

UNIVERSITY OF TARTU  
Institute of Computer Science  
Software Engineering Curriculum

**Timo Soiunen**

**Design and evaluation of a user interface to  
increase trust in autonomous vehicles**

**Master's Thesis (30 ECTS)**

Supervisor: Alexander Nolte, PhD

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## **Design and evaluation of a user interface to increase trust in autonomous vehicles**

### **Abstract:**

Humans have been sceptical of automation throughout history and with the prospect of autonomous vehicles taking over the transportation sector, we are going to need a user interface that can communicate with the passenger in a way that increases trust in self-driving cars. Research has shown that trust is an important factor in the use of autonomous technology and that it is affected by transparency, anthropomorphism, culture and brand name. This thesis aims to develop and evaluate a user interface that could be used in driverless cars which offer ride-hailing services. Based on the research on trust, autonomous vehicles, user interface design and user experience, a web application was developed to use in a case study involving five participants. The case study consisted of multiple tasks with the interface, an interview and a questionnaire about the usability. Analysis of the responses demonstrated that the developed user interface was relatively easy to use and understandable. The results indicate that the overall experience can be improved and suggestions were made to enhance future versions of the interface.

### **Keywords:**

Autonomous vehicles, user interface, trust in autonomy, autonomous ride-hailing

**CERCS:** P175 (Informatics, systems theory)

## **Kasutajaliidese disain ja hinnang isesõitvate autode usalduse tõstmiseks**

### **Lühikokkuvõte:**

Läbi aegade on automatiseerimist umbusaldatud. Tulevikus liigub transpordisektor aina enam autonoomsete sõidukite suunas ning tekib vajadus kasutajaliidese järgi, mis suurendab usaldust isesõitvate autode vastu. Uuringud on näidanud, et usaldus on autonoomse tehnoloogia kasutamisel oluline tegur, mida mõjutavad läbipaistvus, antropomorfism, kultuur ning brändinimi. Käesoleva lõputöö eesmärk on välja töötada ja hinnata kasutajaliidest, mida saaks kasutada sõiduvahendamise teenust pakkuva sõiduauto puhul. Veebirakendus töötati välja viie osalejaga juhtumiuuringu jaoks lähtudes usalduse, autonoomsete sõidukite, kasutajaliidese kujunduse ja kasutajakogemuse uuringutest. Juhtumianalüüs koosnes ülesannetest kasutajaliidese, intervjuust ja kasutatavuse küsimustikust. Vastuste analüüs näitas, et väljatöötatud kasutajaliides oli kergesti kasutatav ja arusaadav. Uuringu tulemused näitavad, et üldist kasutajakogemust saab parandada ning tulevaste kasutajaliidese versioonide parendamiseks on ettepanekuid tehtud.

### **Võtmesõnad:**

Isesõitvad sõidukid, kasutajaliides, autonoomsuse usaldus, autonoomne sõiduvahendusteenus

**CERCS:** P175 (Informaatika, süsteemiteooria)

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# 1 Introduction

The continued advancements in technology across all fields increase the use of automation. Transportation and self-driving vehicles are most likely going to be a part of our everyday life sooner rather than later. With the rise of the popularity of ride-hailing services, companies are looking for a way to introduce autonomous vehicles to the public as soon as possible to increase their revenue when the inevitable change in transportation finally arrives. But as humans have been behind the wheel since the 1900s when the automotive industry started mass production, they are somewhat reluctant to pass over the reins to the computer. There have even been cases where the distrust in self-driving cars has manifested itself in the form of people throwing rocks at the vehicles [1] which makes trust one of the most important areas to focus on.

There has been a multitude of papers on the issue of trust in automation and self-driving cars, but they mainly focus on the driver's seat and increasing consumer trust to make these types of vehicles more approachable for purchase. In our work, we focus on ride-hailing services and the backseat where the experience is different.

As studies have shown that trust can be increased via a user interface [2–4], we built and evaluated one based on existing work on aspects which can influence trust and applied the good practices of user interface design and user experience. In order to evaluate the interface, we conducted a system usability study that was carried out online using video call and screen sharing software to observe the behaviour and any occurring problems. In addition to the study, we make suggestions based on the results to improve the interface and propose an approach to study the user interface's effect on trust.

To test the interface, we devised a scenario where the participant is calling a car to pick him/her up from a shopping centre and drives to downtown. During the ride, we asked them to complete different tasks so that we could observe interactions with the interface. Overall, the results show that the developed user interface performed rather well as the participants managed to easily complete the given tasks and liked its simplicity.

This thesis' main goal is to develop and evaluate a user interface that would increase trust in autonomous vehicles. To design a user interface that would increase trust in autonomous vehicles we first find out what is trust and then if and how we can evaluate it to use it in our case study. Next, as trust consists of various aspects, we take a deeper look into them and analyse how they can affect trust in autonomous vehicles. This can also be examined in the features that already exist in the cars today as there is already a multitude of advanced driver assistance systems in modern cars today like automatic parking and adaptive cruise control [5] which people are using every day with various levels of trust [6,7]. We will also investigate what increases and decreases trust and how can all this be applied to autonomous vehicles and their user interfaces. This plays an important role as it helps us to get a better overview of how to design the interface and which aspects to keep in mind. To develop an interface that is usable and pleasant to the eye we investigate user interface design and the best practices of user experience.

To that end we devised research questions that would help us to achieve our goal:

RQ1: What is trust in autonomy? (section 3.1)

RQ2: How do we evaluate trust? (section 3.2)

RQ3: What do we know about autonomous vehicles and how much are they trusted? (section 3.3)

RQ4: What kinds of aspects can influence trust in autonomous vehicles? (section 3.4)

RQ5: What characteristics should we consider while designing a user interface? (section 3.5)

This master's thesis starts with the literature review, where we take a deep dive into trust, autonomous vehicles and their features. We also discuss the good practices and characteristics of user interface design and user experience. In the interface chapter, we present the most common use scenario and introduce all the features present in the interface with screenshots and tools of the trade we used for developing. Next, we describe the case study we performed in detail in the methodology section. The following chapter includes evaluations and suggestions for changes to further improve the developed user interface. Finally, we propose a case study that could be conducted with an improved version using an actual vehicle.

## 2 Related work

In this section, we give an overview of what has been done so far in the industry to improve trust in self-driving cars, how it is connected to our work and what we did differently. We also outline the research approach we used.

### 2.1 Current work

Most of the papers we reviewed mainly focus on the drivers' trust in autonomous vehicles. We take all that information and apply it to develop a user interface for ride-hailing services to be used in the backseat. Multiple surveys have shown that people are sceptical of using self-driving vehicles [8–10], but these are mainly about using the car as their own, whereas we focus on ride-hailing service.

Research done by Lee and See tells us that trust is an attitude that someone will help achieve somebody's goals in a state of uncertainty and vulnerability [11]. In our case and relation to the first research question, this means that when the passenger sits in the backseat, he/she is put into an uncertain and even vulnerable situation as self-driving technology is still rather new and he/she needs a good reason and purpose to trust the machine enough to use the service. That reason could be an easy to use service that gets the passenger safely to the chosen destination. Granted, some people are more suspicious of new technology, but as time goes on, the overall trust in such a service will rise while more and more people are willing to give it a try [11].

When it comes to evaluating trust in autonomy, there is a survey developed by the United States Air Force laboratory [12] which is also connected to our second research question. This survey can be used as a basis when coming up with a questionnaire for a future case study to assess trust level change after using our developed user interface.

As we develop an interface to increase trust in autonomous vehicles, we must consider different aspects that can affect it. There are several of them as we discovered while answering the fourth research question. In our user interface, we mostly focused on transparency and anthropomorphism. Transparency plays a large part in trusting the vehicle as the passenger can see what is going on with the car, e.g. current location and information about the vehicle, and the trust levels will increase [13]. Anthropomorphism is adding human-like features to the system, which can increase trust, but it can be only done to a certain limit as too much can bring forth negative effects [2] and therefore we opted to only use audio features. As we mentioned earlier, trust takes time to build, so having a brand name that is in good status with the public is also important. In our case, Bolt is a fairly well-known company in Estonia. We can also take note from accidents happened with Uber and Tesla and only test it in public when it is safe enough because when accidents happen the reputation suffers and people would not use it later on even if it is actually safe as trust takes time to form, and even longer to reform [11].

We also need to consider different characteristics to make the interface easily accessible and usable to clients which brings us to the final research question that involves discussing user interface design and user experience. For example, the interface must be clear so that the client does not need to think about what the application is for. Another example is simplicity, where there is no place for unnecessary clutter to make the interface bloated and difficult to understand or navigate. The overall experience of using the interface must also be easy or pleasing, e.g. the application should be useful, all elements are easily findable and accessible. [14–17]

## 2.2 Research approach

To get all the necessary information, we conducted a systematic literature review based on the guidelines provided by Kitchenham [18] that consist of planning the study, performing and reporting the review.

In order to find relevant studies, we used digital libraries such as Springer Link, Google Scholar, IEEE Xplore, Scopus, Science Direct, ACM Digital Library, Web of Science. Additional studies were also found in the reference lists of the papers. Because of our research questions one, two and three, we needed a search query that would reveal results including trust and autonomous vehicles. To that end we used the following query: (trust) AND ((autonomous AND vehicles) OR self-driv\* OR (autonomous AND cars) OR (self AND driv\*)).

As we also needed information about interfaces and user experience to find out about aspects of trust, e.g. transparency and anthropomorphism. The following query resulted in a list of papers we used to answer research questions 4 and 5: (trust) AND ((autonomous AND vehicles) OR self-driv\* OR (autonomous AND cars) OR (self AND driv\*)) AND (user AND (interface OR experience)).

We identified papers useful for answering our research questions. In order to select relevant studies, we went through a filtering process which consisted of the following steps:

1. We selected the papers that could be connected to the research questions by reading the title and abstract.
2. Next, we read the introductions and then included the relevant studies.
3. Finally, we filtered the remaining studies using the inclusion and exclusion criteria shown in table 1.

We found 90 studies/articles and used 29 of them in our literature study. As our research questions involve trust in autonomy and user interface, we needed criteria to include or exclude studies, e.g. experiments with trust, increasing trust, autonomous vehicles, written in language that is not English or is incomplete. Full list of criteria can be observed in table 1.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Includes experiments with trust and autonomous vehicles	Is not written in English
Talks about increasing trust in autonomous vehicles	Has nothing to do with autonomy or trust
Includes experiments with different user interfaces in autonomous vehicles	Is shorter than 6 pages
Talks about autonomous vehicles	Is not complete (gives an overview of a plan for an experiment)

### 3 Background

In this section of the thesis, we present the findings gathered from different papers to answer the research questions. We divided this chapter into two. In the first part, we discover what is trust in autonomy and how we can evaluate it. We also research autonomous vehicles and what has succeeded or failed so far in that segment. This includes different features present in modern cars and the levels of autonomy in vehicles defined by government organisations.

In the second part, we discover various aspects that can influence trust like environment, culture or how anthropomorphic the vehicle's entertainment system is. We also look at characteristics that make a good user interface and user experience.

#### 3.1 Trust in autonomy (RQ1)

The concept of trust has been around for quite some time as all relationships between humans rely on some level of trust, or in some cases, distrust. This can be observed in different aspects of life, like trust between cultures, societies, organisations etc [19]. Lee and See define trust as “the attitude that an agent will help achieve an individual's goals in a situation characterised by uncertainty and vulnerability” [11], which means that normally trust is composed of three parts. The first part includes someone who is giving trust, someone who is trusted (trustee) and a reason for the interaction to take place. Next, the trustee must have a reason to perform the action provided by the trustor and finally, there must be a chance for things to go wrong [19]. As trust can be applied to human-to-human relationships, it can also be applied to human-to-machine interactions which bring us to automation that can be defined as “technology that actively selects data, transforms information, makes decisions, or controls processes” [11].

As noted in [19] and displayed in table 2, trust can be divided into 3 layers: dispositional trust, situational trust and learned trust. Dispositional trust characterises trust in automation without any regard to the context of an explicit system. It is influenced mainly by age, culture, gender and personality. People of different ages deploy varied strategies to calibrate their trust in automation. This might be due to experiences gained beforehand. Different cultures and nations can have diverse levels of trust and this should be considered when introducing new technology. Receiving flattery or compliments from the automated system is met differently by males and females, where the latter are more susceptible to it, while men usually have negative reactions. Dispositional trust is itself a part of an individual's personality and displays the willingness to trust others. Situational trust depends on the current situation of the interaction between the automatic system and human. In this layer, the environment plays a significant part in trust and is divided into two main variabilities: internal and external. Internal variabilities consider the state of the trustor, e.g. mood, attention capacity, expertise. External variability, on the other hand, is all about the automatic system itself, e.g. task difficulty, workload, type of system. Lastly, learned trust considers the past experiences with a specific automated system and is closely connected to situational trust as variabilities may influence the user's perspective of the current situation. The final proposed model of trust is displayed in figure 1.

Trust plays a pivotal role in automation as operators can misuse and disuse automatic systems. A good example of this is the over-trust in Tesla's autopilot which has caused multiple accidents and even deaths [20]. Accidents like these can be avoided if drivers have the appropriate levels of trust and knowledge about the system they are using.

Table 2. Trust layers based on models in [19].

Trust					
Dispositional trust	Situational trust		Learned trust		
1. Culture 2. Age 3. Gender 4. Personality traits	<b>External variability</b>	<b>Internal variability</b>	<b>Initial learned</b>	<b>Dynamic learned</b>	
	1. Type of system 2. System complexity 3. Task difficulty 4. Workload 5. Perceived risks 6. Perceived benefits 7. Organisational setting 8. Framing of task	1. Self-confidence 2. Subject matter expertise 3. Mood 4. Attentional capacity	1. Attitudes/explanations 2. The reputation of the system and/or brand 3. Experience with a system or similar technology 4. Understanding of system	<b>System Performance</b>	<b>Design features</b>
				1. Reliability 2. Validity 3. Predictability 4. Dependability 5. Timing of error 6. Difficulty of error 7. Type of error Usefulness	1. Appearance 2. Ease-of-use 3. Communication style 4. Transparency/ feedback 5. Level of control

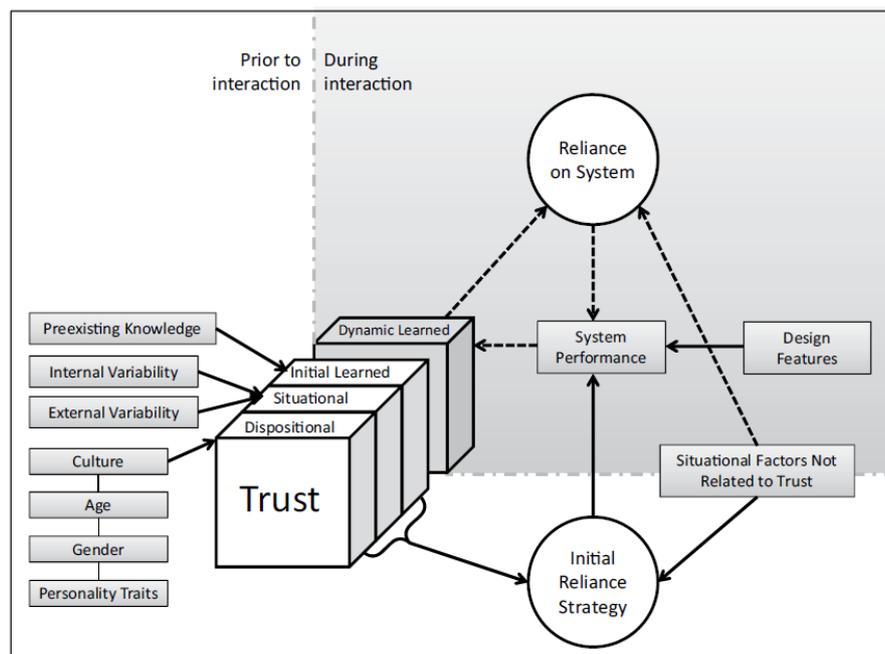


Figure 1. The full model of factors influencing trust in automation [19].

