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EXTERNAL HUMAN-VEHICLE INTERACTION - A STUDY IN THE CONTEXT OF AN AUTONOMOUS RIDE-HAILING SERVICE

Master's Thesis

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I have written this Master Thesis independently. Any ideas or data taken from other authors or other sources have been fully referenced.

External Human-Vehicle Interaction - a Study in the Context of an Autonomous Ride-Hailing Service

Autonomous vehicles have a major potential to save lives in traffic and when implemented into ride-hailing they can also save labor costs. At the same time there is still limited research in human-vehicle interaction, which is considerably an important topic in autonomous ride-hailing. Which is why this paper aims to explore how pedestrian interaction with autonomous vehicles in a ride-hailing scenario can be improved, concentrating explicitly on external interaction. For this we conducted a Wizard-of-Oz study in which participants were asked to negotiate a pick-up by an autonomous vehicle. We introduced changes in speed (slow/optimal) and stopping location (before/at/after the participant) to learn how it affects the interaction. In addition, we used a light panel to indicate the vehicle's locking status and guiding the participant to open the rear door. The speed of the vehicle had little effect on the interaction while the vehicle stopping after the participant created confusion and decreased the feeling of safety in some participants. Light panel was unable to guide the participants as the participants were unable to verify if the panel was meant for them and the exact meaning.

Keywords: autonomous vehicles; external human-machine interfaces; ride-hailing, robotaxi, public transportation.

CERCS: P175, S190.

Introduction

Every year approximately 1.34 million people die as a result of a road traffic crash (WHO, 2020). Pedestrians are one of the most vulnerable road users in traffic as according to WHO (2020) more than half of all the road deaths happen among vulnerable road users like pedestrians, cyclists or motorcyclists. In 2019 a total of 6,205 pedestrians died in traffic which is approximately one in every 85 minutes (NHTSA, 2020). 94% of serious accidents happening in traffic are due to human error (NHTSA, 2020), this is exactly why autonomous vehicles (AVs) have the potential to save the lives of millions of people (Fagnant & Kockelman, 2015).

Over the past three years the estimated investment in autonomous vehicle technology has been more than 80 billion dollars (Karsten, 2017). At the same time, the ride-hailing industry is growing vastly as well, for example Uber managed to serve 6.8 billion rides in 2019 (Wong, 2021). As AVs implemented into ride-hailing could help to enormously save labor costs, but as well as to improve the inefficient use of privately-owned vehicles (Liu et al., 2017) then autonomous ride-hailing has gained popularity. It is estimated that in Los Angeles the autonomous ride-hailing revenue by 2030 could be even up to 20 billion dollars (Heineke et al., 2019). While big investments are made into developing the technology of AVs there is still limited research made about the human-vehicle interaction (Rouchitsas & Alm, 2019), arguably a topic of high-relevance for designing the autonomous ride-hailing service. When we put AVs on the streets, we also cardinally change how traffic participants interact with each other as they lose the option for eye-contact or gestures, which are used today mostly for communication (Riener & Keferböck, 2015).

Even though some general findings from the available studies of pedestrian-AV interaction help to lay out the primary framework for designing autonomous ride-hailing interaction, the underlying task is quite different. In vehicle-pedestrian interaction the goal is to ensure safety of the human while maintaining smooth traffic flow. In the ride-hailing scenario the task of interaction is to make sure that the AV and the passenger can safely interact by making sure they correctly identify one another and negotiate mutual terms for the pick-up up until the passenger is successfully driven to the correct location. Also, there is still some debate whether any special focus on pedestrian-AV interaction is even needed as there is no common understanding of the existence of explicit passenger-driver interaction (Moore et al., 2019). However, the smooth and rapid pick-up in ride-hailing service often relies on the driver and passenger engaging in verbal (over the phone) and/or gestural (hand waves for identification) interaction (Owensby et al., 2018).

The main aim of this paper is to explore how pedestrian interaction with autonomous vehicles in a ride-hailing scenario can be improved, concentrating explicitly on external interaction. The paper investigates and reports which key findings from the research of pedestrian-AV interaction can be considered relevant in the case of designing the autonomous ride-hailing interaction.

Pedestrian-vehicle interaction studies do not yet have one clear understanding whether implicit interaction (e.g. car movement) by itself is enough for pedestrians to understand the vehicle’s intent or if specific explicit interaction (e.g. external display) is needed to convey the intentions, thus the following two research questions are developed:

- **RQ1**: How does the implicit interaction in the form of a vehicle's behavior affect the external interaction between the pedestrian and an autonomous vehicle in a ride-hailing scenario?
- **RQ2**: How does explicit interaction improve the external interaction between human and an autonomous vehicle in a ride-hailing scenario?

To further explore the domain of human-AV interaction for the ride-hailing use case and be open to further findings, a third research question is introduced:

- **RQ3**: What could be improved in the interaction between a pedestrian and an autonomous vehicle in a ride-hailing scenario?

To find answers to the research questions a Wizard-of-Oz user study is designed, in which participants are asked to negotiate a pick-up by an autonomous vehicle. In addition to observing the physical behavior and the gaze of the participants during the vehicle's approach and the pick-up, interviews are carried out to provide qualitative insight into relevant human factors.

Current Master thesis is written in an article format. The goal is to submit it to the Journal of Intelligent Transportation Systems. Style and length are modified to suit the submission criteria.

Related work

Pedestrian-vehicle interaction

Interaction design is creating a dialog between the user and product, system or service (Kolko, 2011). This dialogue can both be emotional and physical in nature, but the main goal is to reduce negative aspects and enhance the positive ones (Kolko, 2011; Rogers et al., 2011). When designing the interaction between an autonomous vehicle and pedestrians we must first understand how pedestrians currently interact with regular vehicles in traffic.

When interacting with the drivers of traditional vehicles pedestrians use various gestures to communicate their intent, including eye, head or hand gestures (Färber, 2016; Riener & Keferböck, 2015). The overall communication between pedestrians and vehicles is complex and varies in different cultures (Färber, 2016). In total there are five main factors established that guide the interaction between traffic participants: (1) traffic rules, (2) expectations, (3) individual differences, (4) behavioral adaptation and (5) informal rules and non-verbal communication (Vissers et al., 2016). When it comes to the design of the interaction with autonomous vehicles there is no possibility to generally affect the traffic rules, individual differences and behavioral adaptations, which means we need to concentrate on the expectations, informal rules and non-verbal communication (Schieben et al., 2019).

When it comes the pedestrians' expectations then they use four main aspects upon which they build their perception of the future actions of the vehicle: (1) information about vehicle driving mode, (2) information about the vehicle's next maneuvers, (3) information about perception of environment, (4) information about cooperation capabilities (Schieben et al., 2019). When we imply these aspects to ride-hailing we get four clear user needs: (1) clearly identifying the car, (2) understanding the current status of the car, (3) knowing that the car is aware of the passenger and (4) knowing the intent of the car (Owensby et al., 2018). These needs must be considered when designing the autonomous ride-hailing experience.

