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An expected journey

Conceptualizing a holistic approach for user interactions with fully autonomous vehicles

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Titel

En förväntad resa - konceptualisering av ett holistiskt tillvägagångssätt för användarinteraktioner med helt autonoma fordon

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Abstrakt

Autonoma fordon anses vara en växande industri och utvecklingen mot helt autonoma fordon pågår i en snabb takt. Medans forskning inom autonoma fordons design och användarupplevelse främst har fokuserat på användares behov, hävdar vi att det saknas en holistisk översikt över potentiella användarinteraktioner före, under och efter en resa med ett helt autonomt fordon. Denna studie undersökte därför hur ett designkoncept teoretiskt skulle kunna underbyggas och visualiseras för att stödja ett holistiskt tillvägagångssätt för start-till-slut användarinterkationer före, under, och efter en resa med ett helt autonomt fordon. Designkonceptet skapades och utvärderades genom att tillämpa metoden för konceptdriven designforskning, och deltagarna upplevde att det sammanhängande tillvägagångssättet var hjälpsamt för att öka deras övergripande förståelse för tekniken i helt autonoma fordon. Resultatet visade även på ett behov av ytterligare användarinteraktioner som kan vara nödvändiga för att användare skall kunna ta sig till sig tekniken, och vi fann att ett holistiskt tillvägagångssätt kan appliceras för framtida forskning inom användarinteraktioner med helt autonoma fordon.

Nyckelord

FAV användarinteraktioner; Helt autonoma fordon; Delade autonoma fordon; FAV användarupplevelse; SAE level 5; Autonom mobilitet-på-begäran; AMoD; FAV översikt

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Title

An expected journey - conceptualizing a holistic approach for user interactions with fully autonomous vehicles

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Abstract

Autonomous vehicles are considered to be a growing industry and the progression towards fully autonomous vehicles is rapidly underway. Whilst research in autonomous vehicles design and user experience has primarily focused on users' needs, we argue that there is a lack of a holistic overview of potential user interactions prior, during, and after a journey with a fully autonomous vehicle. This study therefore investigated how a design concept could be theoretically underpinned and visualized to support a holistic approach of end-to-end user interactions prior, during, and after a journey with a fully autonomous vehicle. The design concept was crafted and evaluated by applying the methodology of concept-driven design research, and participants found the coherent approach to be helpful in increasing their overall understanding of fully autonomous vehicles' technology. The results further showed a need for additional user interactions that may be necessary for users to adopt the technology, and we found that a holistic approach can be applied for future research in user interactions with fully autonomous vehicles.

Keywords

FAV user interactions; Fully autonomous vehicles; Shared autonomous vehicles; FAV user experience; SAE level 5; Autonomous mobility-on-demand; AMoD; FAV overview

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1. Introduction

The advancements in Autonomous Vehicle (AV) technology and the industries' growing market continues to pave the way for a new era of driverless transportation. An analysis estimates that total worldwide investments in the industry for autonomous vehicles now exceed over $200 billion as the market continues to expand (Holland-Letz et al., 2021). Furthermore, countries worldwide have begun testing AVs in the form of autonomous shuttles, and the Netherlands, Norway, and Sweden have made significant progress in increasing their overall readiness for implementing the technology (Nunno, 2021; Silicon Canals, 2019). For example, the Netherlands has been trying to connect vehicles through 5G technology, and their government has been investigating how AVs could be used to improve road safety. Meanwhile, Sweden has successfully developed a two km road that can charge electric vehicles and has used an autonomous delivery truck on public roads (Silicon Canals, 2019).

Research on AVs design has also been conducted, such as designing intelligent autopilot visualizations to convey the systems competence (Haeuslschmid et al., 2017), increasing the transparency of vehicles towards drivers through heads up displays (Detjen et al., 2021), and attempting to increase drivers' situational awareness by conveying a vehicle's perception of the environment through sound effects (Gang et al., 2018).

Apart from allowing passengers to perform non-driving related tasks during travel on the road, Fully Autonomous Vehicles (FAVs) used as a public transportation system holds the potential to reduce carbon emissions, improve overall air quality in cities as well as decrease the number of vehicles being produced (Nunno, 2021). A case where FAVs have already been implemented more widely can be seen in the United Arab Emirates project Masdar City, which could be described as a living lab to propel the initiative of autonomous vehicles forward (Costa & Teixeira, 2018).

Masdar City began using driverless vehicles by launching the Personal Rapid Transit system (PRT), which consists of electric-driven automated shuttles driving on predefined tracks without using a human driver. Passengers initiate a journey with an automated shuttle by pressing a button to open its doors and selecting one of the vehicle's pre-programmed destinations using the shuttles' touchscreen driven user-interface. The project later on introduced the Navya Autonom, a fully autonomous shuttle that operates lidar systems, cameras, and artificial intelligence (AI) to navigate and make autonomous driving-related decisions based on its readings of the surrounding environment. The shuttles are deployed in open urban spaces and are part of Masdar City's transport system (Cugurullo, 2020).

Alongside the continuous exploration of automated vehicles, research in design has investigated users' needs and requirements for FAVs to enhance the user experience (UX) for passengers. The outcome of mentioned research has resulted in an outline of users' needs and design requirements for user experience (Lee et al., 2020). Furthermore, related studies have looked at possible configurations of screens within FAVs and how they influence user interactions during travel (Oliveira et al., 2018) as well as how to increase acceptance of automated vehicles through in-vehicular interaction design (Faltaous et al., 2021).

While individual research on AVs design and user experience has focused on users' needs (Detjen et al., 2021; Gang et al., 2018; Gerber et al., 2020; Haeuslschmid et al., 2017; Janssen et al., 2019; Lee et al., 2020; Oliveira et al., 2018), there is a scarcity of design research about a holistic overview of potential future interactions in FAVs that visualizes how and when such interactions could occur prior, during or after a journey with a fully autonomous vehicle. Based on previous considerations, this study aims to expand prior knowledge by theoretically underpinning and evaluating a design concept that visualizes a holistic approach of future end-to-end user interactions before, during, and after a journey with a FAV, provided that the necessary infrastructure is available.

1.1 Aim of study and research question

Fully autonomous vehicles are becoming common in contemporary society, increasing the idle time that could otherwise become available for drivers. However, there is a scarcity of holistic approaches to FAVs interfaces that allow users to use their time when planning and carrying out a journey. This study aims to expand prior research on FAVs design by conceptualizing a coherent and holistic design of user interfaces in fully autonomous vehicles. The research question that guides this study is: *How could a design concept be theoretically underpinned and visualized to support a holistic approach of end-to-end user interactions prior, during, and after a journey with a FAV?* The research question will be addressed by adopting the methodology of concept-driven design research by Stolterman and Wiberg (2010).

1.2 Delimitations

FAVs are in a state where the main problem is not the technology, but also the infrastructure. The concerns regarding today's infrastructure are that it is not suited for FAVs. This includes roads, electricity demand, and manually driven cars. Therefore, in this paper the infrastructure will not be considered as the usage of FAV's is not currently possible. The ethical dilemmas regarding privacy information when interacting with the FAV's will also not be considered, as this study wants to conceptualize the design aspect rather than investigate the ethical perspectives of FAVs. This also includes the question regarding trust for FAVs. The study is also focused on FAVs being used as a shared service, and thus privately owned FAVs are not included.

1.3 Definitions

- FAV

  The abbreviation FAV stands for fully autonomous vehicle. An FAV can manage all activities that involve safe driving under any conditions, and it has the Level 5 grade on the SAEJ3016 "Levels of driving automation". The only part where a human is needed in an FAV is when starting the vehicle and entering the destination (Scurt et al., 2021).

- SAE J 3061

  The Society of Automotive Engineers J3061 is a taxonomy and definition for terms related to driving automation systems for on-road motor vehicles. It provides a grading system of 6 levels of automation, ranging from level 0 to level 5 (SAE International, 2021).

- AMoD

  Autonomous mobility-on-demand stands for a futuristic form of transport in which people will be transported using autonomous vehicles that are included in Level 4 and Level 5 of the SAEJ3061 standards (Flohr et al., 2021).

- GUI

  Graphical User Interface is how the interface of something is presented in a graphical manner. The most common way to interact with a GUI when talking about mobility applications is by using a touchscreen on a personal device (Flohr et al., 2021).

- CUI

  Conversational User Interface is an interface that uses text or/and voice to communicate. This lets people communicate with a smart device using text-based chat (i.e., a chatbot) or talking like they would with a real human, using their spoken language in a natural way (Flohr et al., 2021).

- UX

  User experience (UX) forms the 5th generation of HCI domain. Although user experience is adopted by the industry, a scientific consensus or a theoretical model of UX does not exist. It can be viewed as an elaboration of usability (Zarour & Alharbi, 2017).

- SAV

  Are vehicles that are owned by mobility providers and they drive exclusively in automated mode, the abbreviation stands for Shared Autonomous Vehicles (Schuß et al., 2021).

1.4 Disposition

First, we introduce the readers to a brief history about FAVs and the various benefits regarding using a FAV as a means of shared transport. We also discuss the necessary infrastructure and delimitations that are the premises for the following work in this thesis. Secondly, we introduce prior research about FAVs as a whole, the user interactions prior, during and after a ride with an FAV, as well as user experience with FAVs. Thirdly, we present our desired use of method, which is concept-driven design research. We also present our chosen participants and how the qualitative interviews were conducted. Fourthly, we present our results, informed by the prior research and the qualitative interviews that were performed. Following this, we discuss our produced results and reflect back on previous decisions that were made during the process and present a conclusion.

2. Background

2.1 Fully autonomous vehicles

The research on *fully autonomous vehicles* (FAVs) dates back to the early 1920s (Scurt et al., 2021). The first vehicle that could operate without a driver was presented in August of 1921. In 1925, a vehicle was equipped with the necessary equipment to perform autonomous driving by using radio waves to control it. Decades later, in the 1980s, research regarding FAVs was investigated in many countries, both for academic and industrial purposes (Scurt et al., 2021).