### 3.2 Evaluating trust (RQ2)

There are different approaches that aim to evaluate trust in automation but the one mentioned most was a study conducted by the United States Air Force research laboratory [12] which designed a seven-point (where 1 = not at all and 7 = extremely) Likert scale [21] questionnaire with 12 statements to evaluate trust between humans and automated systems. The questions can be seen in figure 2. This questionnaire has been the basis for many surveys [6,8–10,22,23] used in papers that experiment with trust in automation to get data from participants to analyse and make conclusions upon.

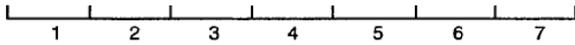
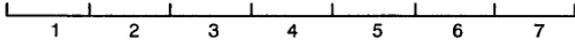
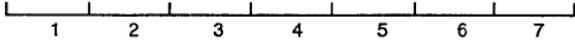
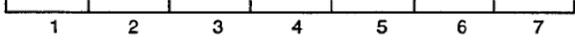
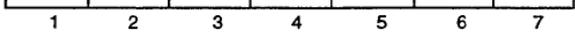
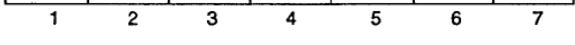
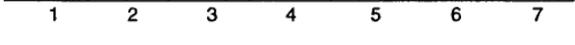
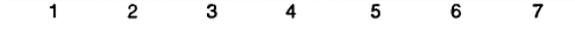
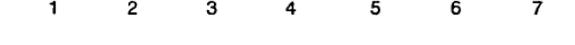
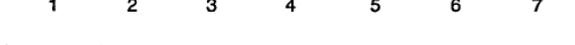
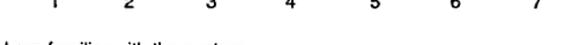
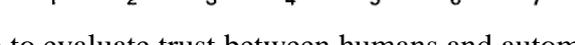
1	The system is deceptive	
2	The system behaves in an underhanded manner	
3	I am suspicious of the system's intent, action, or outputs	
4	I am wary of the system	
5	The system's actions will have a harmful or injurious outcome	
6	I am confident in the system	
7	The system provides security	
8	The system has integrity	
9	The system is dependable	
10	The system is reliable	
11	I can trust the system	
12	I am familiar with the system	

Figure 2. Questionnaire to evaluate trust between humans and automatic systems [12].

#### Building trust

In figure 3, devised by Lee and See [11], we can observe the appropriateness of trust and how it develops in automatic systems. In one block we have individual, organisational,

cultural and environmental context, which affects the main parts of the schematic: information assimilation and belief formation, trust evolution, intention formation, reliance action, automation. In the first step, information is gathered about the automation by different means like reputation and gossip. Based on that, a belief is formulated. In the next step, trust evolution takes place, which is affected by organisational structure, cultural differences and predisposition to trust. This can also affect the first step and make changes to the belief. Next, intention formation takes place where the user's purpose to use the system is devised which takes us into reliance action where the reliability of the automation is assessed. Then the automation and display sections take place and information is assimilated again, and a new belief formation takes place based on the experience and information received. From all this, we can conclude that trust is built over time and is constantly changing, depending on the experiences and different variabilities affecting its formation.

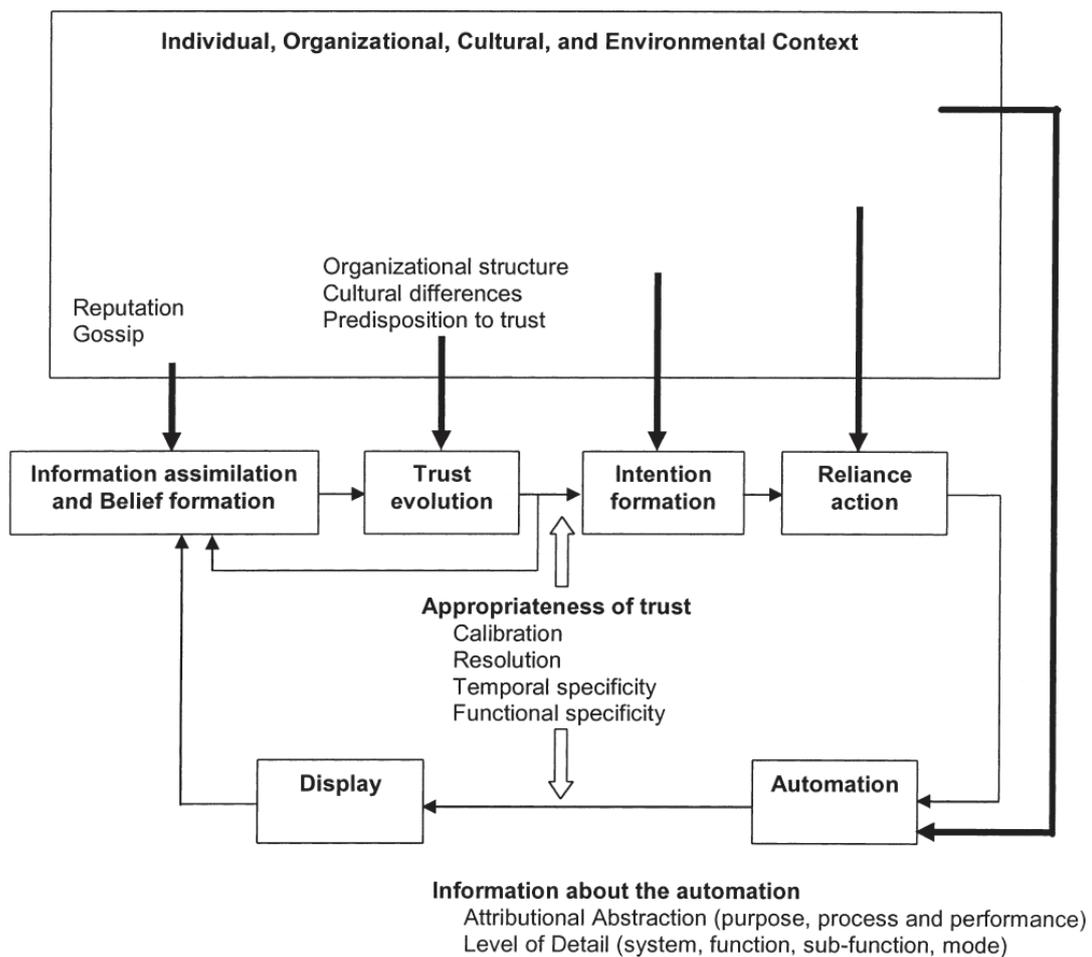


Figure 3. The interaction of different aspects of trust and its formation [11].

### 3.3 Autonomous vehicles and trust (RQ3)

#### Autonomous vehicles

While investigating autonomous vehicles, we reviewed an article [24] that gave an overview of the state of the art and different problems that come with automation. A great example can be seen in aviation where automatization became widely used in the 1920s and '30s. Aeroplanes can take off and land without any human interference, but pilots are still being used in case things go horribly wrong as they are trained to take over the control where

something unexpected happens. This puts pilots into an observing role which is not a good task for humans as we tend to be rather bad at it for long periods of time and pilots may get too dependent on the automated systems. To counter that, pilots are encouraged to take over the reins from time to time to keep their competence and skills as aviators.

The same can be said about autonomous vehicle drivers, when they are not driving and are occupied with non-driving-related tasks, they will not pay much attention to the surrounding environment. This brings us to the next point. As long as we do not have fully autonomous cars, the industry should not broadcast any non-driving activities while driving, as the motorist must be aware of the surroundings to be able to act when a dangerous situation arises. Also, at this time we have laws that prevent cars to take over completely and no non-driving activities are allowed (gaming, sleeping) therefore, to move on to fully autonomous vehicles, we must change the regulations accordingly.

Another aspect of a self-driving car is its complexity. To be able to use them depending on the level of autonomy (figure 4), drivers must be educated on how they work and what features they have. This will avoid dangerous situations and even accidents as overreliance has also been a source of accidents where drivers expect vehicles to do more than they are capable of doing [24].

There are also a couple of restrictions limiting the use of autonomous vehicles: technology design and technology in the real world [24]. Technology design considers the rapid progress and use of intelligent and automation systems and how it affects, for example, labour market and employment. Depending on the country, its government or its political views, social protections can be applied [25]. Technology in the real world puts cars in the traffic and makes them react to the environment. At the present-day, autonomous cars are not able to compete with humans when it comes to monitoring and creating awareness of the surrounding environment. This includes making predictions and decisions, calculating risks and trajectories in complex urban settings. We must also consider edge cases that the vehicle's artificial intelligence has no idea what to do about.

### **Types of autonomous vehicles**

There are two types of automation [26]. The first provides advice but leaves the driver in charge to make all the decisions. This includes directions from a global positioning system and all kinds of warnings that the car is giving, e.g. about driving conditions, the state of the automobile and the position of other cars.

The second one takes control of the vehicle. This includes ADAS (advanced driver assistance systems) like automatic parking and adaptive cruise control (more in RQ2). A vehicle's autonomy is graded on a scale from zero to five, where zero means there is no autonomy and five is a fully autonomous vehicle. These levels are defined in the SAE (Society of Automotive Engineers) report [27] and a short description is presented in figure 1. Other organisations like BAST (German Federal Highway Research Institute) [28] and NHTSA (National Highway Traffic Safety Administration) [27] have produced similar descriptions and their corresponding levels are also present in figure 4.

SAE level	SAE name	SAE narrative definition	Execution of steering and acceleration/deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	BASf level	NHTSA level
<b>Human driver monitors the driving environment</b>								
0	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	Driver Assistance	the <i>driving mode</i> -specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation	the <i>driving mode</i> -specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes	Partially automated	2
<b>Automated driving system ("system") monitors the driving environment</b>								
3	Conditional Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes	Highly automated	3
4	High Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes	Fully automated	3/4
5	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes		

Figure 4. Levels of autonomy in vehicles [27].

### Failures and successes

As autonomous vehicles need a lot of data to teach artificial intelligence (AI) to drive safely [29], companies' success depends on how much information they can gather. Any infractions of the law or accidents can be devastating to the development of autonomous vehicles. This has happened to Uber: a person was killed in an accident and the company immediately halted its experiments [30] and was not able to gather additional data. Tesla has also come under fire as multiple people have died while using the autopilot [20].

There seem to be two main ways to approach the autonomous vehicles considering the technology used. The more popular one is the Lidar system used by most car manufacturers and the other one is using cameras to develop a good imaging system so that the car could truly see what is on the road [29]. Using the cameras has its advantages as the technology is cheaper and data collection is easier. This can be seen in Tesla that has collected vast amounts of data over the years and is constantly using it to develop and upgrade its system and push updates to existing vehicles to make them safer on the road. A disadvantage of this approach is that it is more difficult to develop as the onboard artificial intelligence is still not capable of recognising the surrounding environment to guarantee high levels of safety.

### Trust in autonomous vehicles

There have been multiple studies, questionnaires and experiments on trust in autonomous vehicles. In this section, we go over some of them and give an overview of what we found out about trust in self-driving cars.

A survey conducted in Hungary [31] found that only 15% of respondents trust or would trust a self-driving car which is quite a low number. However, most participants would try and utilise semi-autonomous vehicles. It was also noted that it is expected in the future for cars to take over mundane tasks such as keeping in line with speed limits or irksome tasks like manoeuvring in heavy traffic.

In an experiment with level 2 autonomous [32] cars, it was noted that the initial level of trust increased in all drivers after they experienced real-life situations. One of the key parts of this experiment was to explain exactly what the car's automation features are capable of, which in turn leads to safer driving and higher trust levels. Similar results can be seen in a test conducted in Sweden [33] on a track that cars can complete without any driver assistance. In addition to experiencing self-driving cars, they concluded that to increase trust, the autonomous vehicles must be able to perform scenarios correctly repeatedly and the time spent in the car should be valuable to the motorist, e.g. reading a newspaper or a book.

There have been a couple of large-scale questionnaires regarding acceptance [8] and public opinion [9] about autonomous vehicles. The latter one concluded, after analysing over 1500 responses from the UK, the US and Australia, that the majority (66%) have previously heard about self-driving cars, had a positive initial opinion and high expectations for autonomous vehicles. One of the main concerns that occurred, especially among participants from the US, was about privacy, security and performance. High level of concern was also expressed about vehicles without regular driver controls and cars moving around without anyone in them including buses and taxis. It was also evident that higher levels of concern were expressed by the female population. The widely held notion (65.8%) was that participants would like to have self-driving technology in their vehicles but are not willing to pay extra for it.

We will finish with a study that investigated trust in Tesla's autopilot and summon system among drivers [22]. In this case, they found that trust in those systems is quite high and is influenced by factors like age, frequency of use and if there has been an accident while using the features. It was brought out that the trust increased over time regardless of the accidents or mishaps while it decreased in autopilot as the participant's age got higher. The same effect was not seen in the summon feature. The reason for this might be that older and more experienced pilots see driving as a more dangerous activity than younger motorists. The overall level of trust in the systems reported among Tesla drivers was quite high.

### **3.4 Aspects that can influence trust in autonomous vehicles (RQ4)**

In this section, we present the commonly occurring aspects of our research that influence trust in autonomous vehicles. We also give an overview of existing advanced driver assistance systems (ADAS) and explore the trust in them and their usage.

#### **Aspects that influence trust in autonomous vehicles**

In research done by Choi and Ji [13], system transparency is referred to as "the degree to which users can predict and understand the operations of autonomous vehicles" [13]. This helps to build trust in autonomous vehicles as users have higher levels of trust in automation if they can see what the system is currently doing or what state it is in, which makes the system predictable and more trustworthy as users know what might happen next. A good example of this is the global positioning systems, where users can always see their location. The same can be applied to other features like the state of the vehicle and the position of other cars.

The brand name has been shown to relate to trust in autonomous vehicles [10,34] as some companies are trusted more than others. A reason for this can be the media coverage of accidents or mishaps which lowers the public opinion on certain companies or technologies. If the company responsible does not handle the situation properly, it can lead to even more public backlash and rumours which will all hurt the brand and people's trust in it.

Trust can also be affected by cultural differences - that applies especially to initial trust [11]. This is affected by the dependence on authority and a country's way of rule, e.g. totalitarianism.