Pedestrian-autonomous vehicle interaction

The approach in regards to how the interaction between pedestrians and autonomous vehicles can be designed can be divided into two: implicit and explicit interaction (Moore et al., 2019). In case of implicit interaction car motion for example can serve as an indicator for the pedestrian to understand the vehicle's intentions, while in case of explicit interaction different kinds of additional lights or displays might be used to indicate the vehicle's intentions.

Implicit interaction

When it comes to pedestrians making a crossing decision in front of an AV, multiple studies have shown that pedestrians interpret the vehicle intentions by the vehicle movement alone (Clamann et al., 2017; Fuest et al., 2018; Rothenbücher et al., 2016; te Velde et al., 2005). In a Wizard-of-Oz study by Rodríguez Palmeiro et al. (2018) they studied the gap distance between the car and pedestrians and the results showed no significant gap between a group interacting with an autonomous vehicle compared to the one interacting with a regular vehicle. This indicates that the interaction was not made with specific driver given clues, but rather from the vehicle movement alone (Rodríguez Palmeiro et al., 2018). Further in a study by Clamann et al. (2017) participants reported gap distance as the main determinant of road crossing decision, speed of the vehicle being second in importance and traffic density was third. Experiment by te Velde et al. (2005) where pedestrians' crossing decision was assessed when interacting with a bicycle supports this, as all groups noted distance and velocity of the approaching bike as main influences of making the crossing decision. Another Wizard-of-Oz study where pedestrians' behavior was studied at the crosswalk in case of AV showed that people generally adhere to existing interaction patterns with vehicles unless there really is a breakdown of expectation (Rothenbücher et al., 2016).

While there are studies supporting the fact that pedestrians use vehicle movement to interpret the AV's intentions in a crossing decision, there is still a significant gap in researching how the vehicle movement affects the interaction when we put the interaction in a ride-hailing scenario. In case of a pedestrian crossing the road the pedestrian deliberately wants to avoid close contact with the vehicle to ensure their safety while in case of ride-hailing the goal of the pedestrian is totally different, which might also influence how the interaction must be designed.

External human-machine interfaces (eHMI)

On the other hand, multiple researchers have stated that in some cases vehicle movement alone is not enough for the pedestrian to successfully interact with an autonomous vehicle (Hensch et al., 2019b; Li et al., 2018; Mahadevan et al., 2018). A review of empirical work of external human-machine interfaces for autonomous vehicles by Rouchitsas and Alm (2019) found that in a great majority of covered studies the participants found an interaction with a vehicle equipped with an additional external communication interface as more efficient and safer than the interaction without any explicit interface. A study by Habibovic et al. (2018) showed that in case people get a short training about the external interface they are more likely to understand the signals conveyed with the interface. While all of these studies give a reasoning of using explicit interfaces in case of pedestrian crossing decision to help in safer crossing, then still there is no research made whether external interfaces could also help the interaction between pedestrians and AVs in ride-hailing scenario.

When it comes to the design of the external interfaces a paper by Dey et al. (2020) covered in total 70 different eHMI concepts and found in total five modalities of eHMI pedestrian-AV communications: visual, auditory, haptic, body language and other (which cannot be classified in the previous categories). From the 70 concepts the most commonly used modality in pedestrian-AV interaction studies was abstract visual communication. While there are conclusions that the eHMI helps to mitigate the pedestrians’ obscurity and help them understand the vehicle’s intent, then there is no general consensus regarding the exact type and modality of the nature of the eHMI communication (Dey et al., 2020). In addition, a study by Charisi et al. (2017) showed that people recognize external interfaces which are similar to what they already know (e.g. traffic lights and signs)

When we look at companies developing their autonomous ride-hailing service, we can see that Google, Uber and Lyft have all filed patents for car-to-pedestrian communication using external displays. Google´s patent filed in 2012 concentrated mostly on communication with pedestrians to indicate the intent of a self-driving vehicle and the situation is described in the interaction with pedestrians in road crossing situations (Urmson et al., 2015). Uber took a similar approach as Google, but also added a virtual driver and additional displays for arrows pointing the direction the vehicle would like the pedestrian to go (Sweeney et al., 2018). Lyft's patent on the other hand in addition to regular pedestrian interaction concentrates on its interaction with ride-hailing customers by displaying the customer's name on the windshield (Matthiesen et al., 2019). Although all the patents have been active for at least a year none of the companies have implemented these displays to their active publicly driving autonomous vehicles, making it hard to evaluate whether any of these solutions help in improving the interaction.

While the eHMIs are widely researched in the last previous years the focus has mostly been on improving "safety" and "user experience" while the subject of efficiency of the eHMI is largely unaddressed (Dey et al., 2020). A study by Clamann et al. (2017) assessed the effectiveness of different types of displays and the results showed no significant difference between the effectiveness of these different displays to using no display at all. Also, participants reported in the interviews that gap distance was the main determinant of road crossing decision, while the speed of the vehicle was second in importance and traffic density third, only two participants mentioned that displays for them are the most important information sources (Clamann et al., 2017). There is still a significant gap to research the effectiveness of using an eHMI in designing human interaction with an AV especially in the field of ride-hailing.

Studying implicit and explicit HVI

Rouchitsas & Alm (2019) brought out when analyzing the use of external displays in human-vehicle interaction (HVI) that the methodological parts of the studies varies from using simple monitor based studies, to giving a more realistic sense as a form of VR studies. Only a handful of the covered studies used a real physical prototype in assessing the eHMI. The authors brought out that ideally human interaction with an AV should be studied under real-world traffic conditions, so there is a possibility to maximize the environmental generalization of research findings (Rouchitsas & Alm, 2019).

As the access to autonomous vehicles is currently quite limited, then as also mentioned previously some researchers use the Wizard-of-Oz method in studying the HVI. In this case the human driver is hidden behind a car seat costume to appear as if the car is driving without a human driver. This is also sometimes referred to as the Ghostdriver protocol (Currano et al., 2018; Rothenbücher et al., 2016). It was first introduced by Rothenbücher et al. (2016) in a study, which found that from 67 participants 87% believed that the car was driving on its own and 80% noticed that the driver was missing, indicating that the Wizard-of-Oz method worked well with exploring the HVI for autonomous driving. Another study by Hensch, Neumann, Beggiato, Halama, & Krems (2019a) supported this as 79% participants in their experiment did not notice any driver when interacting with a Wizard-of-Oz autonomous vehicle, but on the other side only half of them actually believed that the car was driving autonomously proving that Wizard-of-Oz is an effective way in researching HVI.

