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Faculty Computer Science

The Influence of User Personality on Requirements for the Communication of Automated Shuttle Buses in the Exterior

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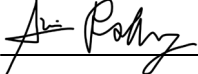
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Affidavit

I hereby declare that I have written this paper independently, have not submitted it elsewhere for examination purposes, have not used any sources or aids other than those indicated, and have marked verbatim and analogous quotations as such.

Ingolstadt,  _____

Alice Rollwagen

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Abstract

The future of automated mobility aims to create significant opportunities for growth and prosperity for the population. An appropriate level of understanding of automated driving, especially in the context of automated shuttle buses, is crucial for improving road safety. Nevertheless, there are many constructs that attempt to predict the factors for people's perception of automated shuttle buses, but there is no known study to date that has directly examined whether people's personality traits influences the perception and interaction with such vehicles. This study examines the relationship between personality traits and people's perception with fully automated shuttle buses. We conducted a study with 40 participants in a virtual CAVE to gain an in-depth understanding of the correlation between the Big Five personality dimensions and the factors influencing the perception of automated shuttle buses. We show that certain personality traits have a main effect on the influencing factors for automated shuttle buses. We found that four of the five dimensions of the Big Five have a significant impact on how people perceive the interaction with an automated shuttle bus. This is particularly seen in the context of Trust, Usability and Acceptance. The results showed that Agreeableness, Conscientiousness and Extraversion had a positive effect on Technology Acceptance, while Neuroticism had a negative effect. Conscientiousness also had a positive effect on the Usability and Agreeableness and Extraversion a positive effect on Trust. Furthermore, it was found that for some personality traits (especially for Agreeableness) the presence of the eHMI has a very high moderate impact on the correlation with the influencing factors. The results are consistent with other studies relating to the Big Five and technology. Suggestions for future research are discussed.

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1. Introduction

In this section, the background and motivation for this work are first explained. The relevance of the topic as well as the research questions and hypotheses that form the focus of the thesis are then highlighted. This is followed by an explanation of the research model and the structure of this thesis.

1.1. Background and Motivation

Automated vehicles that make decisions on their own are no longer a fiction, they are already driving on the roads in controlled environments. This advancement underlines the rapid progress in automated technology and its potential to revolutionise transportation. There are two noteworthy approaches in this context: one approach involves the automation of privately used vehicles and the gradual development of in-vehicle systems that assist the driver, known as driver assistance systems. Another approach is the development of shared-use, automated vehicles, such as automated shuttle buses or automated cabs, without personal ownership. This could provide an opportunity to reduce individual car use and increase the attractiveness of public transport [46]. This work focuses on shared-use, automated vehicles, with a particular focus on publicly used automated shuttle buses. These will be discussed in more detail later in this work.

A study by Jensen [87] shows that just enhancing the public transport system is not enough to encourage people to use public transport instead of private transport. However, achieving this mindset in the population can be strengthened by increasing people's general understanding and attitude towards public transport [48]. This includes promoting acceptance, addressing the needs of users and also improving the communication between automated vehicles and people, which can motivate potential passengers to switch to public transport. Most research into enhancing the communication interface is often limited to the technical and visual aspects as well as the general interaction with the external Human-machine interface (eHMI). However, the personality of the user is rarely considered in this context, even though it is already known that personality has a significant influence on the perception and interaction of users [65, 25]. This finding can be transferred to the fact that personality also plays a decisive role in the deployment of new technologies and the improvement of existing technologies such as design decisions for eHMIs.

Personality models are already a frequently used method in a wide variety of contexts, such as health sciences [94], educational research [21, 115], personnel and organizational psychology [59] or marketing and market research [126, 19], in order to gain a comprehensive understanding of users' personality (see chapter 2.3.1). In the automotive sector, the awareness of the influence of personality is comparatively low, especially with regard to personality models that usually have their origin in psychology (e.g. Big Five) and are not normally considered in the context of automated driving. As a result, when evaluating eHMIs for automated vehicles, the focus is often on the overall picture of the population of users and general requirements and preferences are prioritised, while the opinion of individual users being neglected. In addition, decisive correlations between variables could be misunderstood by not considering the influence of personality. In order to minimise this problem, a more intensive integration of personality models into the development and research process is necessary. This will allow technologies to be adapted more precisely to the different personality profiles of users. At the same time, relationships can be understood that may have an influence on the overall understanding.

This study aims to develop a research model that connects the well established personality traits based on the Big Five with factors influencing the perception and attitude towards automated shuttle buses that have been identified in previous studies, attempting to create an initial understanding of these relationships.

1.2. Relevance of the Topic and Research Question

Amidst the evolving field of automated and connected mobility in the public sector, effective communication between automated shuttle buses and their users (passengers and other road users) is coming into focus. The ability of these vehicles to communicate effectively with their surroundings and people outside the vehicle is particularly important in this context. Communication can be seen here as the exchange of information, commands or feedback, such as the transmission of the status of the vehicle, e.g. giving way or indicating braking. Uncertainty and a lack of communication lead to complicated traffic situations in which the person (and the vehicle) does not know how to react. It is therefore essential that the vehicle is designed to meet the expectations of users according to the necessary requirements [48] to ensure safety, comfort and an overall positive experience. The users' personality can influence their perception of communication with automated shuttle buses. This is a barely studied but highly relevant topic in this context. The following study therefore aims to investigate how different personality traits perceive the communication of these vehicles. Consequently, the research question arises:

RQ: What impact does user personality have on the perception and attitude of automated shuttle buses in the exterior?