Another common aspect of trust in autonomous vehicles is anthropomorphism, i.e. human-like qualities of non-human entities, in this case, self-driving cars and their interfaces. There have been numerous studies concluding that adding anthropomorphic features to autonomous vehicles can increase trust in them [2,3,23,35,36]. As pointed out in [2], human-like features can be added to a certain limit. Passing that threshold results in a negative effect and is counterproductive to increasing trust as humans will start to have negative emotions. Studies conducted to compare graphical user interface (GUI) and conversational user interface (CUI) [3,23] found that CUI achieved higher trust, intelligence and likability ratings, but as humans are different from each other, they might prefer a combination of both.

### **Modern autonomous features in vehicle and trust**

As stated in [5], ADAS can be classified into two categories: information-based and manipulation-based assistance systems. The first one provides various information to the driver but makes no decisions on its own, while the latter can take over control of the car in dangerous situations or when the driver has requested it.

Information-based assistance systems are divided into three categories:

1. Advanced traveller information system (ATIS) that includes features like dynamic re-routing, anticipating traffic and conveying information about the surroundings like the roads, or surrounding vehicles.
2. Inattention alert systems are features that monitor the driver for fatigue and distraction. Those systems do that by analysing eye and head movements, gaze and biological signals. If there is any indication of danger, the systems let the driver know by signals or by other means like haptic feedback.
3. Measuring driver performance is constantly judging the motorist's driving. For example, it considers the distance between cars, how sharp are the turns and even how tightly the steering wheel is being gripped. If the driver is acting differently than usual or performing dangerous manoeuvres, the system brings it to the motorist's attention.

Manipulation-based assistance systems are divided into four main categories:

1. Safety alert and emergency stopping systems monitor the vehicle's surroundings and alert or even stop the car when a collision is likely to happen.
2. Adaptive cruise control's (ACC) main task is to take control of the speed of the vehicle by following the car in front and adjusting it as the situation requires. On open roads without other cars, it follows the speed set by the driver.
3. Overtaking assessment and assist systems to judge the feasibility of the overtaking and notify the driver about it.
4. Automated parking systems usually take advantage of the vehicle's cameras to assess the surroundings to perform a safe parking action.

Most of these systems were an optional or standard feature in more than half of 2017 vehicle models [37] but they cannot be effective if users do not turn them on. A study was conducted with four vehicles and five ADAS systems to find out what makes drivers trust and use some of the features or why they are turned off all together [38]. Trust was evaluated by a survey using a 5-point Likert scale to respond to different statements developed by Jian et al. [12]. It was found that trust in side-view assist was the highest while active-lane keeping scored the lowest. Most common complaints about the systems were false alerts, functionality/performance issues and user interface problems. It was observed that drivers least trusted the systems that gave warnings too early or too many of them, also the user interface was not always correct or was inconsistent in reflecting the lane markings. Carmakers need to produce intuitive interfaces that function in the way the driver expects. As trust takes time to build, it is essential to have motorists use the features which lets them get more accustomed to them. Overall, trust was rather low in ADAS across the vehicles and varied greatly among different features which show that there is room to greatly improve it. A similar result was gathered in an exploratory survey about the attitude and use of ADAS [6] where drivers liked the system but expect it to be more user-friendly and automatically adjust some of the settings. Features difficult to understand or to set up were ignored and not investigated any further.

### **3.5 Characteristics to be considered while designing a user interface (RQ5)**

Developing a user interface involves a lot of work and user testing as people are different and their habits also vary. We cannot cover the entire userbase, but we can create an interface that should be acceptable to most if we keep in mind the good practices of user interface design and user experience.

#### **User interface design**

The user interface is defined as “the means by which the user and a computer system interact, in particular, the use of input devices and software” [39] and it plays a large role in the success of any application or website that is meant for a wider audience. This includes UI for autonomous vehicles as well. But what exactly makes a UI good? What kinds of aspects should the designer focus on when coming up with a UI? In this section, we try to answer those questions by going over the common characteristics of user interfaces.

#### ***Clarity***

One of the most important elements of user interface design is clarity. If a customer cannot understand what the UI is meant to do, then it has failed in its purpose in communicating meaning and function and the user can become annoyed or frustrated and abandon the whole endeavour. A good example of clarity is the use of icons that users can recognise with ease and in web design, there is a hover function that can give even further instructions. It is important to keep all labels, content and navigation as easy to read as possible. [14–16]

#### ***Familiarity***

Familiarity means that the user interface is intuitive: users do not have to stop and think about where they could get the information they need or what to do next because they already know. A good example of this is a hamburger menu icon on websites. Users know that it will bring up a menu with links. [14,15]

### ***Responsiveness***

Responsiveness means mainly two things. First, how quickly the interface loads. Even if the backend is catching up, the front-end should be giving the user some information about what is going on. Slow applications tend to create a negative effect on users as they do not like to wait for things to load and become frustrated. Second, the user interface should provide feedback to the user, let them know what is going on at the given moment. This could include changing the button text or state, adding a spinning wheel to inform that the application is loading or even just displaying some text. [14–16]

### ***Consistency***

It is also important to keep the user interface consistent throughout the application. This way users can develop certain patterns that improve the user experience. This includes maintaining the language, design and layout in all views of the application. [14–16]

### ***Attractiveness***

A good user interface should also look good and appealing to the user. If the UI ticks the right boxes of responsiveness, simplicity, familiarity etc, it also needs to take that extra step further and look pleasing to the eye. This, of course, depends on the audience as beauty is in the eye of the beholder. [14]

### ***Efficiency***

The user interface is efficient when users can perform their intended tasks quickly. To achieve this, task analysis is used: take tasks that are most likely to be performed by users and make them as quick and easy as possible for users. [14,15]

### ***Forgiveness***

A quality user interface is forgiving and does not punish the user for mishaps as it lets them make mistakes and recover from them with ease. If someone deletes something important by mistake, can the application restore it? If the user reaches a page not found view, what do they see? If the application is forgiving the users feel more at ease and explore further. A most common example of forgiveness is the “Undo” button. [14,16]

### ***Simplicity***

Simple user interfaces are easy to understand. They don’t clutter the view with unnecessary information. Great interfaces are made up of essential elements that are logical and concise. This can be achieved, for example, by hiding elements or functions that are a lower priority for users. This way they are still only a couple of clicks away but do not interfere with primary functions. [15]

### ***Hierarchy***

Visual hierarchy in user interfaces lets clients consume important information first. This is mainly achieved by playing with the contrast between different sizes, the colours and placements of elements to make users understand what they are supposed to do. [15]

### ***User experience***

Another important aspect of any application is user experience, which can be defined as “the overall experience of a person using a product such as a website or a computer application, especially in terms of how easy or pleasing it is to use.” [40].

Overall, seven main factors describe UX: useful, usable, findable, credible, desirable, accessible and valuable. [17]

### ***Useful***

If an application is not useful to someone it has no purpose. A product or application also needs to be usable, meaning the user can achieve their end goal efficiently and with as little as effort as possible. [17]

### ***Usable***

Products can succeed if they are not usable, but only if there is not any serious competition and they can get away with it. A good example of this is the MP3 player that started to lose its popularity when Apple's iPod came out as it was more usable than the other MP3 players on the market at that time. [17]

### ***Findable***

Users need to find the information they are looking for quickly and painlessly. For example, if e-store products are categorised differently than usual, then shopping at this store would make a rather frustrating experience. [17]

### ***Credible***

To be credible, the application must make the user feel like he/she can trust the provided service, otherwise, the customer takes their business elsewhere if possible. [17]

### ***Desirable***

A desirable application is used by more people because it is more attractive to them. This is conveyed in design through branding, image, emotional design, identity and aesthetics. [17]

### ***Accessible***

Unfortunately, accessibility is oftentimes overlooked when developing a new product or application because it is thought that people with disabilities make up only a small portion of the end-users. This means neglecting people with hearing loss, impaired vision or motion, and learning disability. Keeping that in mind while designing would increase the number of people able to use the product and it would also be beneficial for the company's reputation. [17]

### ***Valuable***

Finally, the application must create some sort of value for the user and the company offering it, otherwise, there is no real reason to create the product in the first place. [17]

## **3.6 Background conclusion**

The goal of this section was to develop an overview of trust, trust in autonomy, autonomous vehicles and characteristics of user interface design. To do that, we devised five research questions where we investigated self-driving cars and experiments/surveys conducted to find out how much are autonomous vehicles and different features trusted, e.g. adaptive cruise control, summon and automatic parking. To come up with a user interface that increases trust in self-driving cars we investigated trust in general which revealed that it is made up of layers that are affected by many aspects e.g. culture, transparency, anthropomorphism etc.

Trust is commonly evaluated using questionnaires that are based on a Likert scale [21] questions. The gathered data is later analysed, and conclusions are made. To build trust in automation, we must consider different aspects and recognise that it is built over time and is constantly changing, depending on the experiences and different variabilities affecting its formation.

We found that there are six levels of autonomy [27] starting with no automatic features and ending with full autonomy where the vehicle does not need any human interference at all. As autonomous systems are quite complex it can lead to over-trust where drivers are not exactly sure what the machine is capable of, which can cause accidents and even deaths.

Trust in autonomous vehicles varies greatly depending on the interface and features present, level of autonomy used in testing, country, sample size, time, previous experience and knowledge etc. Overall, users want to have autonomous features in their vehicles but are reluctant to pay extra for them and if they are going to use them, they need thorough tutorials to understand the functionality of the system. If users comprehend how a specific feature works or what it is capable of, the trust will increase as well.

To develop the user interface to be used in a vehicle, we must also consider different characteristics of user interface design and user experience to make the trip as pleasant as possible for the passenger. This would include designing the interface to be easy to use, clear, consistent and efficient. When operating the application, it should also be useful; elements must be findable and accessible.

## 4 User interface

In this section of the thesis, everything connected to the user interface is presented. We start with the most common scenario the client would follow while using the service including main views and user stories. Next, we give an overview of the full application including all the features, user stories and views. Finally, we present the development and tools of the trade used.

### 4.1 Most common scenario

To give a good overview of the developed user interface, we devised a most common scenario to introduce the basic flow the user who has ordered the service would encounter. In our case, that means the participant has ordered Bolt to pick him/her up from a shopping centre in Annelinn called Eeden and drive to downtown near Rütli street. Graphical representation of the described flow can be observed in figure 5.

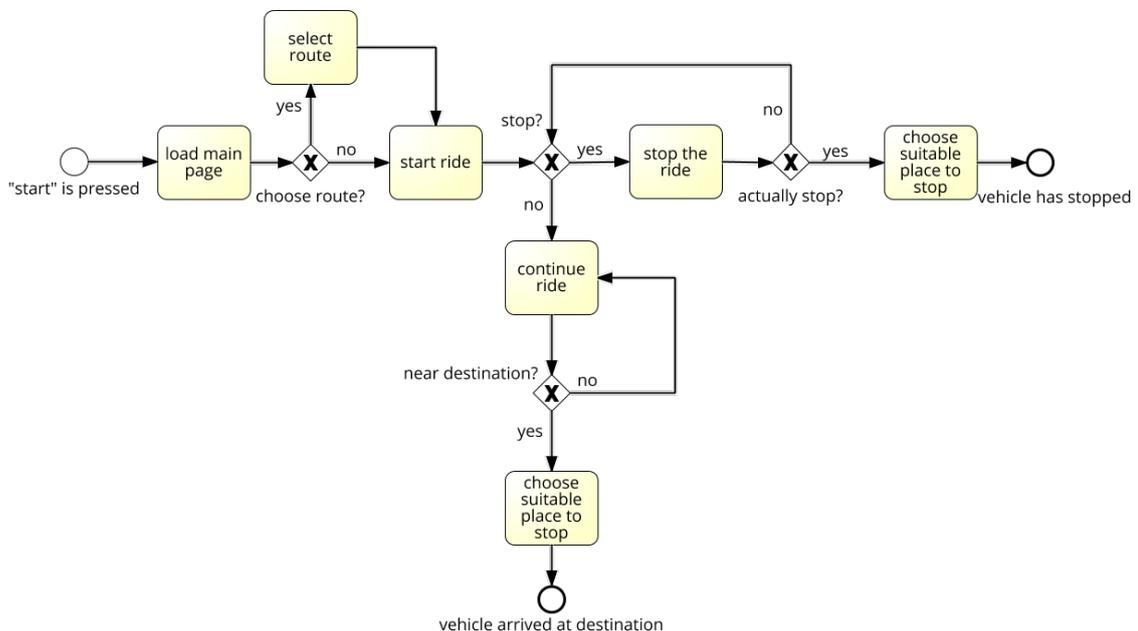


Figure 5. User flow diagram of the application.

The flow would start with the client sitting in the backseat where there are screens with the interface displaying the welcome screen that can be observed in figure 6. This view contains two buttons: “quick guide” and “start”. The start button would appear after the application has loaded itself in the background and displays a text telling the user to wait until it has finished loading. The quick guide button opens a modal to display all the necessary information to use the application which can be observed in figure 7 and satisfies the user story “As a user, I want to see the quick guide, so I can use the application easily.” (full list of user stories is presented in the next section).

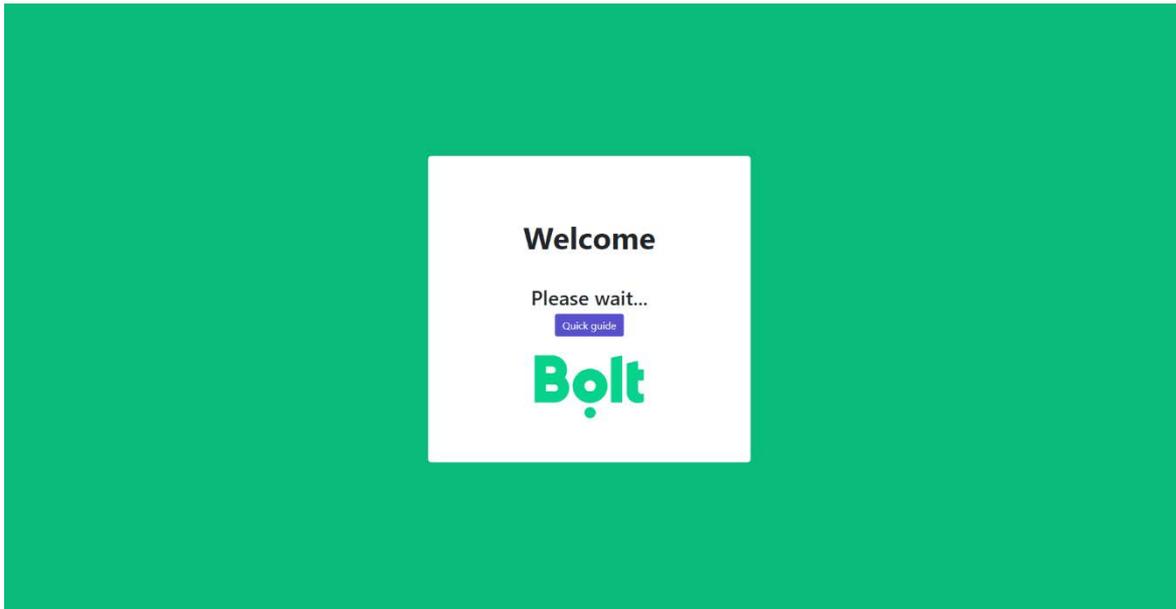


Figure 6. Welcome view.