Methodology

To find answers to the three research questions, an exploratory study is conducted. In the Wizard-of-Oz study the participants are asked to imagine that they ordered a ride-hailing vehicle to their location. The participants wait for the autonomous vehicle to arrive and their aim is to open the vehicle's door after which the study will end with an interview.

Setting

The study took place during 2 days in Tartu, Estonia. University of Tartu´s Autonomous Driving Lab´s autonomous vehicle was used to conduct the study in as much of a real case scenario as possible. The vehicle is Lexus RX 450h which also has a visible lidar system and signs indicating "Autonomous Driving Lab" on both sides of the car (Figure 1a).

Wizard-of-Oz method (the driver was wearing a seat costume depicted in Figure 1b) was used in this study to ensure safety of the participants, repeatability of vehicle's behavior, and compliance with Estonian Road Administration's requirements.

a) b)

Figure 1: University of Tartu´s Autonomous Driving Lab´s car (a) (*Isejuhtivate sõidukite labor*, 2020) and seat costume (b), which were used in the study.

The study location was Pikk street in Tartu, Estonia (Figure 2). This location was chosen as it has light traffic which reduces the possible interventions by other traffic participants. In addition, this location provided a wide parking spot where the vehicle was able to safely stop. When approaching the participant, the vehicle had to cross a right of way intersection with pedestrian crossings.

Figure 2: Participant's field of view when waiting for the vehicle to arrive.

The recruitment and division of participants is shown on figure 3. Participants were recruited through the ride-sharing company Bolt via an email invitation sent to their 2000 more active customers in Tartu, Estonia. All of the participants were informed in the invitation email that the study involved interaction with an autonomous vehicle. Every person who received the email had the option to register for a specific time slot. In total 34 participants registered and 29 people showed up.

As it came out from the related studies for pedestrian-AV implicit interaction the main determinants for the human to understand the vehicle's intent is gap distance and vehicle speed. Gap distance can be implemented into a ride-hailing scenario as the stopping location of the vehicle. In order to study how vehicle movement affects the interaction (RQ1) we developed two interventions in the study: speed and stopping location of the vehicle. For the speed of the vehicle a regular speed and slow speed were be used. For stopping location, we determined three different stopping locations: before (8-10 m) the participant, at the participant and after (8-10m) the participant.

Participants were divided first by the speed of the vehicle and stopping location. The divisions to groups took place according to the registered time slots, so the ghost driver was able to perform similar combinations of speed and stopping location in a sequential order. This was needed in order to minimize potential differences of speed and stopping locations of the same type of interventions.

To study how explicit interaction can improve the HVI (RQ2) a light panel (Figure 4) was attached to the window of the rear door to indicate whether the door's locked by signaling colors red and green. Additionally, the light was intended to guide the participant to open the rear door. For assessing the reaction for the locked doors and effectiveness of light signal the participants were again divided into groups based on randomization.

Figure 4: Light signal used in the experiment.

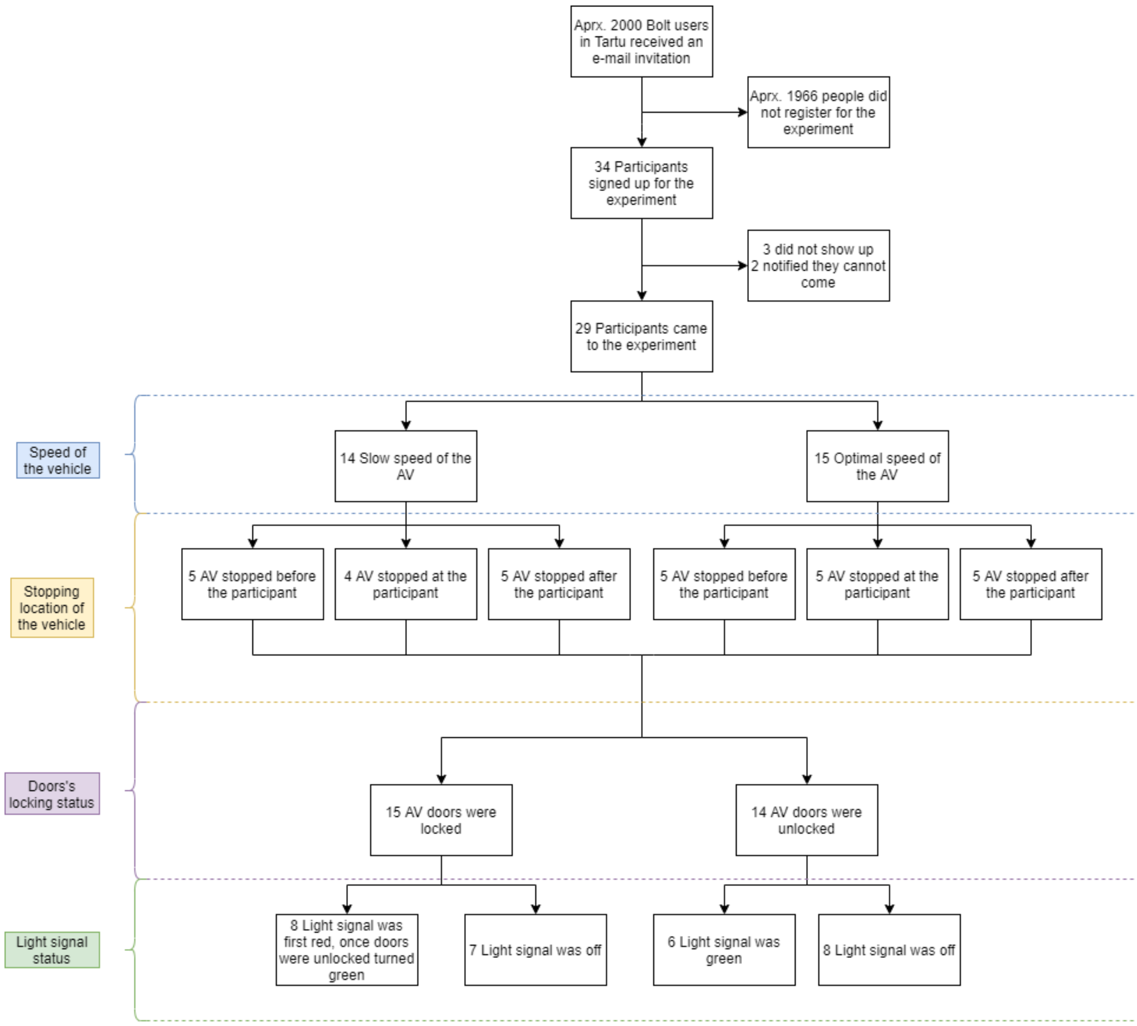

Figure 3: Distribution of the participants based on conditions.

Study procedure

Figure 4 describes the exact procedure of the study. All the participants went through the same study procedure and depending on their affiliation to a group they were assigned with different scenarios.