When discussing FAVs and the different stages of automation, it is essential to consider SAE’s levels of *driving automation* ranging from level 0 to level 5 (Fink et al., 2021; Oliveira et al., 2018; SAE International, 2021). Level 0 includes vehicles with no autonomous driving element, but they could include autonomous features such as an automated braking mechanism. At level 1, a vehicle could consist of an automated system. For example, it could either adopt adaptive cruise control or assistance that keeps a car in position. Level 2 requires a vehicle to have partial driving automation, i.e., a vehicles' integrated cruise control system can maintain speed and lane centring. For a vehicle to be included in level 3, it needs conditional driving automation. This automation requires a vehicle to steer, brake, and accelerate under restricted conditions (e.g., keeping a vehicle in lane, applying braking before a stop sign). If restricted conditions are not met, a car will prompt a driver to regain control of the vehicle. At level 4, the system of a vehicle can fully drive it under specific conditions. For example, a level 4 vehicle is fully autonomous on a particular path that has been determined in advance. A level 5 vehicle would need to handle every situation during a journey without intervention from passengers or a designated driver (Fink et al., 2021; Oliveira et al., 2018; SAE International, 2021).

FAVs are currently available in several cities (e.g., Masdar City, New York, Detroit, Las Vegas) worldwide in the form of commercial shuttle operations and are receiving increased attention due to technological developments, investments, and media coverage (Fink et al., 2021; Oliveira et al., 2018). FAVs are not only becoming more renowned because of their technological development but also for their environmental benefits for society. For example, they contribute with a decrease in emission and offer less traffic if used as a vehicle for shared rides (Fink et al., 2021; Oliveira et al., 2018). In addition, FAVs provide a flexible option for people with mobility, sensory, and cognitive disabilities. The technology has the potential to help individuals to become more independent, work, and socialize more (Fink et al., 2021; Kempapidis et al., 2020). In addition, FAVs offer passengers increased freedom when traveling by utilizing travel time to complete, for example, work-related tasks (Oliveira et al., 2018).

Another aspect that needs to be evaluated is the *infrastructure*. Cities in which FAVs will be operating in will have to take the necessary precautions regarding policies and infrastructure. It is expected that in the short-term autonomous vehicles will be operating and most likely in segregated zones, which separates the autonomous vehicles from the human driven ones. Regardless, this presents some problems that need to be evaluated when discussing the infrastructure. For example, *traffic flow optimization*, *crossing intersections*, *platooning* and other shared resources that exist within the infrastructure today. Platooning is something that is occurring on roads already as they tend to form naturally. However, they are not currently regulated and that is something that is expected to happen in the future. One way to manage traffic flow optimization is by letting digital signals suggest alternate routes to the driver whilst driving towards an end goal, however that solution is limited by the fact that the driver often disregards the suggestion and continues on the original route. This will most likely change when the FAV receives the alternate route and makes the decisions for the driver. Safety issues during intersections or other aspects of controlling the vehicle where there is a risk for a collision will also be more efficient when humans are not driving. These problems are most often controlled by using stop signs or traffic lights, which eventually will be considered obsolete without actual people driving the vehicles (Mariani et al., 2021). Implementing FAVs in our present infrastructure comes down to a selection of different alternatives with different maturity levels. Looking at an optimum implementation as of today, it would likely be to separate the FAVs from other cars and have them drive on separate lanes. This depends mostly on the safety aspects of the users (Anastasiadou et al., 2021).

2.2 Interacting with fully autonomous vehicles

2.2.1 User interactions prior to a journey

User interactions prior to a fully autonomous journey refer to the interactions between a passenger and a FAV before a passenger enters the vehicle. Interactions before embarking on a journey could occur by using a *smartphone application* on passengers' mobile devices through digital *user interfaces* (UIs). Flohr et al, (2021) demonstrated that passengers have a preference to use technology that is already familiar to them. Therefore, the researchers adopted a map-based *graphical user interface* (GUI), similar to ridesharing and *mobility-on-demand* services such as Uber. Passengers were given the possibility to enter their travel-related details such as *departure time*, *destination*, *number of travelers*, and preferred *shuttle class*. The results revealed high scores and positive attitudes towards the adopted user interface (Flohr et al., 2021).Another smartphone-based interface designed as a *chatbot*, also referred to as conversational user interfaces (CUIs), was examined (Flohr et al., 2021). Compared to GUIs, CUIs allow passengers to interact with a computer system through natural language via text. The chatbot in this study acted as a representative of the shared autonomous system. If the CUI is designed well, chatbots can personalize the interaction with a passenger and offer useful context-based shortcuts. The researchers adopted a chatbot that was designed to have a balance between a respectful and informative tone while at the same time being casual and enthusiastic. The chatbot offered passengers to perform activities such as plan and book a ride, change departure time, guide passengers to the location of the autonomous vehicles, and provide an indication when passengers have embarked on a vehicle. The outcome of the research showed that passengers preferred a hybrid interface between a GUI and CUI for a better user experience (Flohr et al., 2021).

Looking beyond the above activities, Schuß et al., (2021) found that passengers may request more detailed and user-accommodating interactions. The researchers investigated how various types of FAVs and HAVs (Highly Automated Vehicles) could be used. They explored participants' expectations of multiple vehicles using interviews, enactments, and UX cards. For shared journeys, the researchers investigated the requirements and preferences for SAVs and Shared Transits (STs). ST is a type of SAV that is expected to be cheaper than mobility-on-demand services. It acts as an extension of public transportation, offering larger shuttles for longer journeys but without the same type of on-demand flexibility. Before embarking on a trip in an on-demand type SAV, participants requested that information such as the vehicle's space and the number of passengers inside was essential to know if they could, for example, bring their kids on the ride or fit their luggage in the vehicle. A user-friendly *booking system* was requested to account for the elderly and individuals in a hurry, allow for changeable drop-off locations, and the ability to quickly be allocated a vehicle within a short time frame after booking. For Shared Transits, female participants expressed fears of being a victim of a crime if they would ride at night. Specifically, they requested features to see the number of passengers in a vehicle before embarking on a journey, as well as an interaction that could either stop a vehicle immediately or contact security personnel in case of an emergency (Schuß et al., 2021).

Research has also examined how passengers could board a shared ride after it arrives to pick up passengers. Kim et al. (2020) applied the Wizard of Oz technique and reconfigured a vehicle to appear as a shared autonomous taxi. Similar to Flohr et al., (2021), a messenger-like application with a chatbot was used by participants to initiate a journey, and passengers would use a supplemental *map* application to designate their destination. Passengers then received walking directions to a virtual pick-up point, a specified location close to the users' proximity that the vehicle could travel safely to, and was shown to them through images in the chat application. A QR-code was used during the pilot study to begin *boarding* and confirm a passengers' identity and a vehicle. Later, the researchers found this method to be inconvenient for passengers and conceptualized a Near Field Communication concept (NFC) for the main study. A passengers' smartphone would automatically unlock the autonomous vehicle by being close to it. During an evaluation, passengers raised concerns that they were unsure if they would be able to identify an autonomous taxi if there were many other vehicles around it. Passengers' feedback indicated the importance of accurately tracking an SAV in real-time before pick up (Kim et al., 2020).

Further interactions that could assist in identifying and communicating with FAVs prior to a journey has been identified by Gluck et al., (2020). The researchers conducted a case study with participants with a mean age of 85, in order to identify design and user interaction preferences for older passengers when embarking on a shared journey. The researchers used enactment sessions where the participants were allowed to freely act out how they would like to approach an SAV, enter the vehicle and decide what their preferred interaction to inform the vehicle of their destination would look like. Participants mentioned that if the vehicle was picking up the passengers in a crowded area, features like flashing the vehicle's light, honking the horn, or making an automated phone call to the passenger informing them of the vehicle's arrival could be useful, in addition to providing smartphone notifications. The participants requested the need for self-opening doors without the requirements of user input to aid entrance for passengers to a vehicle. To easily convey their destination to an SAV and begin a trip, participants preferred to use voice commands as the primary form of interaction (Gluck et al., 2020).

2.2.2 User interactions during a journey

User interactions could occur inside a FAV using different interfaces during a fully autonomous journey. Oliveira et al. (2018) evaluated how various configurations of *screens* inside a FAV affected the passengers' interactions with the vehicle. Participants were invited to take three fully autonomous rides in a controlled environment. The researchers used a Wizard of Oz method in which passengers inside the pod were asked to complete various tasks by using the vehicle's interfaces, such as changing a shuttle's destination and making an unplanned stop, whilst the researchers were the ones that actually controlled the pod from outside. Passengers had three interfaces available to them; their smartphone with a dedicated *app* for the journey, a mounted touch screen-driven tablet positioned at the front of the shuttle, and a mounted *overhead display* close to a shuttle's ceiling. The smartphone application and the *mounted tablet* both displayed a map of the environment, the vehicles' real-time position, the chosen *route*, and the passengers' *estimated time of arrival* (ETA). The mounted overhead display showed similar information but was non-interactable: it displayed the local time, the shuttle's destination, and the weather outside. Participants indicated that the combination of the mounted tablet and the overhead display was the most useful during the journey (Oliveira et al., 2018). The researchers concluded that FAVs interfaces should allow passengers to control a vehicle's journey without solely relying on a passenger's smartphone to prevent unforeseen issues such as, for example, if a passenger's smartphone runs out of battery. The results also indicated a preference for larger screen size for an interface, and that an interface should describe a vehicle's subsequent actions and if it is aware of any *upcoming hazards* (Oliveira et al., 2018).

The quality and quantity of information conveyed to passengers during a journey could also positively or negatively impact user experience. Alpers et al. (2020) reconfigured a vehicle to appear as a shared fully autonomous van, making passengers believe that they were embarking on a fully autonomous ride that was in reality operated by a human. The vehicle had two on-board digital assistants that conveyed information using human-like voices to passengers along with mounted intractable touch screen tablets on the inside. Conveying information using human-like voices have previously been shown to drive user engagement with autonomous interfaces by increasing perceived feelings of safety, social presence and intelligence in AVs (Alpers et al., 2020). Passengers were assigned one of the digital assistants and were equipped with wristbands and chest monitors that analyzed their stress levels throughout their journey. One assistant conveyed less information and without human-like interaction qualities (Alpers et al., 2020). The information conveyed to passengers consisted of (1) welcoming the passenger upon embarking the vehicle, (2) providing assessment checks before a journey, (3) providing a map of a route, and (4) announcing estimated time of arrival. The second assistant had human-like interaction qualities and provided additional information. It displayed *miles per hour*, announced new routes if a road was blocked, displayed any moving objects it had detected, apologized for sudden stops, and thanked passengers once a journey was concluded. By comparing the evaluation of both assistants, it was found that the assistant that conveyed more information with human-like qualities caused passengers to exhibit less tension and anxiety and improved their overall experience (Alpers et al., 2020).