Figure 7. Quick guide modal.

After the application is ready and the client presses start, he/she is directed into the main view of the interface (figure 8) that includes the map with different route options that can be selected. There is also information about the current state of the vehicle, e.g. maximum speed and the distance to keep from other cars in traffic. The client can also see the quick toggle, that would change the mood, i.e. driving style as the vehicle gets more aggressive with different settings. Those settings can be changed only after the ride has started. In the header section, there is also start location and the destination.

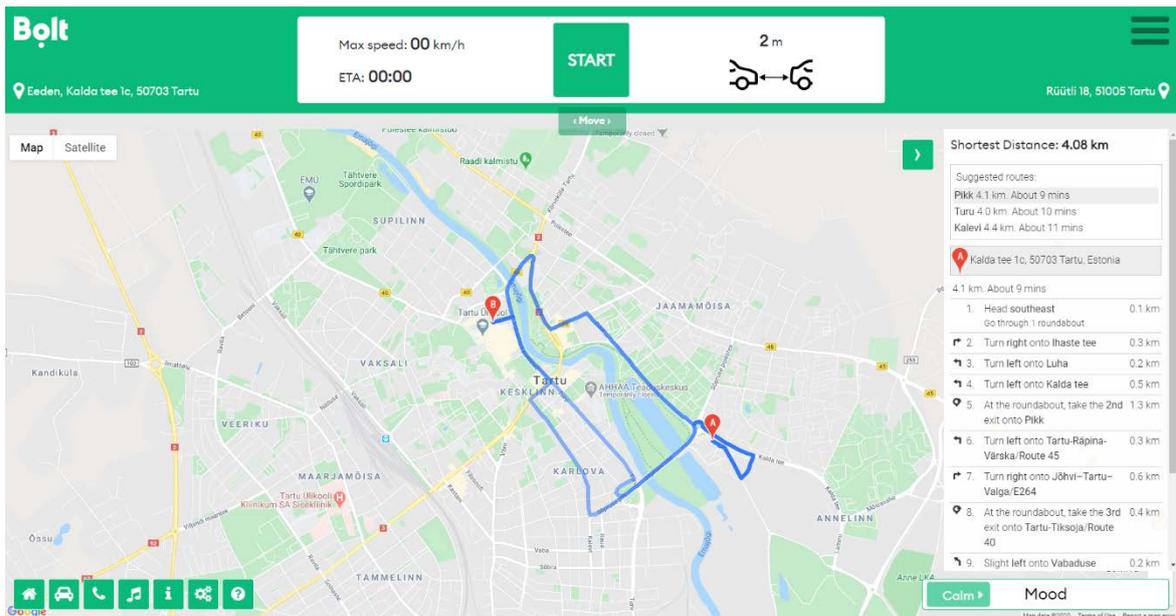


Figure 8. Main view.

When the client has chosen the suitable route and pressed start, the vehicle would start the journey to the destination. The user interface will now also display the correct maximum speed, estimated time of arrival and current location on the map which increases transparency, which is a vital aspect of trust discussed in aspects of trust section. The client is now also able to change the mood setting which holds four states: alert, excited, relaxed and calm. These options give the user some control over the vehicle which should help the trust levels towards the vehicle itself as was mentioned in research question four.

At any time during the ride, the customer can stop the ride. This would prompt a selection to actually stop the ride or continuing it (figure 9). If continue is selected, the ride is resumed. If the stop is selected, the interface will offer the user to select a place for the vehicle to stop at, or the car will select one automatically (figure 10). This option also triggers an audio feature, that lets the user know what is going on. Adding a feature that includes audio makes the interface more anthropomorphic and therefore more trustworthy while offering places to stop gives more control to the user. When the stop button is not activated and the ride is nearing its end, the customer is notified with the same prompt to choose the location for the vehicle to stop. After the car has reached its destination, the client is thanked, and the ride is over.

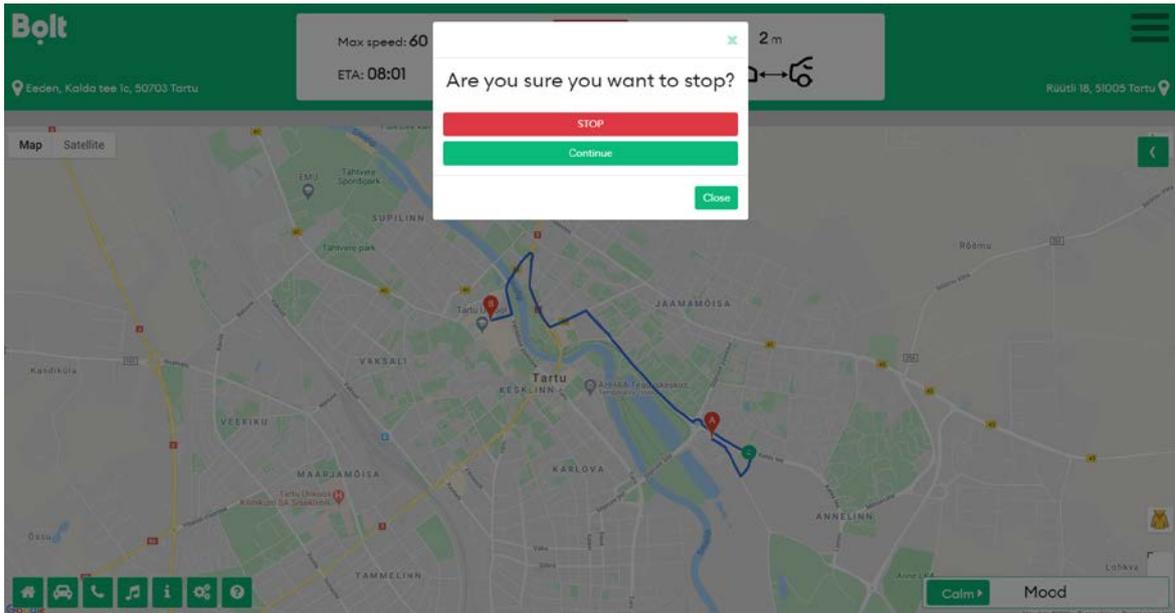


Figure 9. Stop or continue prompt.

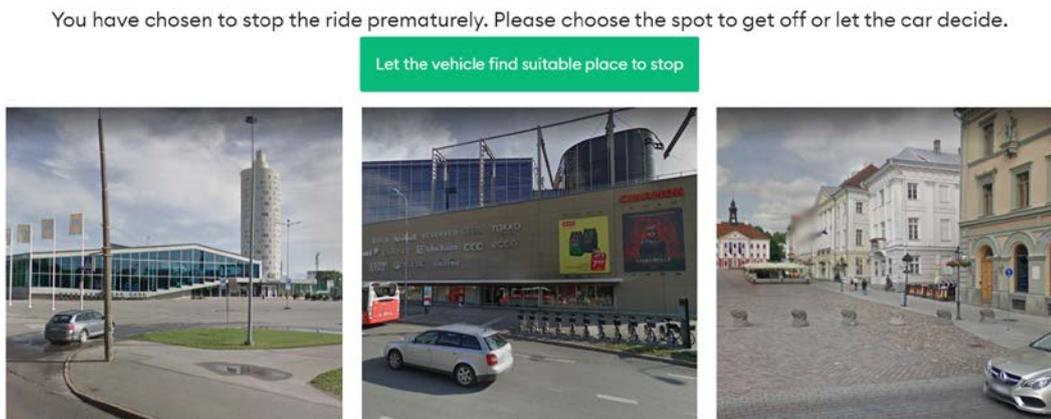


Figure 10. Choosing a place to stop prompt.

## 4.2 A user interface for autonomous vehicles

Considering research in the literature review, we propose characteristics for creating a user interface to increase trust in autonomous vehicles. As this thesis is a part of a larger project with Bolt, we are going to concentrate on a single adult back-seat passenger.

All the design elements, styles and colour schemes are going to be inspired by Bolt and the result of this section is going to be a web-based user interface prototype built with JavaScript [41], jQuery [42] and Bootstrap [43].

From the research done in the literature review section, we can observe that there are a few aspects of trust that we should follow while creating a user interface: transparency, anthropomorphism, culture and brand name. In this case, we cannot affect the brand name as it is

mostly influenced by media. As for the culture aspect, we are going to trust the design team behind Bolt and use their work as inspiration for our user interface.

The research revealed that displaying information to the user about the current state of the car and its surroundings increased trust in the vehicle, although, too much information creates clutter and bad user experience as there is too much to keep an eye on. The user interface should include information and options valuable to the passenger presented in table 3 and all this information should be divided into different views and made available to the user via a simple menu. User interface should also follow the principles of good UI/UX, presented in previous sections. [36,44–48]

We also use generated audio files to activate on different triggers to enhance the user experience and comply with the anthropomorphic aspect of trust. Those audio files are generated using text to speech software provided by Spik.AI [49]. [3,23]

Table 3. Possible user interface features.

Feature	Description
Map	A map that displays route(s)
Live feed	Live feed from the surroundings of the vehicle
Stop button	A button to make the vehicle stop at the first convenient place
Estimated time of arrival	Estimated time of arrival to the destination
State of the vehicle	Various information about the vehicle
Change and choose routes	Ability to change the route
Reports of anomalies and obstacles	The UI notifies the passenger if something unexpected happens
Contact customer service	Ability to contact customer service
Entertainment	Different entertainment options, e.g. YouTube, music library, radio, games
Info about current action	Notify the passenger about the current action taken, e.g. “Finding the first suitable place to stop”, “Setting changed” etc.
Driving style as current mood	Ability to choose between moods, e.g. alert, calm, excited, relaxed
Notify vehicle	Ability to notify the vehicle about upcoming dangerous situations, to keep a long distance from other vehicles

### Application overview

To give an overview of the full user interface, we describe all views in detail including user stories that we took as requirements. We also took the research done in previous chapters as guidelines to design the interface.

## Header and controls

The header section and some of the controls are visible in all the views except the welcome one. At the bottom of the screen, there are two controls: a quick menu and quick toggle. The quick menu consists of buttons that will open a view on click. The buttons themselves have icons, instead of text, to save screen real estate. The quick toggle has two states, calm and alert, which change the vehicle's behaviour. The header displays the start location and the destination. It also has information about the current maximum speed, distance the car should keep from others and estimated time until arrival. Maximum speed and the distance from other vehicles can be controlled with the mood-bar, located below the main header area, and a quick toggle which increases the control over the vehicle's behaviour.

At the top right corner, there is a widely used icon in web design called a hamburger menu that opens the main menu of the application that can be observed in figure 11. In the middle of the header, there is a start button which will change to a stop button once the ride has started. We also devised four user stories to be the basis of developing the header and controls:

1. As a user, I want a menu, so I can access all views.
2. As a user, I want to know the estimated time of arrival, so I can plan my trip.
3. As a user, I always want to be able to stop the vehicle, so I can feel safer.
4. As a user, I want to notify the vehicle of my mood, so I can feel more relaxed during the ride.

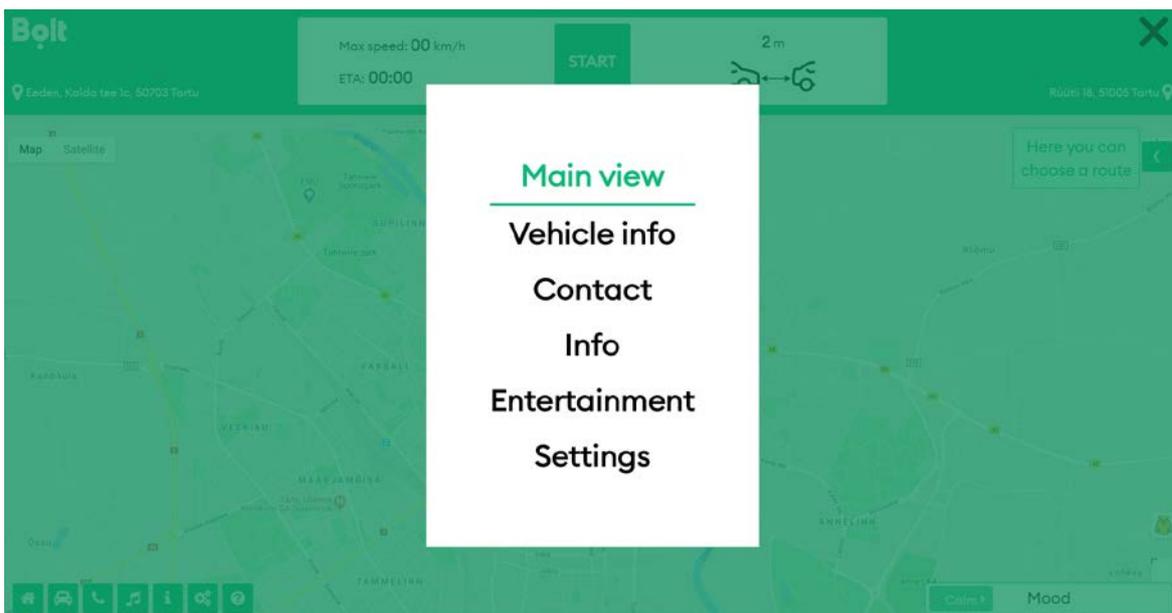


Figure 11. The main menu of the application.

When constructing the design of the application, we followed the guidelines and aspects of trust discussed in research questions four and five. We designed the user interface to be clear in its purpose which makes it useful to the customer. We used icons that the clients should be familiar with, for example, a house graphic used in the quick menu almost always represents a home page or the main view. The interface is also responsive, as it lets the user know when the application is being loaded in the background and when the “alert” or “calm” setting is selected, there is a popup confirming this. To make the application consistent and efficient, we used the same colour scheme and icons across the interface. Important information and the functionality to use the application is always visible and easy to access which makes the interface comply with design characteristics like hierarchy, simplicity,

findability, accessibility and usability. When the stop button is pressed, there is a prompt asking the client to confirm the decision to stop the ride which conforms with the forgiveness characteristic as the application lets the user fix their mistake if the button was accidentally clicked.

We also added audio files, that greet and thank the client for using the service. Audio is also played when the vehicle is nearing its destination and when the premature stopping functionality is activated. This feature makes the application more accessible and anthropomorphic as we used a British female text to speech option to generate the files because research done in the previous section showed that using features too close to human likeness can have a negative effect and this selection still had a bit of a robotic ring to it.

All the features displaying information about the ride or the vehicle and options that give more control over the car should increase trust in the service as they add to the transparency aspect discussed in research question four. These features include the mood-bar and the quick toggle to change the behaviour of the vehicle and all the information, e.g. current position on the map, maximum and current speed.

### ***Welcome view***

The welcome view is the first thing that the customer sees when sitting in the backseat and its purpose is to greet the client and load the application in the background. Functionality and the buttons were discussed in the basic scenario section in detail. We also added an audio clip here that is triggered when the application starts to complement anthropomorphism. For this view we devised two user stories:

1. As a user, I want to see the quick guide, so I can use the application easily.
2. As a user, I want to start the application, so I can start the ride.

Screenshot of the welcome view can be observed in figure 6 in the previous section.