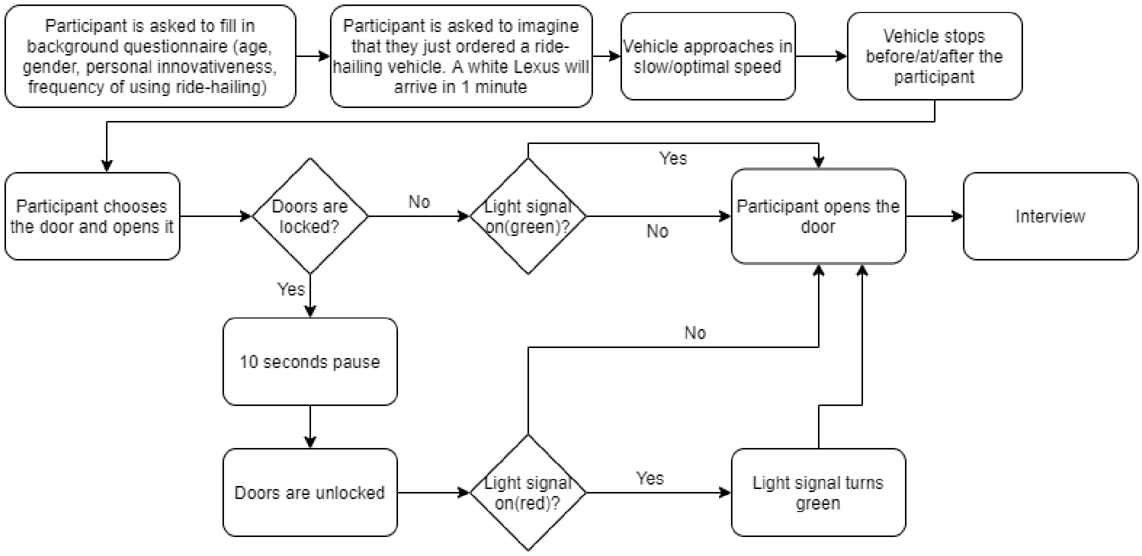

Figure 4: Study procedure

A pilot study was conducted 2 weeks before the actual study to confirm the study structure, review interview questions and measure how long the study will last. In total 4 people participated in the pilot study. The study was previously reconciled with the Research Ethics Committee of the University of Tartu (application code 332/T-26).

Data collection

In order to answer the designed research questions, we gathered data from multiple resources. In the beginning of the study, we asked the participants their age, gender, frequency of using the ride-hailing service and their personal innovativeness with a questionnaire adopted from a personal innovation scale developed by Agarwal & Prasad (1998). During the study, the participants were asked to wear eye-tracking glasses Tobii Pro Glasses 2, which recorded as a video format their field-of-view and the location they were looking at. This was needed in order to research the impact of the light signal (RQ2) as it allowed us to see whether and when the participant looked at the light panel. Additionally, we recorded a video from behind the participant to register any physical reactions to the movement of the vehicle (RQ1) and choice of the door (RQ2).

Our main source of information was an interview conducted after the study. In the interview we covered topics regarding the Wizard-of-Oz method (e.g. *Did you think the car was driving autonomously? Did you notice the vehicle was missing a driver?*), how the vehicle approached the pedestrian (e.g. *What was the car movement like? How did this movement make you feel?*), the participant's experience with approaching the vehicle, in particular about choosing the door and also light signal (e.g. *Describe what happened when the vehicle stopped. How did you decide which door to open? Did you notice a light signal? What do you think it meant?*), opinions regarding autonomous vehicles, opinions regarding autonomous ride-hailing. We asked these questions to firstly confirm the effectiveness of the Wizard-of-Oz method, to understand how the vehicle movement affected the interaction (RQ1), how the light signal affected participants' behavior (RQ2) and to further learn about any aspects that could affect the interaction (RQ3). In addition, we asked the participants after the study to rate on a Likert scale of 1 to 7 adopted from a study by Hensch et al. (2019a) their perceived safety during the study and to reason their decision to learn whether any vehicle behavior (RQ1) or light signal (RQ2) or any other aspect (RQ3) affected their perception of safety.

Data analysis

The main data source for answering the research questions were interviews, eye-tracking and video recordings from the study acted as supporting data. We used an inductive thematic analysis method for analyzing the interviews, meaning we first looked at the raw data to understand it and then created and applied developed codes based on our research questions (*vehicle movement, stopping location, light signal, noticing the driver etc.*). It must be noted that all the interviews we conducted were in the participants' native language Estonian, so all the codes and quotes brought out in this paper are translated from Estonian to English by the authors. Next, we analyzed the videos from the eye-tracking device and from the study behind the participant to look at participants as individuals and tried matching any data points collected from the videos to any data points received from the interviews to form groups.

Results

Participants

In total 29 people participated in the experiment, 15 male and 14 females. The age of the participants ranged from 19 to 57 years, average being 35 years (SD=10,88). Participants were asked to rate their frequency of using ride-hailing from 6 options and the most frequent (n=15) answer was “1-3 times a month”. The average personal innovativeness score of the participants was 21. The personal innovativeness score shows the readiness to experiment with new technology (Agarwal & Prasad, 1998). For the adapted questionnaire, the minimum possible personal innovativeness score was 4 and maximum 28. So, the average score (21) can be considered relatively high and indicate that the participated group was rather open to new technology, so this can also mean more open to autonomous vehicles.

On the scale from 1 to 7, the average perceived safety score was 6,3, which is relatively high. The correlation between personal innovativeness scores to perceived safety scores was -0,045 indicating that there is no direct correlation between the two scores. From Figure 5 it can be seen that perceived safety is relatively high at all different personal innovativeness levels.