Schneider et al. (2021) used a simulator of a shared FAV and investigated if explaining vehicles' driving related decisions using simulated Augmented Reality, text-based information, and LED lights would improve passengers' user experience and feelings of control and safety. The study also investigated if providing explanations of vehicles' driving-related decisions through a smartphone application after a journey had a positive impact on user experience. The research found that providing live explanations during a journey could increase the understanding and ease of use of FAVs. Providing information of events that occurred on a journey by using a smartphone application after a ride would only be beneficial if live explanations are not given to passengers during the journey (Schneider et al., 2021).

Further research found that relying on only one type of user interaction during a journey would not be appropriate since some individuals may be limited in what type of interactions they can perform. For example, relying only on a voice assistant as a user interaction would not work for older people that may have a hearing impairment (Gluck et al., 2020). Therefore, shared FAVs user interfaces need to include both visual and *auditory interactions* for passengers to increase their service usability. Interactions should also not solely rely on using a passengers' smartphone, to account for individuals who may have limited knowledge of those devices or have less technical expertise (Gluck et al., 2020). Other interactions could for example occur by using voice commands (Alpers et al., 2020; Gluck, Earl W. Huff, Boateng & Brinkley 2020) or a mounted touch-screen driven tablet (Oliveira et al., 2018).

2.2.3 User interactions after a journey

For a holistic approach to designing a user interface with a FAV, it is essential to account for all parts of a journey where users interact with a FAV. With the technological development of FAVs, there is an increasing need to attend to user interactions that take place after a journey and from a user-centered perspective.

Since there is a lack of human interaction onboard a fully automated vehicle it is important to consider what the communication between the passenger and ride will look like, even after the passenger has successfully arrived at their designated destination with a FAV. The services after a journey with a FAV will most likely be substituted with a mobile app, instead of the human-to-human communication between driver and passenger. There are currently numerous shared ride services (e.g., Uber, Lyft, GreenMobility) that already have an application with a well-developed graphical user interface for interactions after a shared ride with present drivers, which could be utilized in this case too (Flohr et al., 2021).

Interactions after a journey with an FAV could, for example, include *payment, reviewing a trip*, reach out to and talk to *customer support,* as well as *switching to another form of transportation* (e.g., another FAV, train, other means of public transportation) as a means to continue a journey forward (Svangren et al., 2018; Flohr et al., 2021).

Flohr et al., (2021) conducted a study where they discussed the use of a chatbot as a form of interaction with a FAV. This chatbot could not only be used both before and during a journey with a FAV, but also after. A chatbot, or a virtual personal assistant, could provide an easy way for users to express their needs and wants in their own words, since a chatbot enables the user to interact with speech, text and touch. This could facilitate the user's desired interaction with the FAV through the application, since they can instantly convey their needs and interests through the chatbot instead of manually searching through an application. Therefore, users can write what kind of interaction they want to have (e.g., paying for the ride, changing rides, writing a review, contacting customer support) with the FAV using a chatbot with an easy-to-use graphical user interface in the application (Flohr et al., 2021).

A chatbot or virtual assistant could also make personalized shortcuts to interactions based on already acquired knowledge about the specific journey and passenger (Flohr et al., 2021). If, for example, a user paid for a journey with a FAV beforehand the chatbot could ignore asking for payment after arriving to the designated destination and instead ask the passenger if they would like to write a review of the journey or have other suggestions already available for the user to select from as a next step in their experience and travel.

Gluck et al., (2020) conducted a study to explore the design of shared autonomous vehicles (SAVs). The findings showed a need for *clarification* and *notification* from a FAV when passengers arrived at their destination. This clarification consisted of an auditorial, visual, or verbal notification (e.g., sound, a blinking light, or a verbal message) informing passengers that the FAV had arrived at the destination. The most commonly used and discussed method in this study was the verbal option, where passengers and a vehicle openly communicated using words and sentences (Gluck et al., 2020). Furthermore, participants discussed what the arrival at the destination would look like and how it would work. Finally, participants discussed that the most enjoyable experience would be if a FAV dropped passengers off as close as possible to the destination, whether it would be by a building, bus stop, or specific drop-off zones (Gluck et al., 2020).

The usage of specific notifications, whether auditorial, visual, or verbal, is an integral part of the communication between passengers and a FAV. A unique or specific kind of notification could be used for other interactions that take place after a ride with a FAV. For example, an auditory signal could inform passengers when they have successfully paid for their ride. If passengers have to change FAV to reach their destination, the next FAV could have a special color glowing through the headlight to signal which FAV is passengers’ transit vehicle (Gluck et al., 2020).

2.3 User experience of fully autonomous vehicles

Even though fully autonomous vehicles are considered the technology that can revolutionize the way people travel and mobility systems in society, there is still a lack of knowledge in the *user experience* (UX) part of the journey. There is little to no knowledge about passengers' needs and wishes from a level 5 autonomous vehicle (Lee et al., 2020), but in order for FAVs to live up to its potential of becoming a life enhancing technology, the user interfaces, vehicle applications and interactions should be designed with consideration of what passengers want, and how they would like their needs to be addressed.

Lee et al. (2020) conducted a study that explored passengers' needs and design requirements for FAVs to contribute to enhancing the user experience when traveling with a FAV. The study identified four design requirements: (1) *System functionality*; (2) *input control*; (3) *information display* and; (4) *in-vehicle space* (Lee et al., 2020).

System functionality included requirements that passengers articulated of how they wished a system of a FAV would work. Passengers expressed needs that included a requirement for *connectivity* between a FAV and other personal devices, or even other vehicles. Passengers also expressed a need for privacy protection and protection against potential cyber threats (Lee et al., 2020).

Input control assessed the need for design requirements and for input control interfaces. This requirement considers people with low IT literacy and general interaction techniques. People with low IT literacy can include the elderly, people with disabilities, or any other group that might have difficulty learning to navigate a digital interface. An inclusive and user-friendly design for the interface of FAVs will benefit these target groups (Lee et al., 2020).

Participants exclaimed a need for an information display in a FAV that communicates *driving-related information* to passengers. This could, for example, include information about the speed limit of the road that the vehicle is traveling on and what speed the FAV is currently maintaining, what the road conditions are and recommended speed limits according to those conditions, a map that displays the selected route for the ride, how much time has passed and the estimated time of arrival. Participants mentioned a possibility to utilize the windows of a FAV as an information display that could also be used for both practical and entertaining purposes (e.g., watching a video conference, doing work related tasks, watching TV, playing games). Participants also discussed the issue of motion sickness as a result from using an information display. A visual interface can cause an increase in motion sickness for people prone to it, which means that designers of an information display need to take these challenges into consideration (Lee et al., 2020).

In addition, participants discussed in-vehicle space, i.e., elements of an in-vehicle area that does not solely focus on system functionality and user interface. For example, on the one hand, passengers discussed the option of having adjustable seats for sleeping inside a vehicle. On the other hand, the design and adjustability of seats could be a safety risk for passengers and should not be modified to prevent potential accidents. The seating structure should be designed to benefit passengers' posture, experience, and security (Lee et al., 2020). To promote a positive UX for elderly or disabled passengers, FAVs interior space should allow for increased mobility, as was also mentioned by Gluck et al., (2020). Similarly, instead of using touch-based controls such as a mounted tablet (Oliveira et al., 2018), FAVs would benefit from also having other methods of input control available to them to evoke a positive UX for elderly or disabled passengers. They could, for example, also include *auditory interactions* (Alpers et al., 2020; Gluck et al., 2020; Lee et al., 2020), which was further mentioned by Large et al. (2019) to be a preference by passengers over other user interfaces.

Large et al. (2019) compared the user experience between using a prototype of an anthropomorphic voice agent in a fully autonomous pod, along with a touch-screen driven tablet with a voice interface that could only be activated by using predetermined voice commands. The voice-based interactions were made possible using a Wizard-of-Oz method, in which a professional actor outside of the pod would respond to the passengers' voice commands inside the FAV. The study showed how that an anthropomorphic voice agent could allow passengers to interact with the FAV using a free-flowing, conversational language, and in turn receive human-like replies, where the system, for example, could respond with first-person pronouns and address the passenger by their name (Large et al., 2019). The tablet had a simplified touch-screen driven interface with four main interactions; the option to check the news, access the entertainment system, (e.g., news, music), scheduling & offices (checking to-do-lists, calendars and emails) and run system diagnostics. The tablet was also used to give participants a list of pre-determined voice commands when testing the other, simplified voice-based interaction. The results indicated that users' needs for privacy and security must be addressed in order to make use of voice-based interactions in FAVs, but that the use of voice-based interfaces was given a strong preference over other interfaces. The anthropomorphic voice agent also elicited more pleasure and a forgiving experience for some participants, in the sense that passengers would be more willingly to accept if the FAVs perception of the environment differed from what the passenger could see (Large et al., 2019).

3. Method

3.1 Concept-driven design research

This study will apply the concept-driven design research method proposed by Stolterman and Wiberg (2010) to maintain focus on expanding previous knowledge in FAVs by theoretically underpinning and evaluating a design concept. In contrast to previous research on AVs, this research adopts a holistic approach and does not focus on individual use situations or users' needs (Detjen et al., 2021; Gang et al., 2018; Gerber et al., 2020; Haeuslschmid et al., 2017; Janssen et al., 2019; Lee et al., 2020; Oliveira et al., 2018).

Compared to situation-driven research methods, which often focus on approaching a specific problem or a use situation (Stolterman & Wiberg, 2010), artifacts crafted with concept-driven design research are instead optimized to a particular idea, concept, or theory. The purpose of concept-driven design research is to contribute knowledge to the research field in the form of theoretical development and less emphasis on designing an artifact that addresses situational issues (Stolterman & Wiberg, 2010).

Stolterman and Wiberg (2010) characterize concept-driven design research as having three different properties and these are visualized in Figure 1:

1. The point of departure is conceptual/theoretical rather than empirical.
2. The research furthers conceptual and theoretical explorations through hands-on design and development of artifacts.
3. The end result—that is, the final design—is optimized in relation to a specific idea, concept, or theory rather than to a specific problem, user or a particular use context.