### ***Map view***

The main view includes the map and displays the movement of the vehicle, once the ride has started. The client can also change routes before the trip commences. The route change can be accessed by opening a panel on the right side that slides out when the button is clicked. The panel holds various information, like the shortest distance, current route selected and all the turns the vehicle will take on the road. When the route is changed, all the information with directions is updated as well. This gives the client a good overview of the possible options to reach the destination and improves the transparency aspect of the user interface. The map itself is autofocused on load and the route change is easily accessible and clear which complies with the characteristics of user interface design and user experience. For this view, we devised three user stories:

1. As a user, I want to choose my route, so I can get to my destination faster.
2. As a user, I want to start my ride, so I can get to my destination.
3. As a user. I want to see the vehicle in motion on the map, so I know where exactly I am at all times.

Screenshot of the view is presented in figure 8 in the previous section.

### ***Vehicle information view***

Vehicle information view displays different data about the car which makes it more transparent. The view consists of six blocks of information:

1. The current speed that displays the cars current travelling speed.
2. Tire pressure that lets the user know if the tires are ok. It also has an extra info button which brings out a modal that gives even further details about the tire pressure.
3. The vehicle's make and model, which in our case is Lexus RX 450h. This is a vehicle provided by Bolt that is equipped with different self-driving capabilities. This area also has an extra button to bring up additional information about the vehicle, e.g. a short description and stats like top speed and 0-100 time.
4. Mileage, which displays the distance the car has travelled on the road so far.
5. Last check-up that displays the date on which the car was last inspected.
6. Number plate which displays the vehicles registration number.

As this view only displays information about the vehicle, we only needed one user story:

1. As a user, I want to see the information about the vehicle, so I can feel safer.

Screenshot of the vehicle info view is presented in figure 12.

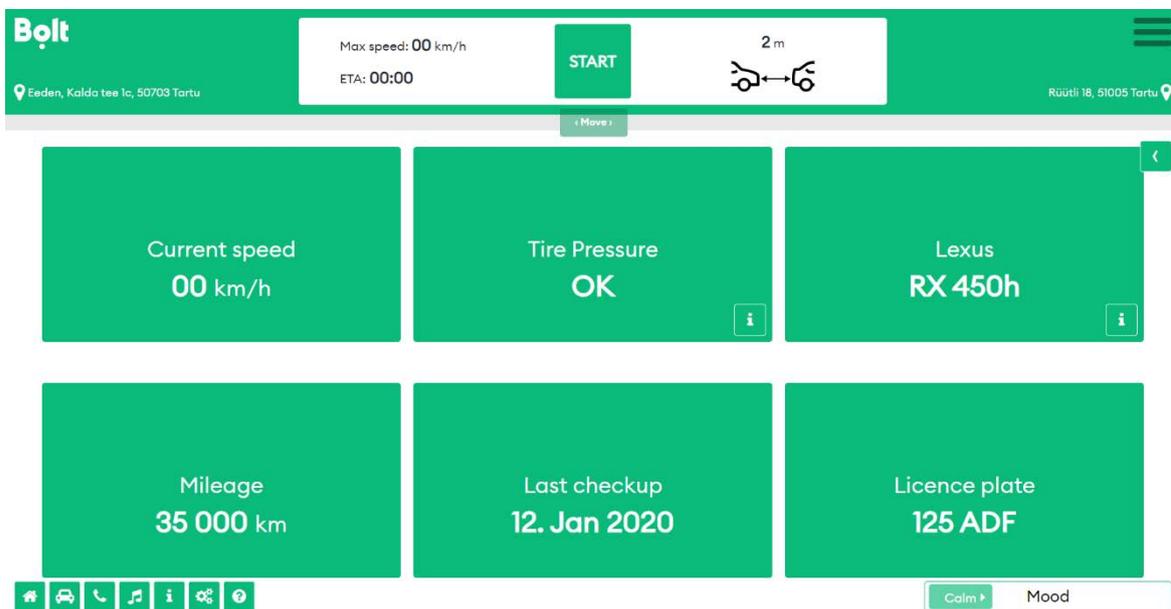


Figure 12. Vehicle information view.

### ***Entertainment view***

Entertainment view includes various radio stations like Star FM, soft rock 97.7 and Sky Plus. There are nine radio stations altogether. The left side of the view has an easily accessible menu where the client can choose between a radio or a news channel. This view only has one goal that is to entertain the passenger during the ride and therefore has one user story:

1. As a user, I want to enjoy some entertainment while the ride is taking place, so I would not be bored.

Screenshot of the view is presented in figure 13.

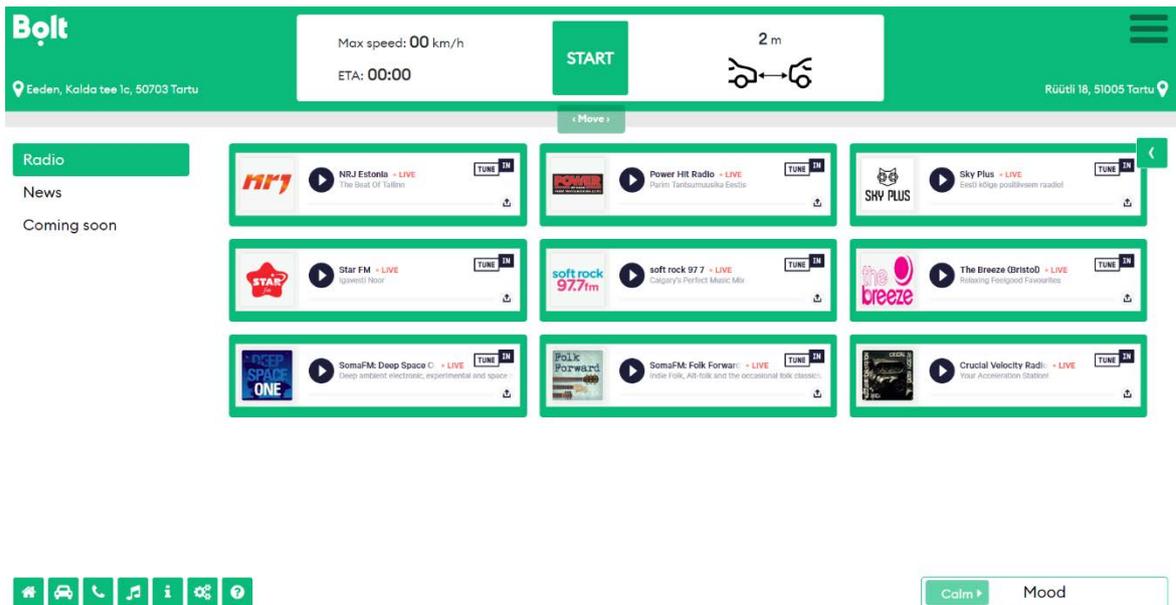


Figure 13. Entertainment view.

### Contact view

Contact view includes a modal that displays a phone number and a QR code so that the client has easy access to the customer service if any problems should occur or additional help is needed. This also creates a situation where the client always has access to a real-life person who can help. As this view is only to display contact information, we formulated a user story that reflects this:

1. As a user, I want to contact the customer service at any point during the ride, to get additional information or help.

Screenshot of the contact view can be observed in figure 14.

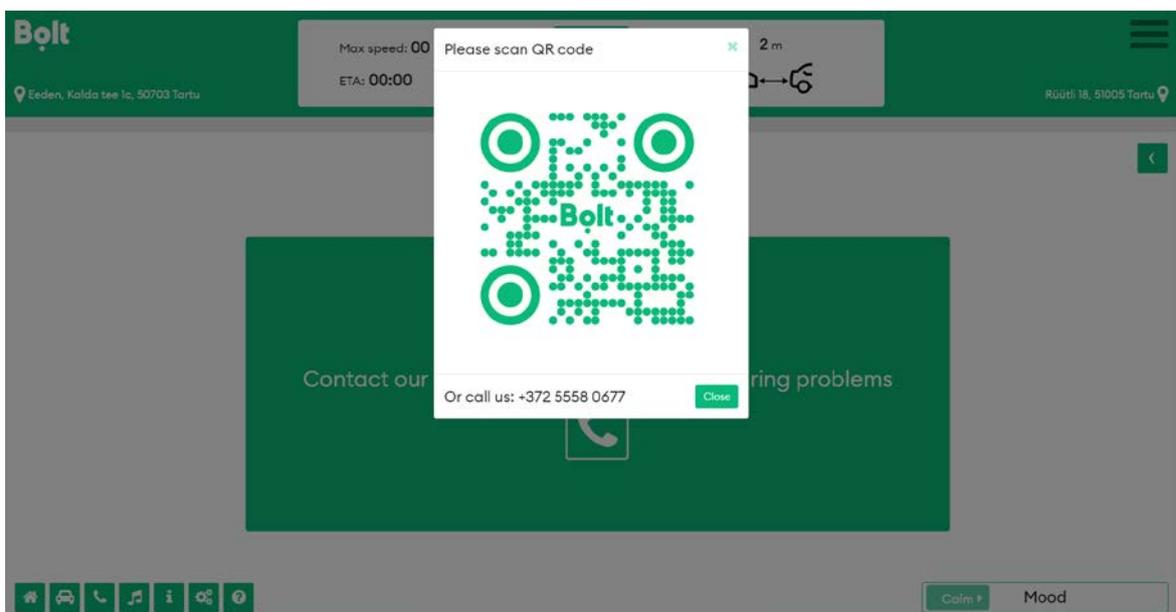


Figure 14. Contact view.

## Settings view

To give passengers in the backseat more control over the vehicle, we created a settings view where the client can have control over the climate and for that, we devised a user story:

1. As a user, I want to have options that I can change, so that I have more control over the ride.

Screenshot of the settings view is presented in figure 15.

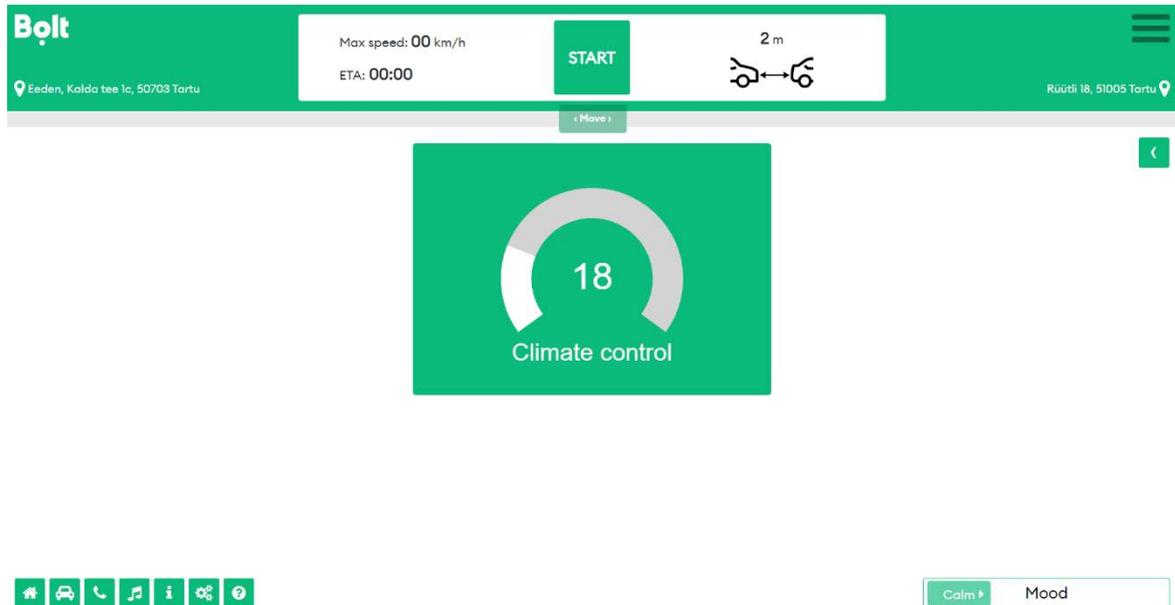


Figure 15. Settings view.

## Information view

As research done in the previous chapter revealed, people want useful information in their entertainment system and to that end, we created the information view that has three blocks with various info. The first block displays the current mood of the vehicle that the client can configure using the mood-bar or a quick toggle. The second one has the weather information for four upcoming days and the last block has the current traffic situation information. For this view, we created the user story:

1. As a user, I want to have an option to view relevant information, so that I can plan my activities better.

Screenshot for the information view can be observed in figure 16.

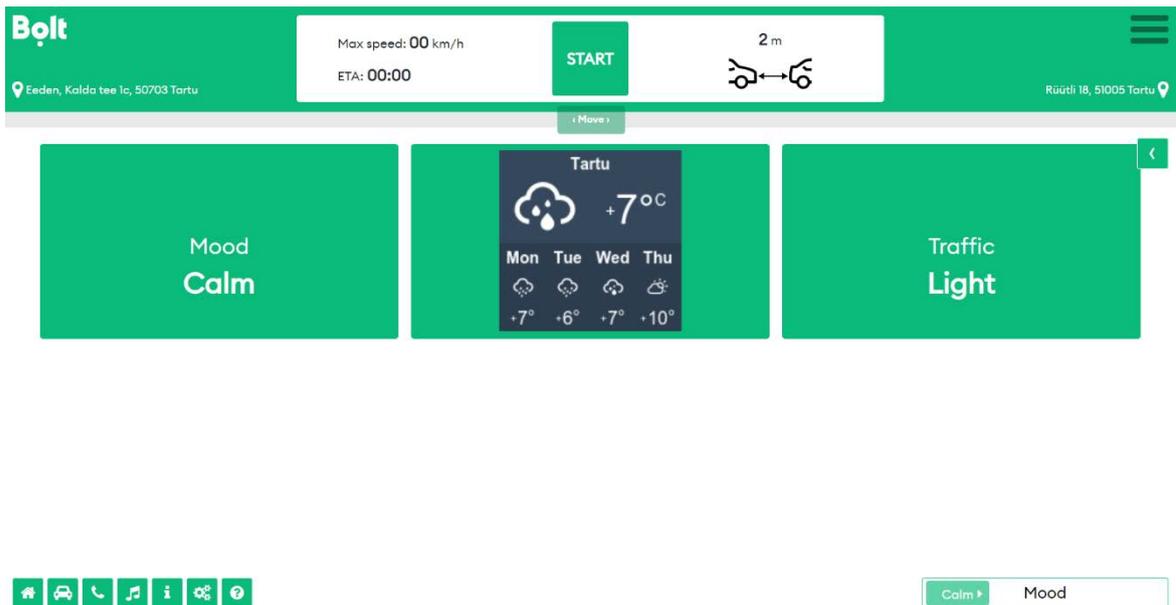


Figure 16. Information view.

### 4.3 Development of the UI

As we need to evaluate the user interface, we decided to only develop a prototype of the front-end as this is enough to conduct the case study and no back-end capabilities were added. The application is developed to work on tablets and larger screens (laptops, desktop computers). Link to the Bitbucket [50] repository can be found in [51] and the developed user interface can be viewed at [52].

Most possible features introduced in table 3 were taken also as requirements for the application and were implemented during the development phase.

#### Technologies, languages, services and methodologies used

To develop the application for the case study, we used several technologies, languages, libraries, services and methodologies.