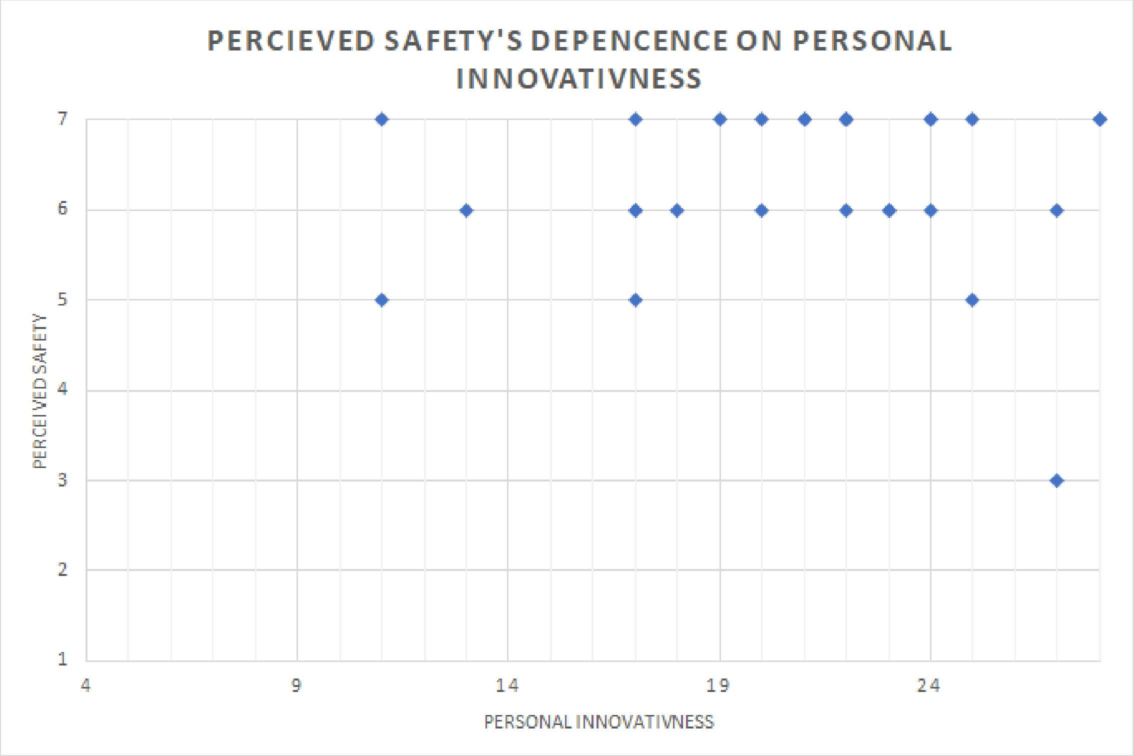

Figure 5: Participants' perceived safety dependence on personal innovativeness score

Effectiveness of Wizard-of-Oz study

In total 76% (n=22) of people believed the car was driving in autonomous mode and respectively 24% (n=7) did not believe the car was driving autonomously. Out of the 76%, 3 people mentioned that they did not look explicitly at the driver seat and the other 19 said they saw no driver. Out of the 24% who did not believe the car was autonomous, 3 mentioned not seeing the driver, but still being sure that it was controlled by someone, 3 people saw the hidden driver and 1 did not look at the driver seat. As only 3 people out of 29 noticed the driver in the seat costume it can be concluded that the Wizard-of-Oz worked relatively well. It is also worth mentioning that all the participants were informed at the end of the experiment and before conducting the interview that the car was not really driving autonomously and introduced the Wizard-of-Oz concept to assure that all participants had equal amount of information.

Two people mentioned the feeling of fright when they noticed there was no driver present. This means that possibly during the transition period from regular vehicles to automated ones, we need to take into account that there is a certain group of people who might feel frightened by vehicles with no drivers.

> *"Even if I knew beforehand that something like that [vehicle with no driver] would come I still got frightened when I did not see anyone there [in the driver seat]." (Participant 25)*

In total for 24 participants, we also successfully recorded a video from their field of view from the eye-tracking device. For 5 participants the video was missing due to participants not being able to wear the devices or due to technical issues. From 24 participants 23 had the vehicle in their field of view most of the time when the vehicle was approaching and also all of them kept the vehicle at the center of their view. As people keep objects of interest in the center of their viewpoint it can be concluded that they were indeed concentrating on the vehicle. One person who did not see the vehicle approaching was observing a road cleaning machine right in front of them.

How does the implicit interaction in the form of a vehicle's behavior affect the external interaction between the pedestrian and an autonomous vehicle in a ride-hailing scenario?

Speed of the vehicle

Figure 6: Word clouds depicting adjectives participants used to describe the movement of the vehicle when it was approaching (a) slowly and (b) at a regular speed.

Words which the participants used to describe the movement of the vehicle in case of slow speed were mostly slow, regular, careful and also safe. On the other hand, one person brought out that the very slow movement made them feel the vehicle was even helpless, further explaining that due to this they had the feeling of wanting to take control of the car. At the same time the slow movement gave them a safe feeling.

> *"It approached so slowly that it seemed helpless. That maybe it doesn't understand where I am and what it has to do. And because there was no driver I felt as if I needed to take control. Because it came so slowly it made me feel it was careful, so I had a safe feeling" (Participant 4)*

It is also worth mentioning that for 2 people the slow and careful movement gave the feeling of autonomy.

> *"That it came so slowly. A human driver would never stop a car like this. It stopped so slow, that it kept moving and moving and moving" (Participant 1)*

For regular speed, the words used to describe the vehicle movement were regular, smooth, peaceful, but also safe, slow and calm. Participants mentioned that the peaceful approach made them not feel endangered and that the smooth driving style gave them a feeling of safety. Generally, none of the participants used negative words to describe the speed of the vehicle. Both speeds were generally acceptable for the participants, which also shows from the high average score of perceived safety for both groups (6,29 for slow and 6,42 for regular speed).

Stopping location

Out of 10 participants for whom the car stopped before the participant, 6 said they expected the car to come closer, 3 said the location was fine for them and 1 person was looking in the other direction when the car was approaching, so they did not notice the car's stopping location. Out of the 6 who expected the car to come closer, 3 said that they were actually fine with the car stopping further, as *"[r]eal taxis do not come exactly to you either, so it doesn't matter really"* (Participant 3). Two out of the 6 said the stopping location did not make them feel any different and 1 believed the car stopped at this location due to a technical bug.

For the 10 participants for whom the car stopped at them, 8 said the location suited them and 2 expected the car to come even more closer. Out of the 9 participants for whom the vehicle stopped after them all mentioned that they expected the car to stop at them not after. Two out of these 9 said it was eventually still fine as they are used to taxis missing them and another 2 trusted the vehicle to pick a suitable location. Participant 25 on the other hand was confused if it was the correct car due to the fact that the vehicle drove past them. The person also added that due to the fact that the vehicle "*passed me so fast*" they got scared and explained that they only started moving towards the vehicle once it had fully stopped. One person mentioned a loss of perceived safety due to the vehicle missing them. They rated the perceived safety as 3 and explained it exactly due to the fact that the car drove past them, which made them doubt how the vehicle could handle similar situations in real traffic.

> *"and then it drove past me, I wondered if it would do the same thing at intersections. That it knows it is an intersection, but still stops in the middle of it. A kind of flicker came into me just due to the fact that it drove past me." (Participant 27)*

Observing the vehicle behavior

Six people also mentioned observing the vehicle behavior in the intersection when it was approaching. They mentioned that they observed if the car followed the rules of the priority to the right intersection. One person also said that the correct behavior in the intersection raised their feeling of security towards the car.

> *"I observed the situation where it was supposed to cross the intersection, but a car came from the right. I looked at how it handled the situation. The vehicle did not get confused and was able to handle the situation correctly, therefore a sense of security arose." (Participant 28)*

Does explicit interaction improve the external interaction between human and an autonomous vehicle in a ride-hailing scenario?