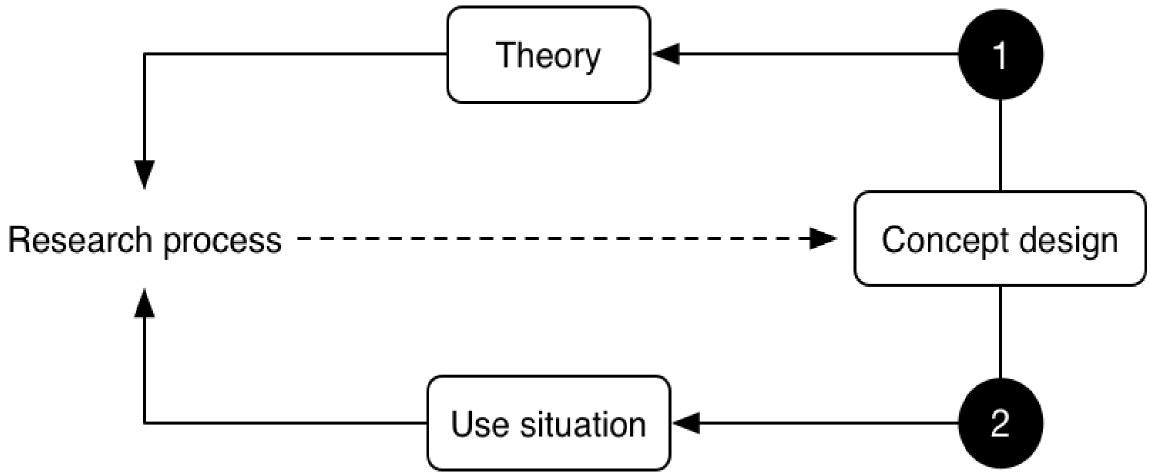


Figure 1. *An illustration of concept-driven design research and its relation to theory and use situation, adopted from Stolterman and Wiberg (2010).*

Concept-driven design research further consists of seven methodological activities: *concept generation, concept exploration, internal concept critique, design of artifacts, external design critique, concept revisited,* and *concept contextualization* (Stolterman & Wiberg, 2010).

Concept generation involves searching for and generating new concepts supported by earlier theoretical work in the field. This methodological activity can, for instance, be undertaken by working with metaphors, conflicting theoretical concepts, assumptions, and theories from related design fields or historical examples. When considering new concepts, the elicited design concept must provide something new to the area of study, which can be done by either combining previous knowledge in a new way or manifesting it as a whole (Stolterman & Wiberg, 2010).

The second activity, *concept exploration*, entails creating models and prototypes and experimenting with materials, forms, and various types of content. By examining new design spaces or exploring the unknown parts of already known territories, the designer opens up the possibilities of conceptualizing something new (Stolterman & Wiberg, 2010).

Internal concept critique refers to the third methodological activity, taking place after having created initial concepts in sketches, low fidelity mock-ups, or prototypes. In this phase, the designer examines the strengths and weaknesses of the selected concepts before proceeding. The chosen concept needs to be evaluated against the underlying theoretical foundation used as a departure point for the research. The chosen concept needs to be assessed against the underlying theoretical foundation used in the research in terms of its uniqueness, how it relates to the existing theoretical knowledge in the field, and how well the concept can be expressed through a concrete design (Stolterman & Wiberg, 2010).

In the fourth methodological activity, *design of artifacts,* Stolterman and Wiberg (2010) state that the previously generated, prototyped, and internally critiqued concept is now manifested in a concrete design. Therefore, when designing an artifact, it becomes crucial that it embodies the core concept design in its entirety, taking on a holistic manifestation that contributes to the theoretical development in the field.

After manifesting the chosen concept in a concrete design, the fifth activity, *external design critique,* begins. During this activity, the conceptualized design is evaluated and tested in its entirety by the public. In other words, the concept as a whole is evaluated and critiqued.

Since exposing a conceptual design to public evaluation will lead to design critique (Stolterman & Wiberg, 2010), the sixth activity, *concept revisited,* requires that the concept is reviewed to undergo further iterations. Such iterations could, for example, occur on an artifact’s basic composition, i.e., the way it is presented in the design or even the core idea of the design.

Stolterman and Wiberg (2010) state that it could be difficult to isolate which variables resulted in the given critique when working with concept designs, thus highlighting the importance of considering different aspects of the artifact during iterations.

After the concept has been revisited, *concept contextualization* occurs, and the final design concept is valued against other related concepts and theoretical knowledge in the area of study. In this activity, the task lies in carving out the uniqueness of the final concept while showing how it relates to already established work (Stolterman & Wiberg, 2010).

3.2 Application of concept-driven design research

The study adopted concept-driven research as the method. The methodology of crafting a design concept with a focus on developing new theoretical knowledge (Stolterman & Wiberg, 2010) supported the study's research question and aim of study.

Following the seven methodological steps outlined by Stolterman and Wiberg (2010), the study started with *concept generation.* At this stage, the study focused on italicizing critical keywords from research mentioned in chapters *2.2.1*, *2.2.2*, *2.2.3* and *2.3*, that either described or was related to user interactions prior, during, or after a journey with a FAV, as well as user experience. The keywords were chosen by their level of significance and their meaning in previously established knowledge of FAVs. Their level of significance and how they described the user interaction was determined by reviewing the findings of previous knowledge in user interactions of AVs and FAV. For example, Flohr et al., (2021) found that participants preferred to use a mix of a GUI and a CUI on a smartphone application to interact with an Autonomous Mobility on Demand (AMoD) system prior to a journey. Using a smartphone application with a CUI in the form of a chatbot, and a GUI the form of a map was for example also used by Kim et al. (2020). The keywords *Smartphone application, Graphical user interface* (GUI), and *Conversational user interface* (CUI) were therefore extracted and placed under the category *User interactions prior to a journey* in a separate document.

Having identified keywords that referred to user interactions in AMoD systems and FAVs, the study utilized this data for the second activity, *concept exploration*. For this phase, the study used the accumulated data and sketched on possible visualizations that illustrated a holistic overview of end-to-end user interactions and the desired user experience and that could occur prior, during, and after a journey with an FAV. Early sketches were made in the form of loop diagrams, flowcharts and infographics using Adobe Illustrator and Figma, on an A4-sized online document. The study also conducted a collaborative workshop session over Zoom, with the purpose of exploring new sketches and ideas of how to present a timeline of when the user interactions could occur. During the workshop session, each part of the concept, *Fully Autonomous Vehicles, User interactions Prior to a journey*, *User interactions after a journey,* and *User experience* was given a time constraint of 20 minutes of which the authors explored various concepts. Figmas online plugin “FigJam”, a collaborative online whiteboard was used as the joint sketching tool of which additional sketches were designed under no time constraints. The group focused on sketching possible concept designs that holistically visualized the extracted keywords as user interactions for each stage of the journey at a time; prior, during, and after a journey with a FAV. Sketches were made that displayed a timeline of the occurring interactions, going from left to right and bottom to top.

During *internal concept critique,* the study examined the strengths and weaknesses of the previously crafted concepts, as well as evaluated their uniqueness and how they related to existing knowledge in AVs and FAVs. The internal critique showed several flaws, for example, a timeline displaying the user interactions prior, during, and after a journey, going only from left to right, did not leave enough space to express all of the critical user interactions found in previous knowledge of FAVs without becoming too wide to present. In addition, sketches that were meant to be read only from the bottom up did not make it easy to understand that the user interactions were occurring as a timeline, prior, during, and after a journey. As such, the study adopted a mix of a bottom-up approach with three separate rows to visualize the three stages of prior, during, and after a journey, with the user interactions occurring from left to right as a timeline within these defined rows. When the study evaluated the proposed concept against existing theoretical knowledge as defined by Stolterman and Wiberg (2010), the concept's structure was found to have similarities to the autonomous taxi service design conceptualized by Kim et al. (2020). However, the concept was unique in the sense that each user interaction explicitly belonged to one of the three phases of a journey, thus simplifying the timeline. The concept also outlined the user interactions from the bottom up instead of the top down, and does not represent a service blueprint for an autonomous taxi service as in the study by Kim et al. (2020). However, the identified similarities strengthened the findings that the chosen concept could be properly expressed in concrete design.

For *design of artifacts,* a presentable visualization that holistically illustrated user interactions during the three stages of a journey with an FAV was made using FigJam, a collaborative version of the online tool Figma, which allows multiple users to create illustrations simultaneously. Three rows were stacked vertically on top of each other on the rotated A4-sized document with the words prior, during, and after written to the left of them, each referring to prior to a journey, during a journey, and after a journey. The three titles on the side of each row had red, yellow and green coloured backgrounds, similarly to the colors of a traffic light, which was used to visually separate the three stages. The color red indicated prior to a journey, yellow indicated during, and green represented after a journey with a FAV. Similarly, to the findings by Gluck et al. (2020), that showed the importance of including features in FAVs that could be used by individuals with less technical proficiency, this study used colors to visualize the full journey with a FAV and account for individuals with various levels of technical expertise and prior knowledge of FAVs. The keywords previously categorized during *concept generation* were then implemented. For example, using a smartphone application with a built-in chatbot that allowed users to enter desired departure time, number of travelers and destination (Flohr et al., 2021) was written as some of the user interactions on the first row, *user interactions prior to a journey*, whilst user interactions such as monitoring the ETA, outside weather and miles per hours (Oliveira et al., 2018) was written under the second row, *user interactions during a journey*. Icons from the online database Freepik were put next to each interaction to convey their meaning.