We decided to use the single page application (SPA) website design approach as the interface is going to be used on tablets. This means that the website is similar in its functioning to an application, as it does not load new pages but instead generates them dynamically using JavaScript's ability to manipulate document object model (DOM) elements on the page. When the application is loaded, all the views are accessible and, for example, when the start button is clicked on the welcome view, a function in the script is triggered which hides the welcome view and makes the main view visible. A similar function is used to go between different views in the application, without needing to reload the entire application. To make the transition seem smoother, we used jQuery [42] animations.

All development was done using free software and libraries. For writing the code itself, Microsoft's Visual Studio Code [53] was used as it provides a lightweight integrated development environment (IDE) with a plethora of available extensions, e.g. live server that allows us to run a local server that serves hypertext mark-up language (HTML) [54] and listens for file changes.

While writing cascading style sheets (CSS) [55] we followed the 7-1 syntactically awesome style sheets (SASS) [56] architecture [57] which allows us to write maintainable and scalable code by dividing it into different sections presented in figure 18. To keep the CSS code

consistent and easy to read, we applied the block element modifier (BEM) [58] methodology which divides the application into reusable blocks that consist of elements and may have modifiers. For example, in figure 17, we have a settings page card element, which belongs to the settings page block. There is also a block called toggle-body that has a variation called “on” and this block can be used in different locations throughout the application.

```
<div class="settings-page__card background background--on">
  <h3 class="settings-page__card-title">Setting 6</h3>
  <div class="toggle-body toggle-body--on">
    <div class="toggle-btn toggle-btn--on toggle-btn--
scale" id="s6"></div>
  </div>
</div>
```

Figure 17. Example of BEM [58] usage.

For version management, we used BitBucket [50] and created branches for development, master and different variations used in the case study for quick and easy switching. The repository can be found at [51]. Full list of everything used with descriptions can be seen in table 4.

Table 4. Technologies, languages, services and standards used in the development.

<b>Technology, language, service, methodology</b>	<b>Description</b>
HTML 5 [54]	A mark-up language used for writing up the application structure.
CSS 3 [59]	Used to describe the presentation of a document written in a mark-up language.
SASS [60]	Used to write code that is later compiled into CSS.
Sassy CSS (SCSS) [56]	Used to write CSS with extra features like nesting, inheritance and mix-ins.
Bootstrap 4 [43]	A front-end component library used to create the application. It offers a wide variety of components that are easy to use, e.g. modals, navigation menus, cards, accordions etc.
Font Awesome [61]	An icon set used to add icons to the project. It offers a large amount of free to use vectors.
jQuery [42]	A JavaScript library used to easily manipulate HTML documents. It also offers event handling and animations that are used in the project.
JavaScript [41]	An object-oriented programming language used to write scripts and add functionality to the application.
Babel [62]	A JavaScript compiler used to compile ECMAScript 2015 and up to backwards compatible JavaScript code that would run on different browsers.
Webpack [63]	A module bundler used to bundle code into single files for easy distribution. In our project, it compiles all SCSS, CSS, JavaScript, HTML, fonts and images to a single dist folder.
Node js [64]	A JavaScript runtime used to run and build the project. Also allows us to use the NPM package manager to add necessary packages to our project.
XAMPP [65]	An open-source cross-platform web server solution used to create a local webserver with Apache, so we can access our application from different devices in the same network.
BitBucket [50]	A web-based version control repository hosting service used to host our application source code and keep track of the changes.
Git [66]	A distributed version control system used in software development to track changes in the source code.
Sourcetree [67]	Software provided by BitBucket that offers a graphical interface for source code version management.
BEM [58]	The methodology used to create reusable components and code sharing in web development.

```
sass/
|
|- abstracts/
|   |- _variables.scss    # Sass Variables
|   |- _mixins.scss      # Sass Mixins
|
|- vendors/
|   |- _bootstrap.scss   # Bootstrap
|
|- base/
|   |- _reset.scss       # Reset/normalize
|   |- _typography.scss  # Typography rules
|
|- layout/
|   |- _navigation.scss  # Navigation
|   |- _grid.scss        # Grid system
|   |- _header.scss     # Header
|   |- _footer.scss     # Footer
|   |- _sidebar.scss    # Sidebar
|   |- _forms.scss      # Forms
|
|- components/
|   |- _buttons.scss     # Buttons
|   |- _carousel.scss   # Carousel
|   |- _cover.scss      # Cover
|   |- _dropdown.scss   # Dropdown
|
|- pages/
|   |- _home.scss       # Home specific styles
|   |- _contact.scss    # Contact specific styles
|
|- themes/
|   |- _theme.scss      # Default theme
|   |- _admin.scss     # Admin theme
|
- main.scss            # Main Sass input file
```

Figure 18. Example structure of 7-1 SASS guidelines [57].

## 5 Methodology

In this section, we elaborate on the study we conducted to test the user interface developed, based on the aspects of trust and characteristics of design reviewed under research questions four and five. To that end, we devised a study that involved five participants. During the study, they completed tasks with the interface, took part on an interview and completed an online survey which we used to score the user interface using the system usability scale (SUS) [68]. To analyse the observations from the test tasks and the interview, we used an affinity diagram [69].

The overall flow of the test was as follows: the study began by sending the consent form to the participant which they had to digitally sign and return before we would continue. After that, we sent a link to the questionnaire which also included the link to the user interface. Next, we contacted the participant over Skype [70] or similar communication software and made a short introduction. We also recorded the whole call and asked the participant to screen share while the interaction with the user interface was taking place so that we could save that as well. After everything was up and running, we asked the participant to answer the intro questions and then moved on to the test tasks where we asked the participant to complete various tasks with the user interface. When the test tasks were completed, we conducted an interview and the study concluded with the participant filling out the remainder of the questionnaire which included modified questions from the SUS [68].

### 5.1 Methods

For the research methods we use a combination of quantitative and qualitative research as we have a survey and interview in our study, we also make observations of the interactions with the user interface.

In the qualitative part of our study, we make observations after the test has finished, as we recorded the whole test. As we must delete those recordings afterwards, we also made a transcript for later use. While observing the participants' behaviour and interactions with the interface, we made notes on various aspects that caught our eye, e.g. were there any difficulties finding elements or how did they react to the audio feature.

We also interviewed the participant and we mainly asked questions about what they liked/disliked about the interface, what they expected from some of the features and what they would like to see in the future version. The answers to these questions gave us the general opinion and shortcomings of the user interface, which we used to evaluate and propose changes to improve it. The following questions were used to conduct the interview:

1. What is your opinion about autonomous vehicles in general?
2. Did you encounter any problems during the interaction with the interface?
3. What did you like about the interface?
4. What did you dislike about the interface?
5. You changed/did not change the route at the beginning of the test. Why?
6. What would you like to see in the improved version?
7. Questions about the mood-bar.
  - a. What did you like about it?
  - b. What did you dislike about it?
  - c. What did you expect would happen if you used it?
  - d. What did you think happened when you used it?
8. What kind of information would you like to see in addition to the existing one?
9. How did you feel about the audio?

### 10. Would you use this kind of a Bolt service in the future?

Notes from the observations and responses to the interview questions were later used to compose the affinity diagram [69] where we went through all the information and wrote down occurring ideas, problems, suggestions and other notable information to sticky notes and divided them into distinct clusters under each question or in the general notes pile which also had its sub-groups. To get a better overview, we then changed the questions into themes and digitalised the diagram which resulted in ten clusters, four sub-clusters and 84 notes. The full diagram can be observed in figure 19.

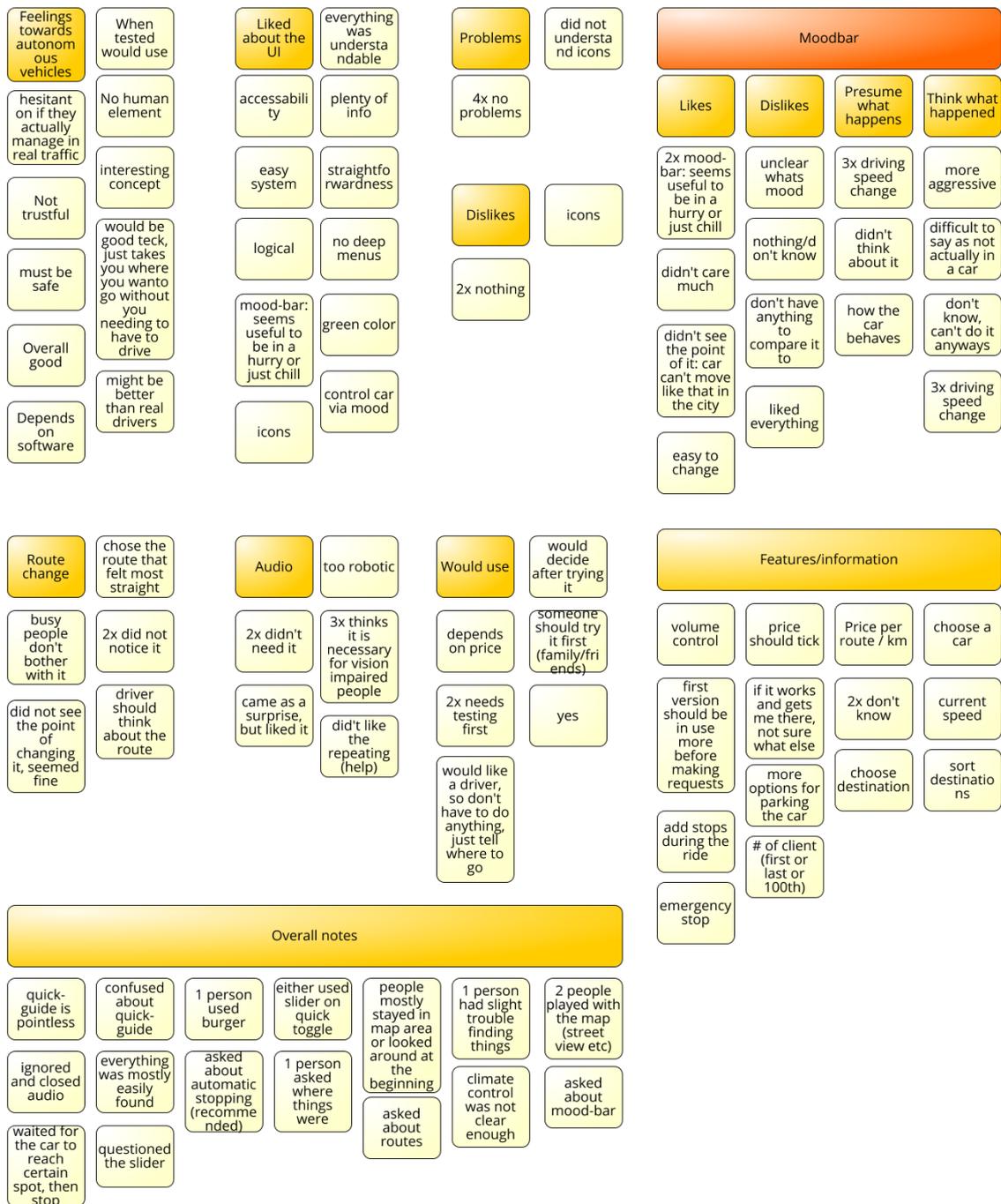


Figure 19. Affinity diagram [69].

For the quantitative part of our study, we used the system usability scale, which is composed of ten Likert scale [21] template questions where we modified the first one to fit our needs [68]:

1. I think that I would like to use this kind of Bolt service frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well-integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

Answers to these questions were ranked from strongly disagree to strongly agree and matched numerical values from one to five. To calculate the score for the user interface usability, we need to subtract one from each odd-numbered question's score, subtract each even-numbered question's score from five, then add up the values and finally multiply it by 2.5. This gives us a score out of 100 where the average score for SUS is 68. [71]

We also asked the participant to write down his/her name, so that we can easily match the survey to the recordings. Another intro question was about their frequency of use of ride-hailing or similar services which we used to get the overall picture of how often these services are used. There was no time limit given to answer the questions.

Participants were chosen based on them having used ride-hailing or similar services in the past. All chosen people were older than 18 and are avid users of computers and smartphones. The full list of participants and their background is presented in table 5. For the study we used five people as it is enough for such a small-scale study and adding a large number of participants would not yield significantly better results. From figure 20 we can observe that using five people gives us the best results as we can catch most of the occurring usability problems. We are testing the first version of the user interface prototype, therefore finding all the problems is not necessary or possible and further testing should be done with future iterations where the solutions for the problems found have been implemented. [72]

Table 5. Chosen participants background information.

<b>Participant</b>	<b>Gender</b>	<b>Age</b>	<b>Frequency of using ride-hailing or similar service</b>
P1	Male	28	Rarely
P2	Male	30	Rarely
P3	Female	25	Rarely
P4	Male	25	Rarely
P5	Female	28	Rarely

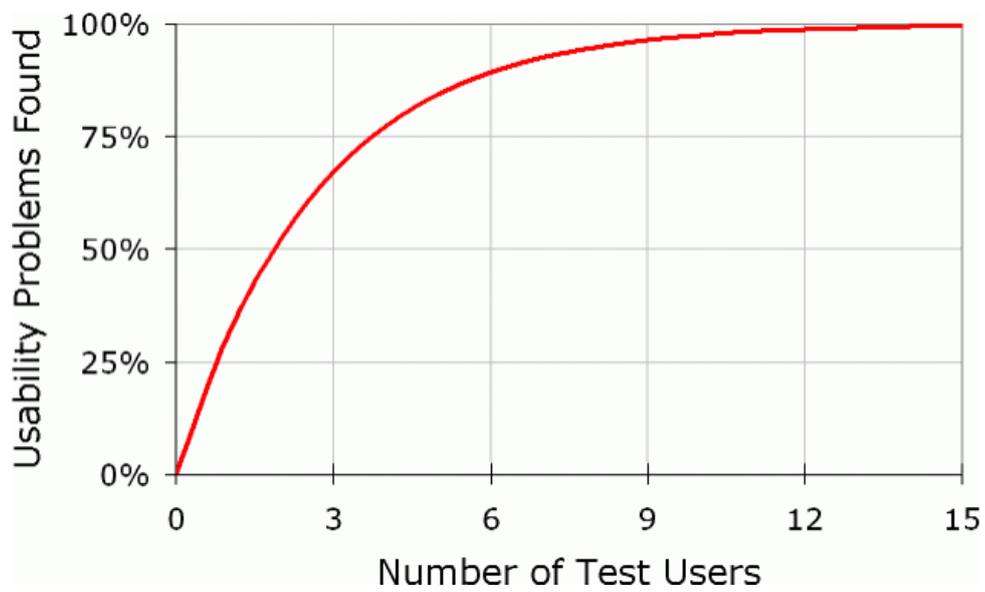


Figure 20. The number of test users and usability problems found [72].

Methods used in the case study fulfilled their purpose rather well as we gathered useful information to evaluate our user interface. The system usability scale [68] responses resulted in a score of 78.5 which is quite good as the average is 68. The affinity diagram helped us to evaluate occurring problems and to give further suggestions to improve future iterations.

## 6 Evaluation and suggestions

In this section, we are going to describe the evaluation of the designed user interface and give suggestions for further improvement. P1 to P5 are used as references for participants and their info is presented in the case study chapter.

