing a street, where SAVs operate, was developed. In this regard, the SAV2P interface aims to enhance the communication for pedestrians encountering SAVs and thereby also prevent accidents. On a larger scale, when all VRUs are included into the design process and also ones with special needs, such as visually-, mobility- or cognitive impaired people, VRUs can benefit from such an SAV2P interface when it is optimized for their needs (Owens, 2016). This means the use of sound for visually impaired, longer crossing times for mobility impaired and a clear and easy understandable communication towards cognitive impaired. This may lead to a higher accessibility and acceptance of SAVs and therefore to a sustainable introduction of this novel technology. The mentioned factors to establish a smooth communication between VRUs and SAVs can additionally improve the traffic flow on the streets, which leads also to a better adoption of SAVs and a more energy efficient operation.

In this research project, apart from the designed and prototyped SAV2P interface, a VR environment was developed that can be used for future research in the communication between pedestrian and SAV. Moreover, it could be used as a tool to bring diverse parties of the automotive domain, such as designers and policy makers as well as users together to discuss designs and policies. This may also facilitate a faster introduction of SAVs.

Regarding research ethics, it can be concluded that the chosen approach to conduct research in a VR environment has the advantage of studying participants behavior without having them to put into any dangerous situation (e.g. hit by a vehicle). Having a human subject in the center of the research, it is essential to put the interests and health of the participant at first (Lazar, 2017).

8.4 Recommendations & future work

The research project raises several open research questions that can be studied and change aspects of the presented work. This encompasses:

Methodology All participants were introduced to how the SAV2P interface works, which might have affected the results on the level of perceived safety and comfort. Therefore, a similar study with a between subject design that does not introduce an interface at all might give further insights on the topic.

Participants Given that this study included only students in a certain age group, more research is needed with other target user groups to fully understand the impact of an SAV2P interface.

SAV & AV The results on the communication between pedestrian and SAV are in line with the research on AV-to-pedestrian communication (Lundgren *et al.*, 2016). This raises the question if SAVs should be seen as a sub group of AVs in terms of interaction design or if the differences such as form factor, no steering wheel and responsible driver at all times.

Interaction design More different designs for an SAV2P interface have to be created and evaluated to find a fitting design for as many road users as possible.

Another open question is whether the (S)AV should communicate its own intentions and/or give the VRU commands/offers (e.g. right of way).

Traffic situations As the street design will shift to a more VRU friendly one with less traffic, new studies with unsigned intersections are necessary to study the environments of the future (researcher of Mercedes Benz, personal communication at Sindelfingen (Germany), July 20, 2017).

Furthermore, as only one interface design was tested in a specific traffic situation, more different types of interaction scenarios needs to be studied. This includes: traffic situations, environments and scenarios.

To use appropriate street designs, real-world environments could be translated 1:1 into a VR environment. Additionally, traffic- and road design guidelines that are researched and road policies can be used as an input for that purpose (E.g. (Boodlal, 2004; Blecic *et al.*, 2013)).

VR research The VR environment developed is a promising platform for performing more future user studies. Future work should investigate its robustness and quality as well as to enhance the ability to control and manipulate the VR environment to enable a smooth and fast setup for the conduction of user studies. On that note, it has to be also researched when using VR is appropriate. The built VR environment could be a useful platform to test potential future interaction scenarios. Above that, VR may be helpful to test also how the infrastructure/crossings should be designed for a better smoother interaction.

On a final note, to ease the adoption of SAVs and a standardized SAV2P interface, it is recommended to conduct and assess research with the help of a VR environment in future projects together with legislative authorities, representatives from the automotive industry, designers and users.

Chapter 9

Conclusions

With the introduction of SAVs, a shift in the communication from a driver-to-pedestrian to a SAV2P emerges. This master thesis degree project had the goal to investigate the impact of an SAV2P interface on pedestrian's experience interacting with SAVs. To study the effects of an SAV2P interface on pedestrians an UCD approach was executed. First, the exploration of how such an SAV2P interface can look like was performed. For this, a literature review and field studies lead to functional and non-functional requirements of an SAV2P interface. In a second step the creation of an interaction concept based on the list of requirements was generated. In the next step, a VR environment and an SAV2P interface prototype were developed using both audio and visual modalities. Finally, a user study was conducted to assess and study the effects of the SAV2P interface on pedestrian's perceived safety and comfort in crossing the street, facing SAVs.