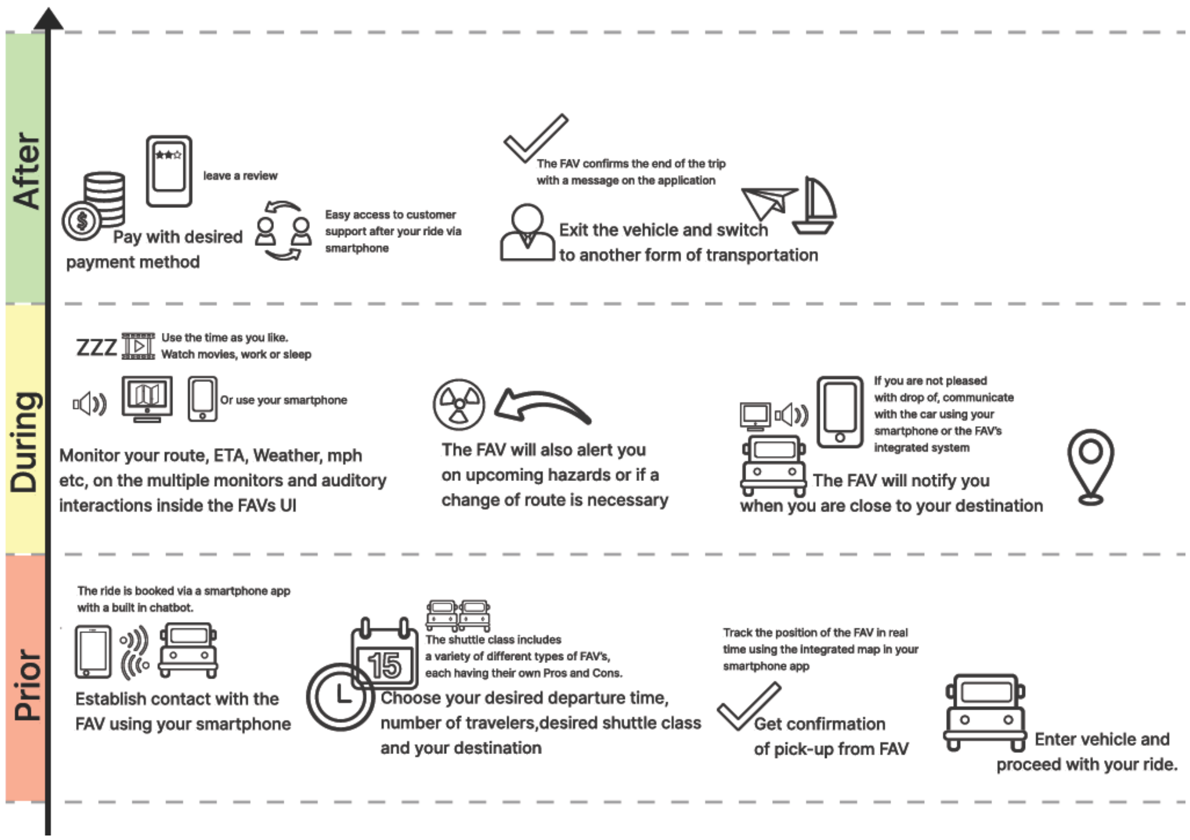


Figure 2. *An operational scheme and user flow for shared FAVs that is theoretically underpinned and provides a holistic visualization of user interactions prior, during, and after a journey with a FAV. See appendix C for the full scaled concept.*

During *external design critique*, the concept was exposed to 6 males and 2 females that had different backgrounds, educational levels, and various levels of pre-existing knowledge of FAVs. The concept was critiqued as a whole by the participants and evaluated against its underlying ideas (Stolterman & Wiberg, 2010). For this study, the design critique was performed over Zoom, of which participants were first asked general questions such as their name, gender, highest level of education and their prior knowledge of FAVs. The participants were then shown the design concept and evaluated it by responding to questions related to their understanding, opinion, critique of what the design concept was presenting, along with suggestions for improvements on the design concept. For instance, *"Do you understand what the design concept is showing?"* was one of the questions related to their general understanding of the design concept, with additional questions specified in the appendix. The sixth and seventh methodological activities, *concept revisited* and *concept contextualization*, are described in the chapters titled "Critique and revision of the holistic design concept" and "Contextualisation of the holistic design concept", which outlines the study's results.

3.3 Participants

A convenience sample was used to invite participants to the study. A total of eight participants consisting of six males and two females evaluated the design concept. The participants had an age range of 28-79 years and differed in education level. Five participants had a university degree, three had a high school degree. Participants' existing knowledge of FAVs varied: two participants had little to no knowledge, two had discussed FAVs with others and one participant knew only from what was available in the media. Two of the remaining participants had traveled in a semi-autonomous vehicle before and one of the participants could differentiate FAVs technical capabilities based on their SAE levels. Presented below is a table that shows each participant's age, gender, occupation, highest level of education and previous knowledge of FAVs. Participants were coded as P1, P2, and so forth in order to preserve their right to be anonymous.

	Age	Gender	Occupation	Highest level of education	Previous knowledge of FAVs
P1	31	Male	Engineer	Master's degree	The participant is aware of the SAE taxonomy and their meaning for FAVs.
P2	73	Female	Senior citizen	Bachelor's degree in social work	Not a lot, but the participant has had some conversations about it with others.
P3	59	Male	Civil engineer	Civil engineer, 180 points at Chalmers University.	Nothing more than what is available in the media.
P4	66	Male	Senior citizen	High school degree	He has had thorough conversations about FAVs through work, since talks about automated garbage trucks was a possibility for a while.
P5	79	Female	Senior citizen	Lower school certificate, called "realexamen" in Swedish	None.
P6	28	Male	Research engineer	University, civil engineer degree	He knows that it has been under development for a while and has traveled in a semi-autonomous vehicle once.
P7	35	Male	Area manager	Certified business economist	He has driven an autonomous vehicle maybe once or twice and read about them online.
P8	42	Male	Warehouse manager	High School degree	Little to none.

3.4 Materials

An informative letter was created using Microsoft Word and was sent out via email to the participants prior to conducting the interviews (see appendix B). The introduction of the letter contained information about the authors, where the study was conducted as well as the study's purpose. The letter also informed the participants that the interviews would be conducted over zoom, and also outlined the interview's structure:

1. Participants would answer basic questions about themselves
2. The study’s concept design would be presented
3. Questions about the participants' experience and perception of the presented design were to be asked, and the participants would make an evaluation of the different parts of the concept.

The letter also contained information as to how the data collected during the interviews would be handled, which is further described in section 3.5 of this study. The participants later on received an email that contained the link for the zoom interview rooms.

A total of 22 questions were asked in the interviews in a semi-structured format where 5 questions pertained to the basic information about the participants and 17 questions were dedicated to the evaluation and critique of the design concept. The questions were self-generated and split up into six categories; (1) *General questions;* (2) *Design concept as a whole;* (3) *Prior to a journey;* (4) *During a journey,* (5) *After a journey* and (6) *User experience.*

General questions consisted of basic questions about the participants themselves, such as their age, gender, and highest level of education.

Design concept as a whole was related to the participants’ general understanding of the design concept, their opinions and critique of the design concept.

Prior to a journey consisted of questions specific to that part of the concept, such as if participants understood how they could interact with a FAV prior to a journey, what could be improved on this part of the concept and what functions they would like to add or remove.

During a journey and *(5) After a journey* both contained the same structure as *Prior to a journey* but pertained to their own, separate parts of the design concept.

User experience consisted of questions about the participants' perceived experience of how a passenger could travel with a FAV and interact with it during the three stages of a journey. For example, one of the questions that were asked was if the participant would travel with a FAV if it were to work as presented in the design concept and why/why not, and another one pertained to what the participant thought was good / bad about the overall travel process working as presented in the concept. See appendix A for the complete list of questions.

The design concept had been saved as an image in a .pdf format to allow for an easy way of opening and showing the visualization during screen sharing in the interview, see appendix C. Both the picture and sound from the participants and the authors in the interview were recorded and saved to a local file using Zooms recording tool. The interviews were later on manually transcribed into text on a Word-document, where the information about the participants were anonymized.

3.5 Procedure

In order to recruit participants for the interviews we utilized our personal networks. Our individual personal networks were tasked to ask their respective colleagues, friends or acquaintances, that neither of the authors of this thesis had any personal contact with before and ask them if they would like to participate. Thus, we could assure a detachment between the participant and us, the authors, when interviewing them which would lead to more sincere and neutral answers. When it came to selecting participants, we didn't have any requirement of them knowing what a FAV is or how to use one, since our study wanted to explore how well our design-concept communicated the possible interactions with a FAV prior, during and after a journey with one despite previous knowledge. What was interesting in our case was to involve participants with a good age variety, since our study mentions the benefit of FAVs for older citizens several times in chapter 2, but we specifically did not limit our study to elderlies and therefore we wanted varying ages between our participants.

Before we booked each interview we sent each participant an information letter, in Swedish, that gave a brief explanation of what our study was about and what we would ask of them. The letter also informed them of ethical considerations we had for each participant. They were informed about the studies content and its purpose, that their participation is completely voluntary and can be canceled at any time, that their information and participation would be anonymized and that the answers and results would solely be used in this study for this specific purpose (Swedish Research Council 2017). We made sure each participant was sent an information letter and that they had read it before their interviews were booked and held.

Each participant was fluent in Swedish and therefore the interview was held in Swedish as well. Most participants could understand English to some degree, while others were not as fluent in English at all. The interview questions were translated from English to Swedish beforehand so that the participants could easily understand the questions. Even though the participants were fluent in Swedish, the concept itself was not translated from English to Swedish, since we wanted to explore its intelligibility disregarding the text.

All interviews were held remotely through either Zoom or Microsoft Teams. We reserved 30 minutes in total for each participant, which was ample enough time for each participant to answer the questions to its full extent. Each participant was asked follow-up questions to each of their answers in order to gather more intel on the subject, create a deeper understanding of the participants view and create a qualitative research process. The answers provided from the in-depth questions were noted under each of the main-questions as a part of their initial answer. If the participant answered in a thorough manner from the start, where the interviewers saw that the answer provided was enough, there weren't always any follow-up questions to the main question. Each interview was therefore unique depending on the participant and their answers. Each interview was recorded and saved on one of the interviewers computers. The recordings were later used to help transcribe each interview. Each interview was also transcribed and translated from Swedish to English in order to use it in this thesis.

The only issues that occurred were some technical difficulties on the participants' side where some of them encountered connection-issues or a lack of knowledge of the used platforms. But in each case the troubles were resolved rather quickly, and the interview could continue as scheduled or be rescheduled to the next day if it was desired by our participants.

3.6 Ethical considerations

The research has taken consideration for ethical dilemmas during the research process. To ensure that the study follows good research practice, we have followed the ethical requirements for research studies according to the Swedish Research Council (2017). The ethical requirements include *information, consent, confidentiality,* and *usage.* (1) Information: All participants were informed beforehand about the contents and purpose of the study. (2) Consent: They were also informed that the participation is entirely voluntary, and they could revoke their participation at any time. (3) Confidentiality: Participants were given information that their participation and all collected data would be anonymized in the study. (4) Usage: They were also informed that the collected results would only be used for the current study without any involvement of a third party (Swedish Research Council, 2017).

4. Results and analysis

4.1 External design critique and revisions

4.1.1 External critique of the design concept as a whole

When asking our participants general questions about the design concept as a whole we got a few varying answers, but in the big picture, every participant understood what the concept was showing them. 4 out of 8 participants (P1, P3, P6 and P7) thought that the concept had similar attributes to using a taxi service that you pay for, similar to services like Uber, but without a designated driver.