### 6.1 Evaluation

For the evaluation process, we used an affinity diagram [69] to gather all the information and insights into distinct clusters for easier processing. For the questionnaire analysis, we used the system usability scale [68].

From table 6, where the scores and the average for our questionnaire are presented, it can be seen that our user interface fared rather well on the scale, reaching 78.5 out of 100 which is quite good for the first iteration. As the average score for SUS [68] is 68. In the terms of grading the usability, the scores would fare as follows: grade A- score of 80.3 or higher, grade C- score of 68 or close to it, grade F- score 51 or under it. [71]

Table 6. System usability scale scores and calculations. Q- question, P- participant.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score
P1	3	2	4	1	4	2	4	2	4	1	77.5
P2	3	1	5	1	4	2	5	1	4	2	85
P3	3	3	4	3	4	2	2	2	3	2	60
P4	2	2	4	1	4	1	5	2	4	1	80
P5	4	1	5	1	4	1	4	1	4	1	90
<b>Average</b>											78.5

We also included a question about the frequency of use of ride-hailing or similar services where all participants responded that they rarely take advantage of such services.

We used affinity diagram to analyse the responses from the study and next we present the results as various themes emerged.

#### The general opinion about autonomous vehicles

The overall response was positive, but participants would like to see extensive testing with self-driving cars before they are accepted and integrated into everyday traffic as participants' answers varied from "At first I am not that trusting of them", "It sounds like an interesting concept, but how successfully they can be integrated into actual traffic is a question of itself" to "If they are safe then they would be really good". P4 later added, "I don't have to drive or do anything myself and if they are safe, they just drive me to wherever I want to go". P5 even figured that autonomous vehicles could outperform regular drivers: "Let's say it depends on the software that drives them, but overall my opinion is good and seems to me that they can even outperform cars driven by regular drivers".

#### Using the service

Participants would like to be sure that the service has seen comprehensive testing before using it as P2 stated: "Entirely possible if it is tested enough". The similar answer came from P1: "If it is a bit more common and let's say preliminary traffic tests have been successfully completed, I don't see a reason why I wouldn't use it". P5 wanted to see other people use

the service first, e.g. family and friends “If somebody that I know tries it first, then sure. I won't be the first Guinea pig”. Price was also important as P5 added “But yeah, it depends on the price. Like, if it is more expensive than a regular taxi, although I don't think it would be, you don't have to pay any salaries to drivers but that depends. Price is still important.”.

### **Problems with the user interface**

Most participants did not encounter any problems during the test, and everything was understandable and accessible as multiple participants stated: “I did not encounter any problems”, “No, not directly. Take a bit of time and get familiar with it and everything is quite straightforward”, “Everything is simple, logical and accessible”, “No, I found everything”. Only P3 mentioned that “No, but some of those buttons used unknown icons. For example, changing the climate control was under the icon where you usually change other things and I did not think that climate control would be there”, which made finding some sections difficult for P3.

### **Positive feedback**

Most common responses were that the system was easy to use, accessible and understandable as participants stated that “All elements in the user interface were understandable for me, I had easy access, I got enough information what was going on outside and inside of the car”, “Well, icons were understandable” and “Most of all, yeah, was that straightforwardness. I didn't have to look for anything from a bunch of menus or anything like that. Everything was quite logically findable”. Two participants also liked the mood-bar and its capability to control the vehicle and stated that “I could change that mood thingy and hope that it would actually work like that. If I set it to fast and I'm in a hurry, then it would actually drive 80km/h in a city, but I doubt that” and “Then it is actually quite useful because sometimes you need to go faster”. P3 liked the system's simplicity but would change the icons.

### **Information and features missing**

P1 could not think of any new features to add and suggested that “Maybe the first version should be in use more before there can be any ideas for improvement. The point is that you need to get used to new things” and then later added, “At least everything necessary for this particular process was present”.

P2 and P3 had some ideas about the map and the ride itself such as sort frequently or last visited places and destinations like cafes and use them as stops and “Ability to add other stops while driving would be good. To see more opportunities to park the car would be good information”. P2 also added “I would definitely like to see the volume control for the radio” and P4 suggested a panic button to stop the vehicle when “if that self-driving car goes like crazy then I just press the button”.

P3 and P5 both mentioned price: “Well you see if you can choose the route then they should have a price difference” and “Price. That is most important actually, how fast it ticks, how it starts”. P5 also asked “Are the prices for all vehicles the same?” and then went on to suggest “There could be an opportunity to choose if you want a Mercedes to pick you up or some fancy car if you are going to a date or whatever, I don't know, or you just need to go from point A to point B and don't care what picks you up”. P5 later figured “Maybe it would be interesting to know if you are the first or 100<sup>th</sup> or some round number” and P4 would like to see the current speed displayed. The lack of Estonian news channels and entertainment option was brought up by P5 during the test tasks.

## **The participant did not change route/chose a longer route**

Multiple reasons were given for not choosing the optimal route at the beginning of the ride:

- “I’m in a hurry and can’t be bothered with it”
- “I don’t know how the car should drive if there are unknown road sections”
- “And if it would be a taxi, then the passenger is usually not the one who decides which route to use”
- “Essentially saw no point in doing so. Based on visual observation they all seemed essentially the same”
- “I guess I didn’t (see the way to change the route)”
- “I chose the route that seemed the most straightforward to me”

Most of these replies can be summarised as the passenger is not that interested in changing the route as they are mostly used to accepting the drivers' decision. If they have specific needs, they would just let the driver know.

## **Perception of the audio**

Most participants understood that it is a necessary feature to include in this kind of a user interface, especially for visually impaired people, but would like an option to turn it off as P1 put it “For me specifically, it was not necessary but people are very different and with very different technological backgrounds. Very different, let's say capabilities. For example, people who have impaired vision problems, this audio feature would be extremely useful”. P4 did not like the robotic voice “I would like it to be more human-like”. It was also mentioned that the audio should only play once when viewing the help modal. To P2 it came as surprise as he/she was not expecting it but received it positively and overall approved it: “Quite surprisingly. Audio support itself was easily understandable “.

## **Mood-bar**

The opinion about the mood-bar is divided into two, participants either did not think much of it or found it useful. The first group included P1 and P3 where P1 mentioned that “At first glance, it doesn’t quite make sense, what does mood mean? I presume it has something to do with the driving style and speed of the vehicle” and P3 had a similar opinion “I don’t see the point of it. Why does it even exist? I didn’t understand, because if you are not a driver yourself or don’t have a driving licence, you basically don’t know the rules. You can’t decide if you want to drive faster or slower as it depends on how other cars are moving”.

The other group who liked it commented that “I could drag it and set it to match my mood: how the car would move. Like fast, slow or really slow.” and “Well I liked that if you go slowly and you have time you can basically just chill in the car and you know you're going to make it on time. Calm driving style. Or if you are excited you can make the car excited as well and drive. And it will drive faster”.

When asked about what the participants expected or thought would happen when the settings were changed, most replied about the speed and driving style: “I presumed that if it is in excited mode it will move faster”, “Car drove faster”, and P5 added about the driving style “I presume that it tries, maybe not drive faster but let's say that 40km/h, not 30 and not stay and wait behind slower drivers”.

Overall participants can be divided into two sides over multiple aspects. They either looked through the whole application after the ride had started (or before the start) or just started it and stayed in the map area. The latter had some minor problems finding different parts of

the UI later, as they were not familiar with the layout. Same can be observed about changing the mood as it was set using either the quick toggle or draggable slider button. When asked to change the mood, most used the quick toggle. This behaviour is most likely since the toggle has the word “mood” written on it.

When arriving in the UI, most participants asked if they should press start. Some made inquiries about the mood-bar, how the route is chosen or if it takes road work into account when calculating the time of arrival. Participants also liked to play with the map: zoom in, look at the route, activate satellite view or go into street view mode. While going between different views, almost nobody used the hamburger icon to open up the menu. This can be the reason, why some found the icons misleading as they did not see the textual representations of them.

Participants P3, P4 and P5 questioned the legality of the driving speed as P3 put it “If I set it to alert which is the fastest and 80km/h then the car can’t drive like this in the city anyway. If, for example, it does drive as the passenger set it, does he/she break the rules?”.

From the videos and the notes, we took, we can observe that in general the participants found everything with relative ease and did not have any major issues with the UI. Most of them described it as logical, accessible and easy to use.

## **6.2 Suggestions**

From the data gathered from the questionnaire, interviews and the test itself, we can make multiple suggestions to improve the user interface in terms of usability, design, transparency and anthropomorphism. While proposing improvements, we need to keep in mind the good practices of UI and UX discussed in the previous sections. After these modifications have been implemented, there should be another usability test.

### **Usability and design**

Even though we scored quite high on SUS [68] with a score of 78.5, some aspects of the user interface design need to be reworked to increase usability. For example, for users who do not want to interact much with the interface, there could be an option, where the car does not ask or offer anything to the passenger, it would just drive to the destination.

As 80% of participants did not use the burger button and the menu it opens, it could be removed altogether or be replaced with a text that says “menu” or something similar to catch the attention of users.

To make the user interface more understandable, the help section needs to be reworked. The current popup modal should activate when a button is clicked in help. The view should also have a frequently asked questions section and descriptions of important features and how to use them. This would mean the removal of the quick guide button from the welcome screen. To make the icons on the left bottom corner clearer and more understandable, we should include an extra button that activates a text bubble with a description of that view which would open when the icon is clicked. Those text bubble could be added to other elements of the user interface as well.

As the mood-bar was confusing to some of the participants, it requires redesigning. We suggest the removal of the draggable button which would also free up some screen real estate to add additional information to the header section. As we already have the quick toggle, we would change it into a button array similar to the menu on the left bottom corner. The buttons would use text instead of icons to make it more understandable to users. We also suggest scrapping the mood concept and replace it with driving modes that are being

used in modern vehicles where different modes make the vehicle behave according to set parameters. Those parameters can be changed under settings to create a custom mode which would also create more transparency. Our proposed solution can be observed in figure 21 where the current mode is set to “Sport” which would make the vehicle get you to the destination as fast as possible.



Figure 21. Redesign of the mood-bar.

The entertainment section also needs some modifications and additions. First, there should be a volume control that manages the overall audio and secondly, there should be more Estonian news and radio stations.

We would also suggest making the application compliant with the laws, e.g. speed limits in and outside of the city.

### **Transparency**

To increase transparency, we suggest adding a view to the application which would include a live 360° camera feed around the vehicle which would also increase trust in the autonomous car as the passenger has a better grasp of the surroundings and can feel more at ease. To further help with transparency, the current display of maximum speed needs to be moved to the vehicle information view and in its place, the current speed should be displayed. As this is a paid service, the price should always be displayed which was mentioned by P3 and P5. Also, when first opening the interface, the panel with available routes and their corresponding prices should be open to draw the attention of the user as it was not always clear to the participants that they can change the route.

In the current version, there exists a stop button, but it does not behave like an emergency stop (it offers a selection of places where the vehicle could let the client off) so there should also be a panic button present to create a sort of sense of security, that the passenger has control over the vehicle and can stop it at any point with a single press of a button.

To further add control over the vehicle the user should be able to change the destination during the ride and add additional stops which were also requested by P2 and P4.

### **Anthropomorphism**

To even further increase the anthropomorphism in the vehicle we could use pre-recorded audio files, instead of computer-generated ones, which would add more human likeness that was also suggested by P4. This could increase trust via the anthropomorphic aspect but as discussed in research question 4, it can also have a negative effect and therefore adding pre-recorded audio files would need additional testing.

Passengers should also have the option to turn off audio all together as it can be a source of annoyance to some users as we observed in the case of P3 and P5 who expressed slight frustration by trying to mute it immediately or by telling it to be quiet.

## 7 Future work

In this section, we propose a case study that could be conducted with the next iteration of the developed user interface. In that study, vehicle provided by Bolt would be used which is equipped with self-driving capabilities that provide an illusion of autonomy to the participant (self-driving vehicles are not permitted in the traffic without the driver interaction). To further help with creating the illusion of autonomous vehicle, the participant would be shown a tour of the car by demonstrating that there is no driver before the experiment begins. Inside the vehicle, the backseat is separated from the front seat with a black curtain. A video loop would be provided of the empty front seat during the ride. Illustration of the setup in Lexus RX 450h can be observed in figure 22.

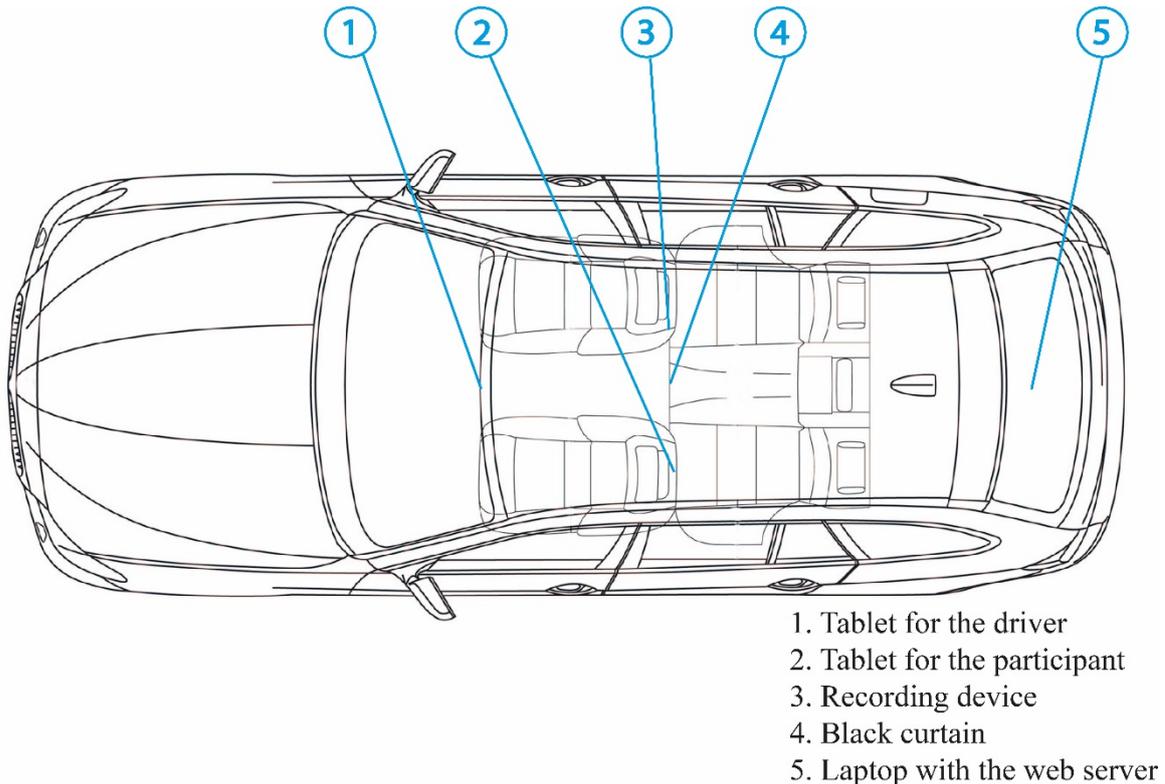


Figure 22. Setup for the case study (the figure is illustrative and does not represent the actual vehicle) [73].