Having completed the previous mentioned steps and performed research, the following major contributions emerge out of this work:

a) knowledge of how pedestrians may interact with SAVs,
b) an SAV2P interface prototype that addresses this interaction,
c) a VR environment to test interactions between pedestrian and SAVs, and
d) a test procedure and method to evaluate an interface prototype in VR.

The evaluation of the SAV2P interface prototype shows that the interface has a positive impact on the pedestrian's perceived safety and comfort in crossing the street when encountering an SAV.

The understanding of the signalization of a specific intent through the SAV2P interface by the SAV was interpreted correctly by all participants. The self-assessed level of confidence was high after a short amount of time. This may show that the introduction of an SAV2P interface for SAVs into the market could go smoothly. However, it has to be considered that in case of an introduction to the market, the interface also has to be tested with other user groups such as elderly, children and impaired people. Furthermore, in the phase of introduction and the novelty status of SAvs and an SAV2P interface, the signals first must be learned by the pedestrian.

Above that also other road users have to be able to interpret the signals. Therefore, simplicity must stand in the focus of the design as the interface must be correctly interpreted by all different kind of road users. On that note, it is vital to develop an standard that can be used from different vehicle manufacturers so that the road users will not have to learn several different interface signals.

For the given reasons of enhancing the communication between pedestrian and SAV, as well as to facilitate the pedestrians' perceived safety and comfort in crossing the street, the acceptability of SAVs may be promoted by an SAV2P interface. For the successful introduction and deployment of SAVs this might be an important step to overcome the cognitive biases (e.g. the technology is read and safe to use) of this novel technology and mean of transportation (Merat *et al.*, December 2016).

Finally, as a concluding remark, it can be inferred that there is a future need for an interface that is communicating the intention of an SAV towards pedestrians a. This also includes the information on the current driving state of the vehicle. The proposed design of an SAV2P interface shows how an SAV can communicate with a pedestrian. However, future research both on other participant groups than students, other traffic situations, environments and scenarios must be conducted to receive complementary insights that can be used to further improve the communication between pedestrian and SAV. Additionally, more different designs have to be explored and examined. Above that, the research area should be extended in the future by including all different kind of road users to enable a seamless encounter of all VRUs, AVs, SAVs and manual driven cars.

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Appendix A

Field studies

A.1 WEPods

A.1.1 Route of WEPod SAVs

The current driving route of the two SAVs within the WEPods project in Wageningen is displayed in Figure A.1. The goal of the project is that the WEpods will be "circulating between Ede-Wageningen railway station and Wageningen University & Research centre (WUR), as well as on the WUR campus".[1]

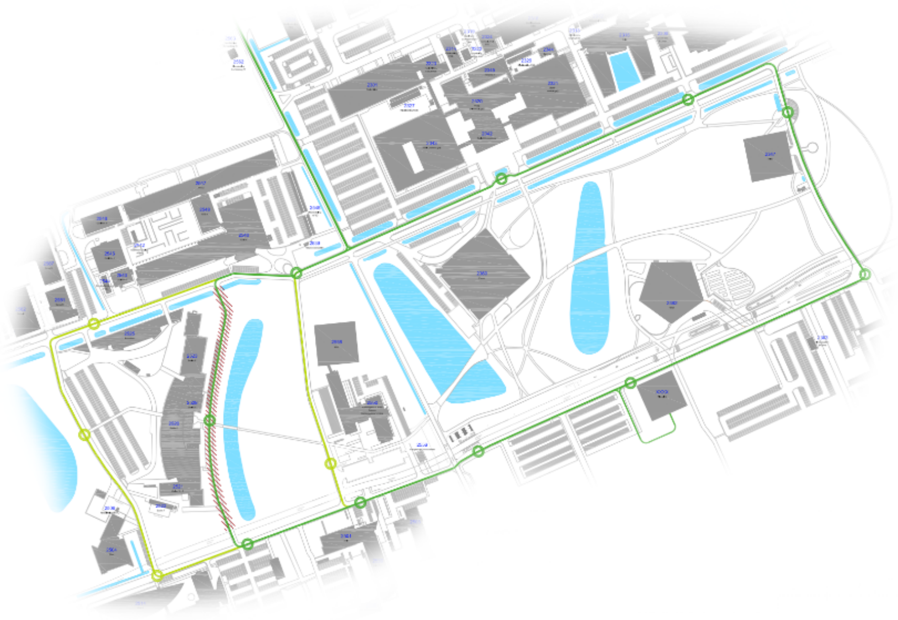

Figure A.1: WEPods driving route. Graphic by WEPods.