In total 93% (n=13) of the participants who were exposed to the light panel on the rear door noticed it. All of them mentioned noticing the light when asked about it in the interview, but also for 10 participants the eye-tracking video confirmed that they looked at the light panel. Only 2 mentioned they chose the rear door due to the light panel, meaning that only for them the light panel served its purpose of guiding the participants opening the rear door. All in all, from the 13 participants, 2 people still first chose to open the front door. It can be said that these two were the ones which the light panel failed to influence but needed to. Participant 20 opened the front door due to curiosity:

“*I chose the door to make it more exciting to drive, to see what is going on there in the front, so [I chose the door] out of pure curiosity*”. This person noticed the light panel, but did not think it was meant for them, but rather “*related to the experiment*”. Participant 4 explained choosing the front door as “*showing that I am not afraid of the nondriver. Generally, I would sit in the back, but this was my first thought that I will show courage and open the front door*.” The person also did not notice the light panel.

Out of 8 people who had the light panel indicating the locking status and locked doors, none waited for the panel to go green before opening the door. On the other hand, 2 people realized that after trying the doors which were locked, they needed to wait for the panel to go green before trying again.

Generally, people had trouble firstly understanding whether the panel was even meant for them and secondly what exactly it tried to indicate. 7 participants mentioned that they did not think the panel was directed to them, some brought out that they thought the light panel was perhaps “*part of a car that was measuring something*” (Participant 1). While 2 people said they just did not understand the meaning behind the light

> *“I noticed the light, but I didn’t understand the meaning right away. I didn’t think it was for me, but rather part of the system.” (Participant 21)*

Reactions for locked door

15 participants in total encountered a scenario in which the vehicle’s door was locked when they first tried the door. Six of these participants' first reaction was to turn to the experiment organizer, which indicated that the first reaction was to find human contact. Participant 11 also explained that he was surprised that the door did not open and that “*[i]n case the car stopped, this is an indicator for me to open the door*”. For 4 people the first reaction was to try and open the other door.

What could be improved in the interaction between a pedestrian and an autonomous vehicle in a ride-hailing scenario?

Opinions of autonomous ride-hailing

When asked about the general opinion of autonomous vehicle from positive factors 15 people brought out their benefit of being safer. They first help to prevent accidents due to human errors because AVs "*do not get distracted*" (Participant 29) and "*cannot violate traffic rules*" (Participant 6) but also because "*people are irrational*" (Participant 27). Also 4 people mentioned that with AVs they as drivers will get the freedom to do other things during the ride. For 5 the autonomous vehicle sector is an exciting field and also people mentioned that they are environmentally friendly, as there will be more efficient use of resources (cars) and logistical effectiveness.

For fears or doubt people have for AVs 8 people brought out the uncertainty to trust the vehicles in reacting in unexpected situations, for example "*if there is road work, which is not included in the system, is the system able to learn and insert it fast enough, so that they are aware of fast changes on the road*" (Participant 17). Five people mentioned the fear of a technical failure: "*with technology there is always a risk that an error might occur, but the same probability is with a human, but it is still the unknowingness whether it will stop or might hit something in case of the error*" (Participant 3). Three mentioned being afraid of how other drivers will react in case of AVs, that AVs "*cannot foresee other foolish drivers who make stupid maneuvers*" (Participant 21).

In a survey done among 4000 Americans regarding automation in everyday life showed similar results. In the survey the participants brought out reasons of not wanting to drive with a driverless vehicle as lack of trust or worry about giving up control and safety concerns (Smith & Anderson, 2017). From positive factors they thought the experience of driving in the vehicle would be cool, it would be safer, they have the freedom to do other things while driving and it is less stressful than driving themselves (Smith & Anderson, 2017). As factors brought out in this survey by participants living in Tartu are very similar to factors brought out in a study conveyed in American then due to this it can be reasoned the following opinions regarding autonomous ride-hailing are therefore relevant.

When asked about the opinion on autonomous ride-hailing them from the positive effects 4 participants mentioned AVs are good for certain routes. Participant 25 mentioned they often ride from the Tartu city center to the train station, so this route could be in their opinion easily automated. Three people also mentioned the taxi service will become more accessible and service more cheaper. One also mentioned that autonomous ride-hailing would help to more effectively use cars.

Nine participants also brought out losing the social part, but here the opinions of whether this is a positive or negative factor split. Some argued they like to talk to taxi drivers and some brought out they usually do not want to talk to the driver. Most commonly people said it depends on their mood or the driver itself and participant 9 brought out as a solution that "*in the future I think you can choose in the app which one I will order [autonomous or with a human driver]*".

From negative factors 7 people brought out that taxi drivers will lose their jobs. Five participants mentioned that in the case of autonomous ride-hailing flexibility is much more complicated. For example making a stop in the middle of the drive, is much more complicated than with a human.

> *"[...] humans are much more flexible than machines no matter how intelligent the machine is. I haven't until today ever seen a very very flexible machine. Through the (ride-hailing) app I can tell my needs, but it is much more complicated than telling the taxi driver that hey stop here for a minute, I will go there for a moment*

and come back. I don't even know how I would do this with a self-driving car."
(Participant 2)

Other possible issues brought out were the vehicle's hygiene, as the fact that AVs cannot choose their customers could make intoxicated customers as an issue and one person mentioned that due to the new technology the service will become more expensive.

Two participants also mentioned that in case they are in a hurry they would choose a human driver instead of an AV. Participant 13 justified it that in case of AV there is no driver to whom they can tell to drive faster and for participant 20 said if they are in a hurry the driver needs to violate traffic rules, but with AV you cannot do this.

Five participants said that for them as a customer nothing changes. Explaining the fact that ride-hailing with mobile apps is already very automated and not many adjustments can be made, so the transition to a vehicle with no driver would not be abrupt.

Discussion and conclusion

There is a significant gap in research regarding the pedestrian-AV interaction in the ride-hailing scenario. While there are millions of dollars invested in developing the technical solutions, there is still very little research regarding human-vehicle interaction, which is notably a very important part of designing autonomous ride-hailing service. This paper begins to fill in this gap by exploring the interaction between the human and the autonomous vehicle in a ride-hailing scenario, concentrating on external interaction. To do this this paper looks for answers to three research questions: (RQ1) how does the implicit interaction in the form of a vehicle's behavior affect the external interaction between the pedestrian and an autonomous vehicle in a ride-hailing scenario, (RQ2) how does explicit interaction improve the external interaction between human and an autonomous vehicle in a ride-hailing scenario, (RQ3) what could be improved in the interaction between a pedestrian and an autonomous vehicle in a ride-hailing scenario? As this study is the one of the first to explore autonomous ride-hailing external interaction then it helps further research with developing a specific methodology suitable for exploring interaction in ride-hailing.