> *"It's like using a taxi service. I recognize this idea from what I've seen in visions about fully autonomous vehicles. This is an independent car, I don't own it, I just order a car and it collects me and tells me circa when I will arrive, hazard, it wakes me up when I have arrived. Then I pay when I have arrived by my desired method." (P3).*
>
> *"My quick and spontaneous thought is that this is some form of uber where I pay through an app and enter some sort of vehicle where I can follow the ride, see the weather and such, and I can choose the date and such, but it's all over automatic. But some sort of paid system like a taxi without a driver." (P7).*

4 out of 8 participants (P1, P5, P7 and P8) also noted that a smartphone with a mobile application would likely be a reoccurring form of communication with the fully autonomous vehicle. One participant (P8) explained it as follows: "*Yes, it's how to use an app to order an autonomous car and you can decide what to do during the ride, like resting and such.*".

When asked about potential improvements with the concept that could help their understanding of it, we received a few helpful tips. 2 out of 8 participants (P4 and P5) expressed a need for the concept to be in their native language, which was Swedish, since they didn't think they were proficient enough in English to understand some of the words used in the concept. 2 participants (P1 and P4) mentioned that the abbreviations without explanations were not clear to anyone that isn't familiar with the subject and would like explanations to what each of them meant in order to more easily understand the concept. One participant (P1) explained the issue regarding the abbreviations like this: "*The only issue is the abbreviations (i.e., FAV, GUI, UI, etc), unless you are already familiar with the abbreviation it can be hard to understand what it means*". 2 participants (P1 and P7) also brought up points such as clarifying if this was a shared ride or if you could choose to travel without other passengers onboard, as they didn’t understand if that could be a choice or not, but other than that it seemed like the participants understood what was presented to them.

The participants were also asked what they thought was good about the concept in general. 3 out of 8 participants (P1, P4 and P7) stated that they liked the use of pictures and icons in the concept that helped them understand the text, and 3 out of 8 people (P1, P6 and P7) specifically mentioned that they preferred when the information presented through text was short and succinctly.

> *“I really enjoy the icons and pictures you have used in the concept; all the icons are well recognized and associated with different tasks. I also like that the text is short and to the point, it makes it look clean and less confusing.” (P1).*

> *“It’s good that there's not only text, I, personally, like it when there's some pictures that quickly catches the eye. It makes it easier to notice the text next to it. I am allergic to only text in a presentation.” (P7).*

We also asked participants about what sort of problems or issues they saw with the concept, and what they would advise us to change or revise as well as why. 5 out of 8 participants (P1, P2, P3, P4 and P6) commented that the design concept appeared to be “upside down”, where 2 out of them (P3 and P6) brought it up multiple times during the interviews. They exclaimed that the order was unintuitive to them, and one participant (P2) stated that they initially read the concept from the wrong direction. One participant (P7) explained their concern about a possible power outage during a journey, and wondered how one would be able to retrieve information about what to do in those cases. They also explained that some cars today have an emergency button that contacts the central for the company and explained that including one of those buttons might be required for user-safety (P1, P3, P7). Another participant (P6) thought that the colors that were used in the concept could act as a red herring since they have certain associations connected to them.

4.1.2 External critique of the design concept prior to a journey with a FAV

After we asked them about the concept as a whole, the participants evaluated the different parts of a journey with a FAV. First, we looked at their understanding of the first part of the concept; user interactions prior to a journey with a FAV. The overall understanding of this part of the concept seemed clear for 6 out of 8 participants (P1, P2, P4, P6 and P8), whereas the other 2 participants (P3 and P5) exclaimed some sort of confusion but still understood this part of the concept.5 out of 8 participants (P1, P4, P5, P6 and P8) understood that this part would mainly focus on the communication with the user and the FAV through your smartphone by using a mobile application. 2 out of 8 participants (P6 and P7) commented on the fact that part of the communication prior to a journey might occur through the use of a chatbot, which one of the participants (P7) thought was a good idea for simpler questions and tasks, whereas the other participant (P6) didn't think a chatbot would be necessary and didn't understand the purpose of including a chatbot in the first place. Interestingly enough, one participant (P3) immediately requested the need for a different user interaction on this part of the concept, even though that question had not yet been asked;

> *"I also have a question here, I won't know how long the car takes to drive to my destination. It might be better to choose a desired time of arrival and get a suggestion of a time of departure. It might be based on traffic and such. There's a lot of data that you could put into something like this. It's more important to me to know I get to my destination on time."* (P3).

This showed that for some users, it would be more important to choose when they would like to arrive at their destination.

When the participants were asked about what could be improved in this part of the concept, we got feedback about both the functions and interactions with the FAV, as well as on the concept itself. For the concept itself, we got some feedback on including the specific icons for Google-play and App-store to make it easier for the viewer to associate it with downloading an application on your phone. We also received feedback and questions about the calendar icon, as it depicts that the user is able to use this service also as a daily commute other than only spontaneous taxi rides. But the participant (P1) exclaimed that there might be a better way to display that this is a day-to-day option for transportation and not just a taxi, since the calendar didn't really make it clear enough.

When it came to functions and interactions of the FAV itself, participants brought up points about maybe being able to choose the specific route that the vehicle takes, choose a desired time of arrival for workplaces rather than choosing when to get the ride and having some form of offline state that makes you able to still make changes with your ride or the vehicle while having limited connection to Wi-fi.

When asked if the participants would like to add or remove anything from the concept. One participant exclaimed the desire to read and know more about the concept:

"I would like to know where I could read more about the concept. Would it count as a public transport that can use bus files or such? How will I be notified if the vehicle will be late? How late into the journey can I cancel or book the journey and such?" (P1).

2 out of 8 participants (P3 and P6) desired a way to notify the vehicle if they might be a bigger party of people or are carrying extra luggage and need the extra luggage space. 1 out of 8 participants (P7) also explained the desire to be able to choose what kind of vehicle you travel in for special events or dates. One participant (P6) thought it would be a good idea to be able to see how many FAV's that are nearby:

"Maybe it would have been good to know which parts of a town a FAV can pick you up rather quickly. If I'm at one place I have to wait this amount of time, but If I'm over there it's a shorter waiting time." (P6).

Making it easier for the user to get a sense of pick up time.

4.1.3 External critique of the design concept during a journey with a FAV

Secondly, we looked at the interactions and functions during a journey. When the participants were asked if they understood this part of the concept, 5 out of 8 participants (P1, P2, P4, P7 and P8) proclaimed that they indeed did understand this part of the concept and the possible interactions they could have with the FAV during the ride. One participant (P7) compared this part of the journey as interacting with a GPS;

"Yes, it seems like a GPS, and explains it thoroughly. For example, if there was a traffic jam on the road it would choose an alternative one. And time is money so that's really important. So yes, a self-driving GPS, and when you are closing in on the destination it notifies you. I think that's good." (P7).

One of the participants (P6) who was not completely sure of the concept explained that they didn't really understand what kind of communication they can have with the vehicle. Another participant (P3) exclaimed that they simply didn't want any interaction with the vehicle and just wanted to arrive at their destination.

"In my case I just expect it to take me to my destination via my desired route. Maybe there can be a form of emergency break for necessary situations. I understand that I can communicate through screens and my phone, but I don't really know what I would like to communicate to it." (P3).

The participants were then asked about desired improvements with the concept and there were a few good inputs from the participants. 4 out of 8 of the participants (P1, P3, P4 and P5) mentioned the "hazard" part in this part of the concept, where 2 of them (P4 and P5) didn't really understand what the sign meant at all and called it either a "radioactive sign" or a "atom-mark". The other 2 participants (P1 and P3) thought that this part of the concept focused too much on the potential hazards and that this could be a bit worrying to the people reading it. 2 participants (P5 and P1) mentioned that maybe adding a button that lets the user access a human-call-center where they can communicate with a human-being when desired. Other than that, a participant (P7) mentioned the following:

> *"If you arrive at a new city you might be appreciated to, during the ride, to get some information about the city and your journey like restaurants, nightclubs and such. Since you are already looking at your phone it might be nice to get some information throughout the journey, from a sort of a chatbot-guide in your phone."* (P7)

Implying that the previously mentioned chatbot could function as a guide during your journey, handing out valuable information about the place that you are currently traveling through. When asked about potential functions that the participants would want to add or remove from the concept there were either no new points made about this part of the journey, or they simply didn't have anything that they wanted to add or remove.

4.1.4 External critique of the design concept after a journey with a FAV

Lastly, for the three different parts of the journey, we asked about the concept of interaction with a FAV after a journey with one. When asked if the participants understood this part of the concept an 8 out of 8 participants answered yes. However, 2 out of 8 participants (P3 and P6) brought up that they didn't really understand why they should be paying for the service after the journey. Both of them exclaimed that they much rather wanted to know the price before a journey with a FAV and would much rather pay for the journey before entering the vehicle. One participant (P3) even mentioned the option of having automatic withdrawals from their bank account when using this kind of service. They exclaimed:

> *"The money might even automatically be withdrawn from one of my accounts when I arrive. I just think the payment might be a side-part of the journey and not just after. The important part is that I should be aware of the price beforehand."* (P3).

When asked about what could be improved in this part of the concept, 6 out of 8 participants (P1, P2, P3, P4, P6 and P8) didn't think there were any necessary improvements that needed to be done to the concept. One participant (P7) mentioned the addition of icons and pictures to symbolize what kind of payment methods are available, like for example Swish and PayPal. They proclaimed that this information might be good to have beforehand, especially if you've traveled from out of the country and have limited payment options.

When asked if the participants wanted to add or remove any function in this part of the concept, 6 out of 8 participants (P1, P2, P4, P5, P6 and P8) didn't have anything they would like to add or remove. One participant (P3) mentioned that the vehicle should have a function that can indicate if the passenger has removed their luggage or not, so nothing gets left behind. The luggage storage should also be convenient for the passenger and should be easily accessed from the side that they exit the vehicle from. Another participant (P7) highlighted the importance of customer reviews and that in order for them to use or buy a service they always look at the reviews first, so it should be an important part in this part of the concept.

> *"I think it's really important with customer reviews, so that should definitely be there. So, people can say how they view the ride. Many people today are scared of FAVs because of the lack of control and knowledge. And I know if I'm buying something new, I'm looking at the reviews first and then I look at the price. I would definitely include that."* (P7).