[1]Source & futher information on: `http://wepods.com`

A.1.2 Interview & observational questions

- Observational leading questions
    1. How does the vehicle look like in general?
    2. Does the vehicle have any communication interface towards the surrounding road users?
    3. How do pedestrians react when encountering the SAV?
    4. Is the steward observable as a steward from the outside of the vehicle? (Rodriguez *et al.*, 2016)
- Interview questions
    1. Does the vehicle have any communication interface towards the surrounding road users?
    2. How do pedestrians react when encountering the SAV?
    3. Which are situations in which there is a moment of stuckness between SAV and VRU?
    4. How often does the steward has to intervene into the driving activities of the SAV?
    5. Are people testing to step in front of the vehicle?
    6. How integrated are the vehicle in the community? Is the vehicle well-known?

A.2 Stockholm bus 50

A.2.1 Route of bus 50

The bus 50 is a route starting from the campus Lappkärrsberget which is the biggest student campus in Stockholm. The route starts at the bus stop Lektorsstigen passes by several unsigned zebra crossings and goes through the inner city of Stockholm to the final bus stop Moa Martinsons torg. All bus stops and the bus route are illustrated in Figure A.2.

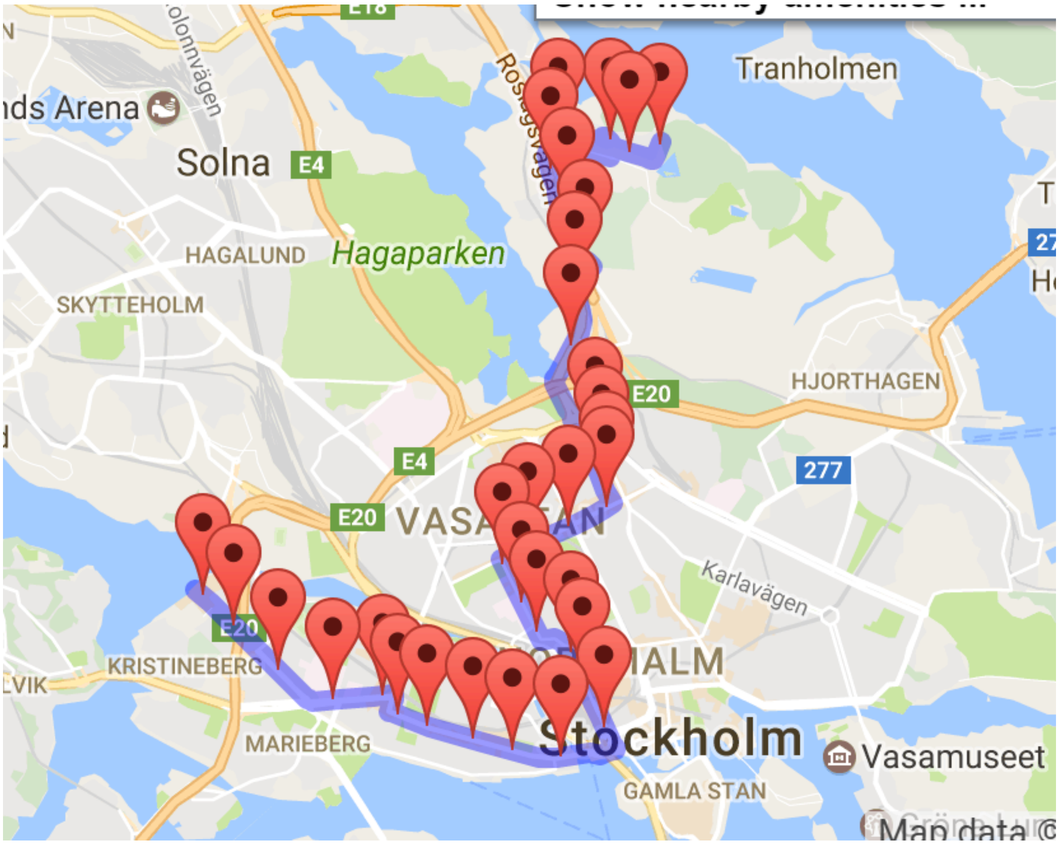

Figure A.2: Stockholm Bus 50 driving route beginning from Lappkärsberget. Graphic by Google Maps.