Implicit interaction

When it comes to how vehicle movement affects the interaction the study looked at the vehicle movement from two perspectives: vehicle speed and stopping location. The results show that speed did not have a large effect on the interaction. Although slow speed gave a certain group of participants a feeling of autonomy, which could indicate that these people expect that the driving style of autonomous vehicles is slower and more careful than a car with a human driver.

It is also worth mentioning that all the participants were successfully able to understand the vehicle's intention of stopping only using implicit interaction, which confirms findings of Clamann et al. (2017), Fuest et al. (2018), Rothenbücher et al. (2016) and teVelde et al. (2005). It can be argued that this can also be due to the fact that the vehicle was equipped with noticeable Lidar systems making it distinguishable in the traffic and also due to the fact that the study took place in a location with relatively light traffic. When autonomous ride-hailing service becomes more accessible there might be a need for an explicit interaction similar as to which Lyft has filed a patent to (Matthiesen et al., 2019) to fill the customer need to clearly identify the vehicle which was also brought out by Owensby et al. (2018).

Explicit interaction

The study used a light panel, which tried to indicate to the participant the locking status, but also to direct the participants into opening the rear door. None of the participants waited for the panel to go green before opening the door, showing that the light panel was not able to indicate its correct meaning. Generally, people were confused whether the light panel was meant for them and did not understood its meaning. This relates to Hensch et al. (2019b) findings that people have trouble understanding new arbitrary signaling concepts. On the other hand, for a group of people, the light panel was able to serve its purpose after a while when people had the time to get acquainted with it. This is also what was brought out by Habibovic et al. (2018) that people need time to get acquainted with external displays in order to fully understand their meaning.

Regarding guiding the participant to choosing the door, the findings show that the light panel was not able to guide a certain group of people, who very deliberately chose the front door due to the fact that the vehicle was driverless. As both participants who chose the rear door walked straight to the front door then there might be a need for a panel also on the front door to guide these users to the back. In addition, it is important to note here that choosing where to sit might be connected to cultural differences as in Estonia it is mostly possible to sit in the front while in other countries sitting in front is prohibited when using regular ride-hailing service. It could be that the habit of sitting in the front was too strong that the light panel was not able to break this.

Other findings

From the results it can also be seen that there are people who are longing for a feeling of wanting to take control of the car when they see that it has no driver. This is also one factor participants in a survey by Smith & Anderson (2017) brought out why they do not want to drive in a driverless vehicle, that they have the feeling of wanting to take control.

In the study we also asked the opinions of autonomous ride-hailing and the results showed diverse results. There was a group of people for whom nothing would change as for them ride-hailing service is already very automated and they have little contact with the driver. For this group of people, the crossover to autonomous ride-hailing would be the smoothest. On the other hand, multiple possible problems regarding autonomous ride-hailing were brough out by participants: flexibility is complicated (e.g. stopping in the middle of the drive, guiding the driver to stop at a specific location), vehicle's hygiene and also losing the social interaction component. For the social part there were multiple types of people: some who said they will miss the social part, some who are happy that they do not need to talk to the driver and some who said it depends on their mood. When moving to autonomous ride-hailing the crossover needs to be gradual, which also allows people in the beginning to possibly choose if they want an autonomous vehicle or with a driver. This would allow all groups to be satisfied but also help people gradually get used to vehicles without drivers. Further the role of the human driver in ride-hailing is something that should be further studied, especially when it comes to internal interaction.

An interesting factor is also that the results showed that some people would choose the human driver instead of an autonomous service when they were in a hurry as AVs are not allowed to break the traffic rules. The question whether autonomous vehicle should be allowed to break the rules is a factor that is widely discussed also when it comes to the ethics of the autonomous vehicles. The Law Commission of England and Wales and the Scottish Law Commission even went that far to launch a join public consultation to see how to adapt the laws for self-driving vehicles, as there are certain scenarios where this is needed, for example when the vehicle needs to cross the line of red light to allow an emergency vehicle to pass through (Scroxton, 2018).

Furthermore, it is interesting to note that the very high average score of perceived safety could indicate overtrusing autonomy when we consider the current abilities of an AV. The problem that people could have an unrealistic assessment of the capabilities of the AV and due this they tend to overtrust the vehicle in the situation as also brought out by Holländer et al. (2019). Overtrusting AVs is an issue as it might lead to possible accidents, for example Tesla's Autopilot was in at least three fatal accidents during the period of 2017-2019 due to people underestimating the consequences and overreliance on the product (Holländer et al., 2019).

Limitations

Due to limited prior research an exploratory study was conducted to gain first insight for further research. However, there are certain limitations to these types of studies. Firstly, the study was conducted in a certain location, with a certain group of people over a limited time, meaning that if the same study is conducted in another place and another time with other participants the results might be different. Meaning the results gained should be rather considered as a trend towards identifying relevant aspects for future work.

When recruiting participants, we addressed that the study will include an autonomous vehicle. It could be that due to this we attracted people who are more interested in autonomous vehicles and open to new technology. In addition, we could have created expectations in people regarding the interaction. For future studies it would be good to also do the study with people without any prior knowledge of the study to see if there is any significant difference in results.

The study also used Tobii Pro Glasses 2 to catch the sight of the participants. Unfortunately, as these glasses are very sensitive to sunlight and the second day of the experiment was extremely sunny, then due to this a lot of potential data for analysis was lost. Still this study is very unique by using such a device and data to research the interaction between a pedestrian and an AV.

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Appendix A: Table with participants' details.

Participation ID	Vehicle speed	Stopping location	Were the doors locked?	Light panel color	Gender	Age	Ride-hailing frequency	Personal innovativeness score	Perceived safety score	Did they believe the car was autonomous?	Noticing the driver	Did they notice the light?
1	slow	before	locked	red=>green	M	44	1-3 times a month	24	7	yes	did not look	yes
2	slow	before	locked	off	M	39	1-3 times a month	11	6	yes	did not see the driver	0
3	slow	before	unlocked	green	M	49	Once a year	28	7	yes	did not see the driver	yes
4	slow	before	locked	red=>green	N	57	1-3 times a month	17	7	yes	did not see the driver	no
5	slow	before	unlocked	off	M	46	1-3 times a month	27	6	yes	did not see the driver	0
6	slow	at	unlocked	off	M	43	Few times a year	21	5	yes	did not see the driver	0
7	slow	at	locked	off	N	19	1-3 times a month	17	7	yes	did not see the driver	0
8	slow	at	locked	off	M	36	Once a week	22	6	yes	did not see the driver	0
9	slow	at	unlocked	off	M	34	1-3 times a month	11	7	no	saw the driver	0
10	slow	at	locked	off	M	26	Multiple times a week	18	7	yes	did not see the driver	0
11	slow	after	locked	red=>green	M	40	1-3 times a month	23	5	yes	did not see the driver	yes
12	slow	after	locked	red=>green	N	33	Few times a year	25	6	yes	did not see the driver	yes