4.1.5 External critique of the user experience

After we asked about the different parts of a journey with a FAV, we moved on to questions about the overall user experience of a journey with a FAV. Firstly, the participants were asked if they would want to travel with a FAV if it worked as the concept had shown them. 6 out of 8 participants (P1, P3, P4, P5, P6 and P7) answered that yes, they would travel with a FAV if it worked as shown in the concept. 2 out of those 6 (P1 and P3) participants were only worried about the price range, since they perceived the service to be of the more expensive kind, but if it was priceworthy, they would indeed like to travel with a FAV. One of the participants (P2) was on the fence about whether or not they would want to travel with a FAV, since they seemed unsure about the safety of the technology and didn't like the feeling of not being in control. The last 1 out of the 8 participants (P8) answered that they would not ride with a FAV regardless, since they wanted full control over their vehicle.

Secondly, we asked the participant what would make the ride with a FAV more convenient for them. One participant (P5) advocated that it's important that the service is available where they live, and that it should be easy to change between the means of transport if so desired. 2 out of 8 participants (P4 and P7) exclaimed that they did not want to be the first one trying this service or vehicle out, they wanted others to have tested it first and read previous reviews about the experience before trying it out for themselves. One participant (P6) also said that there has to be a manual "fallback" in the vehicles just in case for emergencies, where the passenger can contact someone from the company. Other than that, there were desires for making sure the vehicle is clean and taken care of. One participant (P1) explained it as follows:

> "*If I think about it, I would like to know who takes care of what? If there's no driver, then who takes care of the cleanliness of the car? How do I know that the vehicle I ordered is clean and taken care of? For example, if you're at a fast-food restaurant you usually see who cleaned the toilet last time and when on a plaque. Other than that, it seems like a pleasant option to drive your own car or public transport."* (P1).

First and foremost it was important that the FAV keeps its promises about arrival time and if the car can't keep its promise of arriving at a certain time, it should communicate that even before the passenger steps into the vehicle and not when the passenger is already late to their destination. P3 explained the importance of the FAV keeping its promises and communicating them as follows:

> *"It's important that the system and the concept actually keeps what it promises. And it needs to keep its promises from the first or second time, otherwise people will give up on this service. It's like car-users taking the bus for the first time at Walpurgis Night when all the buses are full and late, then they won't want to take the bus again after that. If a car says it will arrive at a certain time, then it has to arrive at that time. Sometimes it might get late, but then it has to tell me that when I'm just ordering the car and not when I'm already late."* (P3).

All in all, this can be summarized as a need for clear and transparent communication between the vehicle and the user, as well as the company who owns the service.

Thirdly we asked the participants what they think is good as well as bad with the travel process presented before them. Overall, 7 out of 8 participants (P1, P2, P3, P4, P5, P7 and P8) were happy with how the concept was presented and what it portrayed. One participant (P1) mentioned that it might be good to specifically highlight the selling point of FAVs and this service: "*A question is what the selling point of riding with a FAV vs other options is? Is it more safe? More price-worthy? Environment friendly? Time efficient?*" (P1). Another participant (P3) mentioned that it's convenient to not have to drive the car yourself, and if the service is praiseworthy, it could be a good alternative to owning your own car.

Fourthly and lastly, we asked how they think the design concept might enhance the user experience when traveling with a FAV. 2 out of 8 participants (P1 and P6) exclaimed that it was difficult to give an answer to this question since they have not seen any design concepts that they could compare this one to. 2 other participants (P2 and P3) exclaimed that this is just a means of transportation for them and not "fun driving". They said that they do not need any extra functions or options for their transportation, they just want to make sure that they arrive at their desired destination at their desired time safely. 2 other participants (P4 and P6) talked about how the concept brought them information and gave them a preparation for the journey, which in turn also creates a form of safety for the passenger since the more information you get the safer you feel.

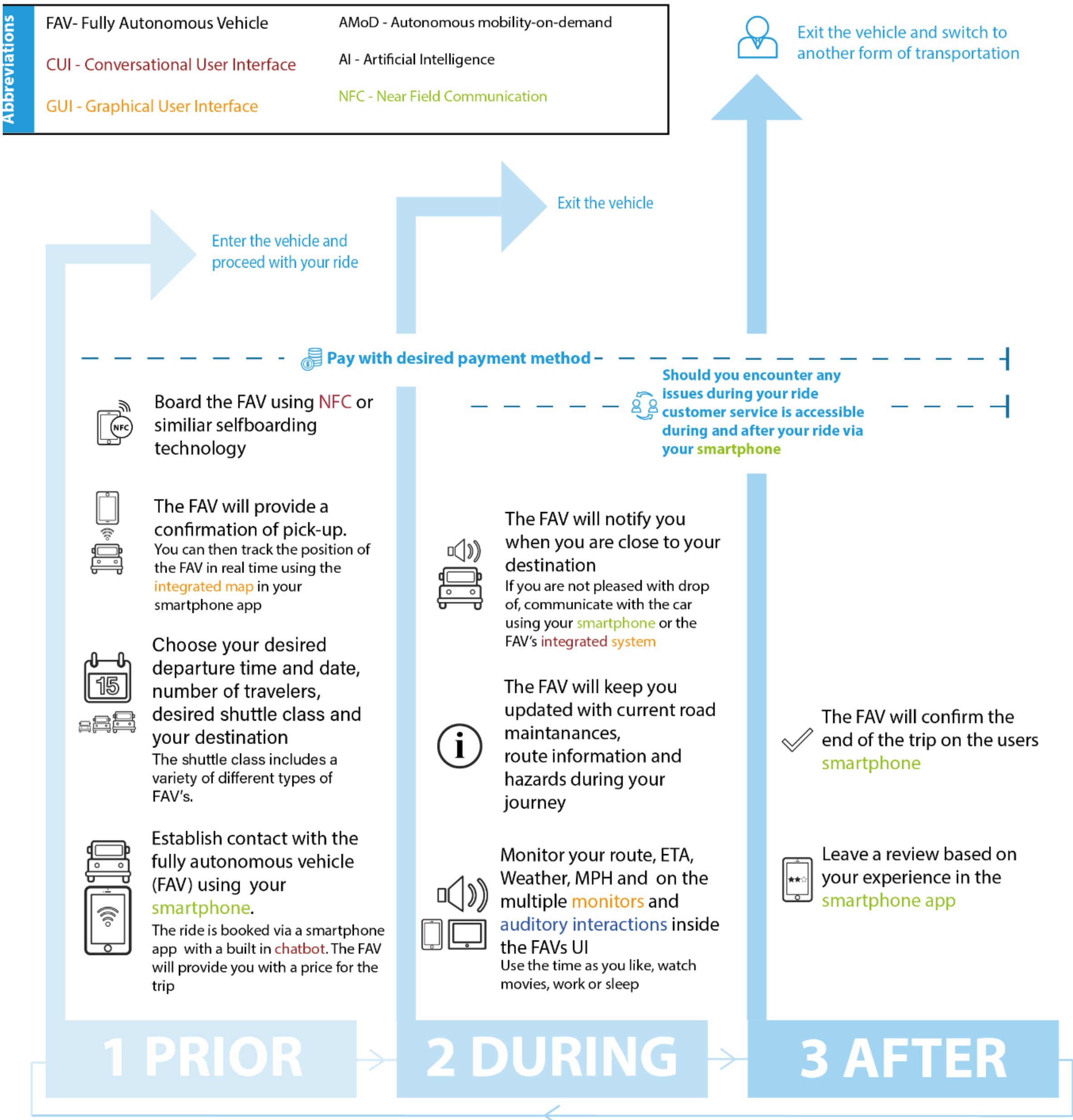
4.1.6 Revisions of the design concept based on external critique

Based on the previously mentioned design critique, we took a few suggestions and ideas into consideration for our revision of the design concept. First and foremost, we noticed that almost every single one of our participants (as mentioned in chapter 4.1.1) mentioned that the then presented format seemed unintuitive and made it harder to read the concept. Therefore, we changed the concept so that instead of focusing on reading it from bottom-to-top, it now is displayed and read from left-to-right, which is more intuitive for the viewers.

We also added definitions and declarations to any abbreviations that occur in the design concept, to aid the viewer to a better understanding of what they are reading (as requested in chapter 4.1.1). We also added an expanded explanation of the technology to aid the viewer to better understand the ins-and-outs of the concept and feel more safe and informed when using a product or service like this (as mentioned and requested in chapter 4.1.5). Other than that, we also made some changes to the “hazard” symbol and included some more information about what this symbol means for the passenger of the vehicle (chapter 4.1.3). We added the possibility to make contact with a real human during and after the journey since three participants stated that it would feel safer to know that you are able to establish contact with real humans and not only the FAV’s AI (4.1.1).

We made sure to include the option to pay for the journey and service either before, during or after the ride, depending on what the user feels most comfortable with. The price is also disclosed to the user before the journey to avoid any confusion (as mentioned in chapter 4.1.4). The colors of the concept were also changed in order to detain any form of miscommunication within the concept itself (chapter 4.1.1). We decided on a calm blue color with some color variations to connect different abbreviations with its definition and explanation. Lastly, we also included an option for the user to choose their desired size or style of vehicle for either special occasions or trips with extra luggage and people (as mentioned in chapter 4.1.2).

We added the possibility to interact with the FAV’s doors using NFC technology to provide a more convenient way for the user to unlock and open the doors of the FAV (Kim et al., 2020). We also added the possibility of interaction with an Anthropomorphic agent since previous studies have shown that it is the most preferred interface. (Large et al., 2019). Apart from the feedback from the participants, our own study of the holistic design concept found that the basic composition of the presented artifact needed to be iterated. The chosen concept lacked insights into the various types of technology that is involved in communication with an AMoD service in general. In addition, the first concept also lacked clarification that prior, during, and after a journey with a FAV could be seen as a recurring cycle of events. As such, we also incorporated additional arrows that connected these three stages in the revised concept. As defined by Stolterman and Wiberg (2010), iterations on the artifacts basic composition may sometimes be necessary. To properly manifest the theoretical knowledge, we made some general changes on the layout of which the previous knowledge of FAVs is presented in the design. These changes involved defining three separate vertical columns for prior, during, and after a journey, as well as presenting the general concept in a vertical format instead of a landscape rotated visualization.