To serve the developed user interface to the tablet, a laptop would be used that has a web server set up. From that tablet, everything is going to be mirrored to another one so that the driver would be able to react to the subject's actions, e.g. pressing the stop button or changing a setting. The whole test would be recorded to gain additional insight into the subjects' actions during the ride. Recordings would include filming the participant and screen recording the tablet that is being interacted with. Changes must be made to the developed user interface to continue with this step. The application is not capable of tracking real-time movement as we previously had to mock the travelling aspect with a timer and could not use current location positioning as it gets its data from the network and is not that accurate when using local area networks instead of mobile ones.

The overall flow the study would go as follows: participant would be greeted and given a tour of the vehicle as described before and introduced the study itself. Next, the participant would sign a printed-out consent form and fill out a survey on a provided laptop to attain the base level of their trust in autonomous vehicles. After that, the study would continue

with the ride part that follows a scenario where the participant has called Bolt to pick him/her up from the university building and drive to a predetermined location (location is dependent on the current time of the day as we must consider the traffic situation and if there is any road work going on). During the ride, the participant would complete different tasks using the user interface. The participant would be encouraged to be vocal about their thoughts and actions. Arriving at the destination would be the end of the ride part of the study and on the way back we would have the interview. After the ride, the participant would fill in another survey where changes in the levels of trust would be seen. The participant would be asked to fill out a system usability scale [68] to score the improvements from the previous study.

Variations of the user interface were devised to test which ones are. Possible variation details can be seen in table 7. These were constructed keeping in mind the aspects of trust: transparency and anthropomorphism. For example, removing the voice components and detailed information about the vehicle from the user interface should result in a lower score in the trust questionnaire as they increase trust. As this would be a small-scale case study, two variations were chosen: 4 and 5.

For that study, ten participants would be used: five for the first variation of the interface and five for the second one. Requirements for the participants, research methods, data collection and analysing the results would be similar to the previous study, except this time there would be an extra questionnaire about trust.

Table 7. Possible variations and features they include.

Variation	Features included
1. All proposed features + voice	All the features from table 3
2. Minimalistic + voice	Only the basic features are present with the voice
3. All proposed features without voice	All the features from table 3 without the features that include voice
4. Minimalistic without voice	All the features from variation 2 without the features that include voice
5. All proposed features with the ability to activate/deactivate features	All the features from table 3 with the ability to activate/deactivate certain features, e.g. voice, some controls etc.

## 8 Conclusion

This thesis aimed to develop and evaluate a user interface for autonomous vehicles to increase trust in them. To achieve that, we first took a deeper dive into the self-driving cars and trust in the shape of a literature review where we sought the answers to the questions like “What is trust in autonomy?”, “How do we evaluate trust?”, “What do we know about autonomous vehicles and how much are they trusted?”, “What kinds of aspects can influence trust in autonomous vehicles?” and “What characteristics should we consider while designing a user interface?”.

We found out that all relationships between humans rely on some level of trust and the same can be observed in interactions between human and machine as well. There are layers of trust in automation: dispositional, situational and learned trust. The first layer characterises trust in automation without any regard to the context of an explicit system and it is influenced mainly by age, culture, gender and personality, it is itself a part of an individual’s personality and displays the willingness to trust. The second layer depends on the current situation of the interaction between an automatic system and human where the environment plays an important role such as internal variabilities, e.g. mood, expertise and external variabilities, e.g. workload, task difficulty. The third layer is closely connected to situational trust and considers past experiences with a specific automated system. Evaluating trust itself is mainly done with a Likert scale [21] type questions and it is built over time and is constantly changing, depending on the experiences and different variabilities affecting its formation.

Modern vehicles, already have several automatic features like dynamic rerouting, adaptive cruise control, automatic parking, emergency stopping systems etc. Most of these features are standard in more than half of all new car models. We also found that there are six levels of autonomy starting with no automatic features and ending with full autonomy where the vehicle does not need any human interference at all. As autonomous systems are quite complex, they can lead to over-trust where drivers are not exactly sure what the machine is capable of, which can cause accidents and even deaths.

When developing the user interface, we mainly focused on transparency as it allows us to include different types of information about the vehicle and give some control to the passenger while anthropomorphism enables us to add a human-like feature such as voice to the application. We also followed the good practices of user interface and user experience which included characteristics like responsiveness, clarity, efficiency, simplicity and usefulness.

We built the prototype with JavaScript and Bootstrap 4 as they are popular tools for quick and easy prototyping. We also used other popular tools such as Git, Webpack and Node.js. The application itself included features like a map with a route selection, entertainment, climate control and had seven different views.

For the case study, we decided to go with an online survey to evaluate usability and conduct a small-scale case study where we observed the participants while they were performing different tasks with the user interface. We also asked various questions in the form of an interview.

Overall results were quite good as we scored 78.5 out 100 on the usability scale. From the interviews with the participants, we observed that the application was easy to use, accessible, understandable and straightforward. Even though the application scored well on the usability scale, some aspects of it need to be redesigned and changed, such as the whole mood-bar concept as participants did not always understand it at first glance. We would also include some new features like a live feed from the vehicle's cameras to stream the 360° of

the outside view and add more control over the vehicle itself, e.g. emergency stop and the ability to add stops during the ride. Currently displayed information should be reviewed, and some changes made, e.g. adding current speed and price of the trip.

Future work could involve implementing the suggestions and conducting a new case study with an actual vehicle to evaluate the trust and usability of the new version of the application. This would involve getting the base level of trust from the participants before the test and then measuring it again after it has completed. This way it can be determined if the user interface improved the levels of trust in any way and what can be done to advance it further.

Overall, the case study was a success as we gathered valuable information to further improve the developed user interface for future iterations.

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## Appendix

### I. Glossary

Term	Definition
Anthropomorphism	Attributing human-like features to objects, software, phenomena etc. For example, adding a human-like face to a robot.
Integrated development environment	Software that provides wide-ranging facilities for software development.
Mix-ins	Allows to define styles in SASS [60] that can be re-used throughout the stylesheet.
Single page application	A web application or a webpage that dynamically rewrites its contents as the need arises, instead of loading entire new pages.
Document object model	A standard used in webpages to represent the structure of a document.
Git	“Free and open-source distributed version control system designed to handle everything from small to very large projects with speed and efficiency” [66].

## II. Test procedure

### Study goals:

1. Evaluate the usability of the developed UI.

**Materials:** survey, Skype or similar software, developed UI, Bandicam for recording

**Introduction:** As a person who has experienced the ride-hailing services like Bolt, we selected you to participate in this study which is conducted for a master's thesis on the topic of „Design and evaluation of user interface to increase trust in autonomous vehicles“.

The purpose of this study is to evaluate the user interface we developed to find out what could be done to improve it in terms of usability. During the study, you are going to complete a survey which involves completing a short test with the user interface. To test the user interface, you are going to be given different tasks to complete. The study will take 20-30 minutes and is conducted online using Google forms and Skype or similar software for communication. Sound and video are going to be recorded.

The user interface is for a self-driving vehicle that people could call like any other ride-hailing service. For this case study, we came up with a simple scenario that takes place before the global outbreak of COVID-19, where you have called a car to pick you up from Eeden and it is going to drive you to downtown. At any time, it is possible to stop the ride.

**Introduction in Estonian:** Tere. Me valisime Sinu osalemaks meie uuringus, kuna sa oled kasutanud eelnevalt Bolti või sarnast teenust. Antud uuring on magistritöö jaoks nimega „Disain ja hinnang kasutajaliidesele töstmaks usaldust isesõitvates autodes“.

Selle uuringu eesmärk on hinnata meie poolt väljatöötatud kasutajaliidest, et selgitada välja, mida saaks selle kasutamisevõimaluste parandamiseks ära teha. Uuring hõlmab endas kasutajaliidese lühikese testi täitmist ja küsimustikule vastamist. Kasutajaliidese testimiseks antakse teile täitmiseks erinevaid ülesanded. Uuring võtab umbes 20-30 minutit ja see viiakse läbi veebis, kasutades Google'i vorme ja Skype'i või sarnast suhtlustarkvara. Heli ja video salvestatakse. Testi käigus soovitame, et te oleksite vokaalsed oma otsuste ja tegevuste üle. Probleemide või arusaamatuste puhul palun küsige julgelt.

Kasutajaliides on mõeldud isesõitva sõiduki jaoks, mille inimesed võivad endale järgi kutsuda nagu tavalise takso. Selle juhtumianalüüsi jaoks lõime lihtsa stsenaariumi, mis toimub enne ülemaailmset viiruse puhangut, kus Sa oled tellinud Boldi, et sõita Eedenist kesklinna. Sõidu saab igal ajal peatada.

### Interview questions in Estonian:

- Kuidas sa suhtud isesõitvatesse autodesse üldiselt?
- Kas sul esines mingeid probleeme või arusaamatusi kasutajaliidese kasutamise ajal?
- Mis sulle kasutajaliidese juures meeldis?
- Mis ei meeldinud?
- Miks sa ei proovinud alguses teekonda vahetada?
- Milliseid lisasid ja uuendusi sooviksid sa näha järgmises versioonis?
- Järgmised küsimused on „mood-bar'i“ kohta. See oli nupuke peapaneeli all, mida lohistada sai.
  - Mis sulle selle juures meeldis?

- Mis ei meeldinud?
- Mida sa eeldasid, et juhtub kui sa seda kasutasid?
- Mida sa arvasid, et juhtus kui seda kasutasid?
- Millist informatsiooni sooviksid sa veel näha selles kasutajaliideses?
- Kuidas suhtud audiosse antud kasutajaliidese puhul?
- Kas kunagi tulevikus kasutaksid sellist isesõitva auto teenust?

### **Test procedure**

**Observation:** We are going to observe the whole interaction with the user interface and focus on potential issues that may come up. This would be done using Skype or similar software and screen sharing. We also provide any support necessary during the interaction. We also encourage users to be vocal about the current situation, so we could gain a better insight into how the user is doing.

During the interaction, we are also going to take notes.

### **Post-interview:**

- Ask about the general opinion regarding autonomous and self-driving vehicles.
- Ask about the issues the participant had during the test.
- Ask what they liked about the user interface.
- Ask about the route if she/he did not change it at the beginning and why.
- Ask what they disliked about the user interface.
- Ask what they would like to see in the improved version.
- Ask the participant about her/his perception of the mood bar.
  - What did she/he like about it?
  - What did she/he dislike about it?
  - What does she/he think happened when she/he used it?
  - What did she/he expect to happen?
- Ask what kind of information the participant would like to see.
- Ask if she/he liked/disliked the audio.
- Ask if she/he would step into an autonomous Bolt vehicle.
  - Why not?

**Survey:** [Link to survey](#)

### **Test tasks:**

1. Start the application and use it as you would during the ride (for about 5 minutes).
2. Set your current mood (scrollbar over the map).
3. Set the mood bar to calm (bottom right corner).
4. Check help.
5. Search for entertainment options.
6. Look for the vehicles licence plate (menu -> car info).
7. Adjust the mood bar if necessary.
8. Adjust the climate control.
9. Stop the ride.
10. Continue the ride.
11. Look for today's weather information (menu -> info).
12. Look around in the UI until the ride is over or.

13. Stop the ride permanently.

**Overall procedure:**

1. Before the test:
  - a. Send consent form and confirm it was signed.
  - b. Send a link to the survey, which will contain all the information: link to UI.
  - c. Share Skype details or any other means for communication.
2. Start the call.
3. Greet the participant.
4. Check if all materials are there.
5. Introduce the study.
6. Give a brief overview of the UI (what is it for).
7. Ask the participant to open the sent link to the survey.
8. Ask the participant to start with the survey.
9. Remind the participant to “think aloud” during the test and ask questions.
10. Ask the participant to turn on screen sharing when he/she reaches the UI testing section and start screen recording.
11. Instruct the user complete the UI test tasks (Test tasks).
12. Ask follow-up questions.
13. Ask the participant to continue with filling out the second part of the survey.
14. Thank the participant.
15. Stop the call.
16. After the test:
  - a. Name the files properly to make sure we know which file is for which participant.

### III. Consent form

#### Consent to Act as a Participant in a Study

**Study title:** Design and evaluation of a user interface to increase trust in autonomous vehicles

**Investigators:** Timo Soiunen, Alexander Nolte

**Introduction:** As a person who has experienced a ride-hailing service like Bolt or similar, we selected you to participate in this study which is conducted for a master's thesis on the topic of „Design and evaluation of user interface to increase trust in autonomous vehicles “.

The purpose of this study is to evaluate the user interface we developed to find out what could be done to improve it in terms of usability. During the study, you are going to complete a survey which involves completing a short test with the user interface. To test the user interface, you are going to be given different tasks to complete. The study will take 20-30 minutes and is conducted online using Google forms and Skype or similar software for communication. Sound and video are going to be recorded.

The user interface is for a self-driving vehicle that people could call like any other ride-hailing service. For this case study, we came up with a simple scenario that takes place before the global outbreak, where you have called a car to pick you up from Eeden and it is going to drive you to downtown. At any time, it is possible to stop the ride.

**Participation requirements:** Any person 18 or older who has experienced ride-hailing or a similar service

**The expected duration of the study:** The study will take about 20-30 minutes of your time.

**Risks and Benefits:** The risks that are associated with this study are no greater than those ordinarily encountered in daily life. There are no direct benefits to participants, but the investigators anticipate future improvements to the developed user interface to potentially benefit autonomous vehicle usage in ride-hailing services.

**Privacy and Confidentiality:** In order to protect the participants' identities during this study the investigators will follow the following procedure: The original recordings will only be accessible to the investigators. The video files will be used to analyse the interaction of the participant with the developed user interface. The audio contained in the recordings will be transcribed, potential identifiers will be removed or aggregated, and the original recordings will be deleted afterwards.

Your data and consent form will be kept separate. Your consent form will be stored securely and will not be disclosed to third parties.

By participating, you understand and agree that the data and information gathered during this study may be used by the participating universities for publication purposes. However, any identifiable information will not be mentioned in any such publication or dissemination of the study data and/or results. The University of Tartu requires all study records to be maintained for at least 5 years following final reporting or publication of a project. Aggregated data will thus be archived by the Principal Investigator for that time span.

**Questions about the Study:** If you have any questions, comments, or concerns about the study either before, during, or after participation, please contact one of the investigators

(timosoiunen@gmail.com).

**Voluntary Participation:** Your participation in this study is voluntary. You may discontinue participation at any time during the study. Your decision regarding whether to participate in this study will not result in any loss of benefits to which you are otherwise entitled.

I am of age 18 or older. I have read and understood the information above, and I want to participate in this study:

Yes  No

**Participant:** The above information has been explained to me and all of my current questions have been answered. I understand that I am encouraged to ask questions, voice concerns or complaints about any aspect of this study during its course and that such future questions, concerns or complaints will be answered by a qualified individual or by the investigator(s) listed on the first page of this consent document.

**Investigator:** I certify that I have explained the nature and purpose of this study to the participant, and I have discussed the potential benefits and possible risks of study participation. Any questions the participant had about this study have been answered, and we will always be available to address future questions, concerns or complaints as they arise. I further certify that no component of this study has started before this consent form was signed.

Participant \_\_\_\_\_ Investigator \_\_\_\_\_

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