A.2.2 Interview & observational leading questions

- Observational leading questions
    1. What is the indication, if the bus stops or not?
    2. How do pedestrians indicate that they want to enter a bus?
    3. How do pedestrians indicate that they do not want to enter a bus?
- Interview questions with pedestrians
    1. How do you show the bus driver that you want to enter a bus when it is approaching?
    2. How do you see that the bus will stop for you?
    3. Is it always clear that the bus will stop for you on a scale from 1-5, where one is strongly disagree and 5 is strongly agree?
    4. In which sitautions is it unclear that the bus will stop for you?

5. You are crossing the street in front of a bus at a zebra crossing, how do bus drivers indicate that they will stop for you?
6. Is it different compared to other vehicles?

- Interview questions with bus drivers

1. How do you see that a pedestrian wants to enter the bus when there are only one to three persons standing close-by a bus stop?
2. How do you see that a pedestrian does not want to enter the bus?
3. How do you signalize to give pedestrians way, if they want to cross the street in front of the bus, for instance at a zebra crossing?

Appendix B

User study

B.1 Additional figures

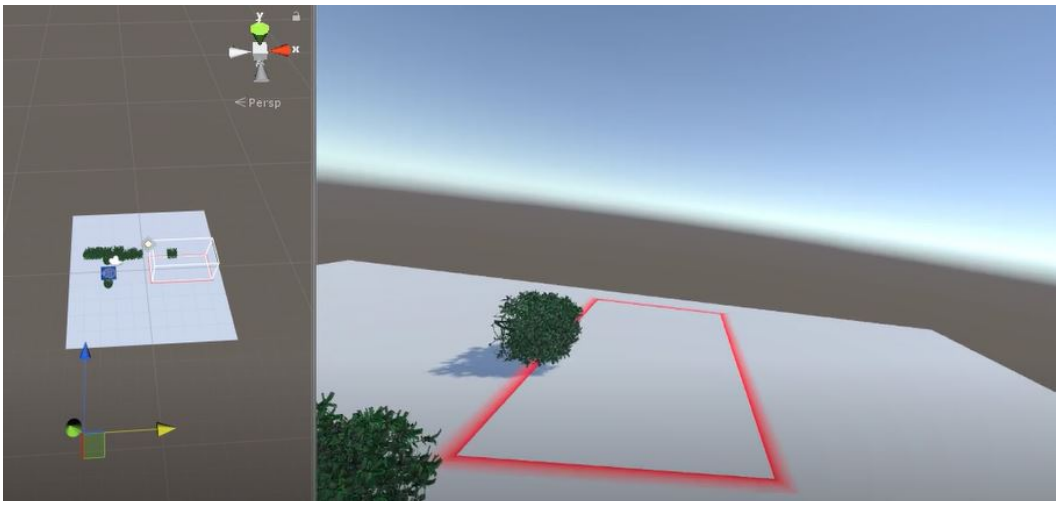

Figure B.1: VR test scene.

B.1.1 Questions – Assessment of participant

1. How old are you?
2. Are you a student?
3. Please state your knowledge of SAVs on a scale (0 – no knowledge to 5)
4. How often do you use public transport such as metro, tram or bus (daily, weekly, monthly, less than once in a month)
5. How often do you walk as a pedestrian in the inner city? (Daily, weekly, monthly, less than once in a month)

B.1.2 Questions – First encounter of SAV

- Describe what you saw?
- What do you think the SAV wanted to indicate you?
- What functions did the LEDs and the audio signals have?

B.2 Questions – Second encounter of SAV, verification of understanding

- Do you have any further questions about the system?
- Do you understand, how the system works?
- How confident are you in your understanding of the system? (Likert-Scale 0-5)

B.2.1 Questions – Level of understanding

- What did the SAV communicate to you?
- How confident are you with your answer? (Likert-Scale 0-5)

B.2.2 Questions – Test & measurement on perceived safety and comfort

- Did you feel safe around the vehicle? (Likert Scale 0-5), please explain.
- Did you feel comfortable in crossing the street?, please explain.
- Did you feel the communication from the vehicle(bus) helped you? Why/Why not?
- Did the vehicle do what you expected? Yes/No, please explain.

B.2.3 Questions – Interview on general impression for verification

- Did you experience any difference, encountering the SAV with the interface active or not active?, please explain.
- Did you feel any difference in terms of safety? Please explain why or why not?
- Did you feel the vehicle knew what you were going to do? Yes/No
- Did you feel there was a point of time where neither you nor the car would move? Yes/No (if yes, please explain)
- Did you feel unsure about the actions of the vehicle at any point in time? With the interface on/off.
- If you would see an SAV now on the street, would you trust the SAV more, or less after interacting with it? More/Less.

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