Operational scheme and user flow for shared FAVs

Technology

AI
The FAV uses different types of AI to communicate with the user.

CUI
Using CUI the FAV is able to communicate with the user using auditory interactions such as voice commands, anthropomorphic voice agent and/or textbased AI.

GUI
The GUI is communicated via monitors to the user.

Smartphone
To communicate with the FAV and it's AI a smartphone is being used.

NFC
The FAV can interact with the phones NFC reciever, this could be used for opening doors

App
To communicate with the FAV you will need an application on your smartphone that is built for the FAV system.

AMoD
The technology that is cooperating creates the Autonomous mobility on demand. Which enables a holistic view.

Figure 3. *A revised operational scheme and user flow for shared FAVs that is theoretically underpinned and provides a holistic visualization of user interactions prior, during, and after a journey with a FAV.*

4.2 Contextualization of the design concept

As defined by Stolterman and Wiberg (2010) for the sixth methodological activity, the design concept was valued and related against the current body of concepts and knowledge in the field. First, when reviewing the research in user interactions prior, during, and after a journey in FAVs, only one study was found to have visualized a concept similar to this study's holistic visualization of future user interactions in FAVs.

As was also found during the *internal concept critique* in chapter 3.2 of this study, Kim et al. (2020) designed a blueprint for an autonomous taxi service as part of their study. Their study showed how a passenger could travel with an autonomous taxi service and how user interactions, issue points and circumstances could arise for the passengers prior, during, and after a journey with an autonomous taxi service. However, Kim et al. (2020) had conceptualized a virtual taxi stand, since AVs as of now, cannot travel without geographical limits. The virtual taxi stand used in the study acted as movable, predetermined locations that an autonomous vehicle could travel to. As such, the visualization presented in that research meant that the AV could not pick up or drop off the passenger at their specific choosing and without geographical limits. In addition, the concept was not elicited by expanding on previous research in FAVs but was instead designed through first analyzing how a journey with a manned taxi service looks like (Kim et al., 2020).

Other research compared how user interfaces could be used in a mobile application when interacting with an AMoD service (Flohr et al., 2021). Even though the researchers in this study explored a passenger's journey from start to finish and included interactions prior, during, and after a ride, the study and their participants focused mainly on how a mobile application could be used during these stages and which mobile interface was most favorable. The study did also not investigate potential user interactions with the FAV itself that could occur outside of the mobile application as well as participants' evaluations of them.

Further research that was brought up in this study had investigated user interactions and user interfaces during specific parts of a journey with a FAV. For example, Oliveira et al. (2018) focused on how various configurations of screens in a FAV influenced user interactions during a journey, and Schneider et al. (2021) evaluated if displaying system transparency during and after a journey with a FAV translated into a positive UX. Similarly, for both of these studies on FAVs, they did not consider participants' user interactions at all stages of a journey with a FAV and how this might impact if they require more or less information presented to them during a journey. With this in mind, this study was able to build on this knowledge and conceptualize a holistic visualization that investigated if, for example, the interfaces and information presented to passengers in Oliveira et al. (2018) during a ride would be sufficient for passengers if they also considered what type of information and interactions would be available to them prior and after a journey. The concept design expanded on previous knowledge in the same way for the design requirements and UX in FAVs. Lee et al. (2020) focused on exploring users' needs and design requirements to enhance the UX for FAVs, but the study focused on the design requirements and UX when passengers would be present in the vehicle itself during a journey and did not investigate the requirements that could occur when participants considered the travel process as a whole.

The presented concept acts as a holistic carrier of prior research in FAVs and evaluates how previous findings can be expanded when participants consider them as part of a complete travel journey. In addition, the evaluation and revised concept design contributed with knowledge of additional user interactions that may be necessary to properly facilitate journeys in shared FAVs, in order for technology to be adopted in the future.

5. Discussion

The purpose of this study was to investigate how a design concept could be theoretically underpinned and visualized to support a holistic approach of end-to-end user interactions prior, during, and after a journey with a FAV. The outcome of the current research was a revised design concept that portrays previous findings in FAVs user interactions as part of a compositional whole. The design concept was crafted and evaluated following the recommendations set forth by the methodology of concept-driven design research (Stolterman & Wiberg, 2010).

The findings for user interactions showed that using a smartphone application with a simplified user interface was considered as an appropriate way to communicate with FAVs and AMoDs services in general. This aligns with the findings by Schuß et al. (2021), which found that a user-friendly booking system was perceived as important by potential future passengers in shared FAVs. A likely explanation for this could be that potential future users of FAVs find comfort in controlling the majority of their journey with technology that they have already been exposed to before. This would in turn align with the findings by Flohr et al. (2021), which showed that passengers have a preference to use technology that is already familiar to them. These findings could influence design approaches for shared FAV services in general, as they imply that recurring user interactions in AMoDs and FAVs could naturally have higher acceptance rates if the interfaces that are used by passengers have similarities to today's technology. The study also showed that the ability to easily communicate with an outside human operator was perceived as important by males. This lies in contrast to the findings by Schuß et al. (2021), which found that this feature was mainly perceived as important for female passengers riding at night. This implies that the need for user interactions that facilitate communication with outside personnel is important regardless of passengers' genders. A possible explanation for this could be that the idea of relinquishing control to a FAV induces some level of anxiety in both male and females, and that the thought of being able to communicate with a human provides a form of safety net. If so, this would also align with the findings by Kim et al. (2020), which found that human intervention plays an important role in reducing user anxiety during emergency situations and should be considered as an important user interaction for shared FAVs.

However, the need to communicate with a human operator during rides in FAVs does not necessarily imply that users would be more prone to socialize with other passengers. Previous research has investigated the viability of using SAVs as a hub for social interactions (Gluck et al., 2020), but it was found that potential users may be dismissive of the idea since they still consider other passengers to be strangers. Another reason for this could be that shared FAVs would still be considered as a form of public transportation (Gluck et al., 2020), which could imply that previous norms in social interactions on public transportation would still apply. However, this could also differ depending on the culture and country. Nevertheless, the study showed that potential future users of FAVs perceived this study's holistic visualization of user interactions as helpful and improved their overall understanding of FAVs technology. Since previous research has shown that providing transparency to passengers of how FAVs work is correlated to an increased understanding and ease of use towards the technology (Schneider et al., 2021), the revised design concept can provide understanding and ease potential future users' concerns towards FAVs. As such, the concept can contribute to the adoption of shared FAVs, contributing to less traffic and a decrease in emissions (Fink et al., 2021; Oliveira et al., 2018).

As this study was primarily focused on expanding existing research in FAVs and conceptualizing a first, holistic approach of future end-to-end user interactions prior, during, and after a journey in a FAV, the study itself presents some limitations that should be taken into account. First, the concept was evaluated by 8 participants whereas the youngest participant was 28 years old. Including more participants, specifically younger participants, would provide further insights from a broader demographic. Secondly, although the concept design is theoretically underpinned and supported, it was not exposed to experts in FAVs technology which would have provided further insights and critique of its’ composition. Exposing future holistic approaches of FAVs user interactions to experts would provide deeper insights into the technology and contribute to a more nuanced understanding of future journeys in FAVs. Furthermore, this study was focused on FAVs being used as a shared service. Future research could investigate holistic approaches to user interactions with FAVs that would instead be owned privately.

6. Conclusions

This study investigated how a design concept could be theoretically underpinned and visualized to support a holistic approach of end-to-end user interactions prior, during and after a journey with a FAV. The research question was answered by first examining research supported user interactions with FAVs and identifying which stages throughout a journey that prior studies have found them to be applicable for. This study was then able to use concept driven design research to successfully conceptualize a theoretically underpinned design concept, resulting in a holistic visualization of user interactions prior, during, and after a journey with a FAV. The design concept was evaluated by participants with different backgrounds, ages and pre-existing knowledge of FAVs to strengthen the concept's validity. With the advancements in FAVs technology and its growing market, this concept can bring a better understanding of the different user interactions that could occur throughout a journey from a user's point of view, and lead to more coherent user interfaces and services for future users. In addition, the study contributed theoretical knowledge on FAVs user interactions within the field of informatics. The revised design concept showed that a holistic approach can be applied for future research in user interactions with FAVs.

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Appendix A

Interview Questions

Participants information

- Age
- Gender
- Occupation
- Highest level of education
- What do you know about FAVs?

Design concept as a whole

- Do you understand what the design concept is showing?
- What could be improved to make the design concept easier to understand?
- What do you think works well when presenting the concept this way?
- What problems do you see with the design concept?

Prior to a journey

- Do you understand how one could interact with a FAV prior to embarking on a journey?
- What could be improved on this part of the concept and how?
- What functions would you add or remove?

During a journey

- Do you understand how one could interact with a FAV during a journey?
- What could be improved on this part of the concept and how?
- What functions would you add or remove?

After a journey

- Do you understand how one could end a journey with a FAV?
- What could be improved on this part of the concept and how?
- What functions would you add or remove?

User Experience

- **Would you want to travel with a FAV if it were to work as presented in the design concept?** If no: Why? If yes: Why?

- **What would make the process of riding with a FAV more convenient for you?**
- **What do you think is good / bad about the travel process working like this?**
- **How do you think the design concept would enhance the user experience when traveling with a FAV?**

Appendix B

Information Letter

Welcome,

You have been invited as a participant to the bachelor thesis by Jack Blossby, Sandra Arndtsson and Eric Geldern which is written at Kristianstad University.

The purpose of the study is to investigate how future journeys in fully autonomous vehicles could be visualized and how users' interactions could occur with the associated technology. The study investigates this from a ride-sharing perspective, i.e. that fully autonomous vehicles are used as a form of public transportation.

The participation will occur in the form of a semi structured interview over Zoom where sound and image should work. The participation is expected to take approximately 30 minutes and will work as following:

1. General questions about you as a participants are asked

2. The study's design concept is presented

3. Questions about your perception of the presented design concept are asked and you will get to make an evaluation of the different parts of the concept.

4. Finish

The interviews will be recorded and transcribed into text, and will later on be deleted. Data that was acquired from the participation will be anonymized and your identity will not be revealed in the published research.

Participation in the study is voluntary and you reserve the right to cancel your participation at any time without any repucissions. The information from your participation will only be used for the study's research purposes. Citations from anonymous participants may be used in the published research, and by participating as a participant you hereby give consent to this.

If you have any questions, you are welcome to contact us at:

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Appendix C

Operational scheme and user flow for shared FAVs.