13	slow	after	unlocked	off	M	26	1-3 times a month	22	6	no	did not see the driver	0
14	slow	after	unlocked	off	N	45	Multiple times a week	19	7	yes	did not see the driver	0
15	regular	before	locked	off	N	24	Few times a year	23	7	no	did not see the driver	0
16	regular	before	unlocked	off	M	27	1-3 times a month	22	7	yes	did not see the driver	0
17	regular	before	locked	red=>green	M	27	Once a week	24	6	yes	did not see the driver	yes
18	regular	before	unlocked	green	N	33	1-3 times a month	20	6	no	saw the driver	yes
19	regular	before	locked	red=>green	N	30	1-3 times a month	22	7	no	saw the driver	yes
20	regular	at	unlocked	green	N	35	Few times a year	17	6	yes	did not see the driver	yes
21	regular	at	locked	red=>green	N	27	1-3 times a month	13	6	yes	did not see the driver	yes
22	regular	at	locked	off	M	25	1-3 times a month	28	7	yes	did not see the driver	0
23	regular	at	unlocked	off	N	56	Once a week	24	5	yes	did not look	0
24	regular	at	locked	red=>green	N	23	1-3 times a month	22	7	no	saw the driver	yes
25	regular	after	unlocked	green	M	24	Once a week	21	3	yes	did not see the driver	yes
26	regular	after	unlocked	green	N	55	Few times a year	25	6	yes	did not see the driver	yes
27	regular	after	unlocked	off	M	31	Once a week	27	7	yes	did not see the driver	0
28	regular	after	unlocked	green	N	46	Few times a year	20	7	yes	did not see the driver	yes
29	regular	after	locked	off	N	24	1-3 times a month	17	7	no	did not look	0

Resümee

INIMESTE JA SÕIDUKITE VAHELINE VÄLINE INTERAKTSIOON – UURING SÕIDUJAGAMISTEENUSE KONTEKSTIS

Kristina Meister

Isejuhtivatel sõidukitel on meeletu potentsiaal päästa inimeste elusid. Kui neid kasutada sõidujagamisteenuses, siis nad suudavad samuti säästa tööjõukulusid. Samal ajal on inimese sõiduki interaktsiooni väga vähe uuritud, mida võib tegelikult pidada väga oluliseks komponendiks just isejuhtivate sõidukite kasutamisel sõidujagamisteenuses. Selle tõttu antud töö eesmärk ongi uurida, kuidas inimese interaktsiooni isejuhtiva sõidukiga saaks parandada ja seda just sõidujagamise situatsioonis keskendudes välisele interaktsioonile. Selle jaoks viisime läbi uuringu, kus osalejatel paluti ette kujutada, et nad on äsja tellinud endale sõidujagamisteenuse sõiduki ning informeeriti, et sõiduk saabub 1 minut jooksul. Kasutades *Wizard-of-Oz* meetodit, kus autojuht oli peidetud istmekostüümi taha, läheneb osalejale pealtnäha isejuhtiv sõiduk. Uuring lõppes kui osaleja avas auto ukse. Inimese ja isejuhtiva sõiduki interaktsiooni valdkonnas ei ole veel selgust, kas inimesed suudavad suhelda autoga sõiduki liikumisest lähtuvalt või on tarvis ka väga konkreetset välist kuvarit, et anda edasi sõiduki kavatsusi. Seetõttu uuris see töö mõlemat perspektiivi. Sõiduki liikumisest lähtuvalt kasutas auto uuringus kahte erinevat kiirust (aeglane ja optimaalne) ning kolme erinevate peatumisasukohta (enne osalejat, osaleja juures ning pärast osalejat). Lisaks kasutati uuringus tulukest sõiduki tagumisel aknal, mille eesmärgiks oli suunata osalejaid avama tagumist ust ning näidata osalejate ukse lukustusstaatust. Selleks, et uurida inimese interaktsiooni isejuhtiva sõidukiga kasutati uuringus intervjuud, pilgujälgimise prille ning videot katsest.

Tulemused näitasid, et mis puudutab auto liikumist, siis sõiduki kiirusel on üsna väike mõju inimese interaktsioonile. Mõlemad kiirused olid inimestele aktsepteeritavad. Mis puudutab auto peatumiskohta, siis inimeste eeldus oli, et sõidujagamisteenuse sõiduk peatub nende juures. Samas olid nad isejuhtiva sõiduki peatumise osas üsna paindlikud. Küll aga tuleb välja tuua, et kui auto peatus pärast osalejat, tekkis mõningatel inimestel sellest segadus ning vähendas tajutavat turvatunnet. Tulukene sõiduki tagumisel aknal ei suutnud oma eesmärki täita. Inimestel tekkis segadus, kas antud tuluke on mõeldud ikka neile ning ei saadud aru tulukese täpsest tähendusest. Lisaks selgus uurimusest, et on grupp inimesi, kellel tekib tahtmine haarata kontroll sõiduki üle kui nad näevad, et sõidukil puudub juht.

Uuringu käigus uurisime ka osalejatelt nende üldist arvamust isejuhtivate sõidukitega sõidujagamisteenuse turule tulekust ning tulemustest selgus, et on teatud grupp inimesi, kelle arvates muutub juhi kadumisega üsna vähe just seetõttu, et mobiilirakendustega sõidujagamisteenused on juba tänasel päeval vägagi automatiseeritud ning suhtlust juhiga on vähe. Teisest küljest toodi välja problemaatiliste kohtadena paindlikkuse puudumine ning sõiduki hügieeni. Toodi ka välja sotsiaalse poole kadumise, kuid selle osas olid inimeste arvamused erinevad: mõningad inimesed naudiksid kui neil puudub juht, kellega rääkida, teised jällegi tunneksid sellest puudust. Väga mitmed inimesed tõid ka välja, et sotsiaalne pool oleneb väga nende tujust ning nad sooviksid, et neil oleks rakenduses valik, kas tellitav sõiduk tuleb juhiga või mitte. Need kõik on kindlasti faktorid millega tuleb arvestada kui disainitakse inimese interaktsiooni isejuhtiva sõidukiga sõidujagamise situatsioonis.

Antud töö on unikaalne oma sõidujagamise konteksti poolest ning aitab kindlasti luua baasi inimese interaktsiooni uurimisel just sõidujagamise kontekstis. Kindlasti tuleks edasi uurida ka interaktsiooni sõidujagamises, mis puudutab just sisest interaktsiooni, sest tulemused juba antud tööst toovad välja mitmeid problemaatilisi kohti juhi puudumisel (peatumiskohtade küsimine keset sõitu, inimeste soov haarata kontrolli jms.). Lisaks kasutati uuringus pilgujälgimise prille, mis on väga ainulaadne interaktsiooni uurimisel.

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supervised by

Karl Kruusamäe, Alexander Udo Nolte, Andres Kuusik

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