Previous research in the area of automated shared-vehicle driving has rarely examined individual personality differences in connection with other influencing factors. The application of the Big Five personality dimensions to analyse the correlation with influencing factors that could influence the communication interface between pedestrians and automated shuttle buses is innovative and promises potentially insightful results. If the presented hypotheses or other correlations prove significant during data analysis, it would deepen and broaden our understanding of the preferences and interactions for automated driving based on individual personality profiles. Furthermore, a comprehensive study of these dimensions not only promises insights into the different needs of different users, but also helps to inform future developments in the field of human-machine interaction in the context of automated vehicles for specific use cases. The research on this topic will not only contribute to the scientific literature, but will also potentially have practical implications for the design and implementation of automated mobility solutions.

Hypotheses were formulated when a correlation between personality dimensions of the Big Five and a factor influencing attitudes and perceptions towards automated shuttle buses was presumed based on the literature review. Providing a better overview, the hypotheses were subdivided according to the influencing factors (perceived Safety, perceived Trust, User Experience, Usability and Acceptance) discussed in chapter 2.2.

Perceived Trust

H1: Higher levels of Extraversion correlate positively with perceived Trust at the communication interface between automated shuttle buses and pedestrians

Other studies [19, 126] found a positive influence between Extraversion and Trust in the context of mobile applications and services. According to Behrenbruch et al. [19] extraverted people promote Trust in technology through their energy and willingness, while less extraverted people tend to be reserved and show little interest in building Trust in new technologies or exploring new forms of social interaction. Therefore, the interaction and communication with an automated shuttle bus could also be strongly dependent on the level of Extraversion.

H2: Higher levels of Agreeableness correlate positively with perceived Trust at the communication interface between automated shuttle buses and pedestrians

People with a high level of Agreeableness are often classified as cooperative, kind, forgiving and helpful [62]. Agreeable people tend to get on well with others and are generally trusting [59]. However, this assessment is usually based on interpersonal relationships in most studies, but other studies show this character trait is also transferable to technology. Positive significant correlations between Agreeableness and Trust were also observed in research fields such as mobile commerce [126]. Furthermore, a study by Schadelbauer et al. [109] on intelligent virtual assistants shows that people who have a high level of Trust in the technology have a stronger affinity for interacting with it, which in turn makes them more likely to adopt the technology. It can therefore be assumed that this also applies to Trust in the communication interface between humans and the automated shuttle bus.

Perceived Safety

H3: Higher levels of Neuroticism correlate negatively with perceived Safety in the communication interface between automated shuttle buses and pedestrians

H4: Higher levels of Neuroticism correlate negatively with Crossing Initiation Time in the communication interface between automated shuttle buses and pedestrians

People with a high level of Neuroticism are more quickly stressed or show discomfort faster than people with a low level of Neuroticism [123]. In addition, neurotic people tend to be emotionally unstable, which in turn leads to feeling insecure in a variety of situations [18]. It is therefore reasonable to assume that neurotic persons who are placed in an unfamiliar scenario in which they only interact with an automated shuttle bus rate their perceived Safety very low. This group of people also prefer to be careful than to have regrets later, especially in the context of imminent danger [79]. So an additional assumption would be that people with a high level of Neuroticism need more time (Crossing Initiation Time) to gain a sufficient feeling of safety when crossing the road while interacting alone with an automated shuttle bus.

User Experience and Usability

H5: Higher levels of Openness to Experience correlate positively with Pragmatic Quality at the communication interface between automated shuttle buses and pedestrians

H6: Higher levels of Openness to Experience correlate positively with Hedonic Quality at the communication interface between automated shuttle buses and pedestrians

People with a high level of Openness to Experience are described as intelligent, curious and interested in many things [62]. It is therefore reasonable to assume that these people have a great interest in new technologies, learn to interact easily and therefore rate the Pragmatic and Hedonic Quality highly. In the study by Kortum et al. [93], the influence of personality on the subjective assessment of Usability for 20 different products and systems was examined. As a result, Kortum et al. [93] found a strong positive correlation between Usability and Openness to Experience.

H7: Higher levels of Conscientiousness correlate positively with Pragmatic Quality at the communication interface between automated shuttle buses and pedestrians

This thesis is supported by the fact that people with a high level of Conscientiousness tend to be more organised and efficient [62]. When people are conscientious, they tend to plan and execute tasks with care. In terms of the interface between automated shuttle buses and pedestrians, this could mean that conscientious people are aware of their surroundings and behave consciously, for example by ensuring that they understand the interaction of the shuttle bus before they act. This in turn could lead to them perceiving the communication as more efficient and effective and therefore rating the Pragmatic Quality better.

Acceptance

H8: Higher levels of Neuroticism correlate negatively with perceived Ease of Use at the communication interface between automated shuttle buses and pedestrians

Neurotic people tend to be anxious and more insecure [62] when using technology, which in turn can affect their perceived Ease of Use. This was also shown in the study by Salam et al. [106] where a negative correlation was found between Neuroticism and perceived Ease of Use when testing a new computing system. Another study by Qu et al. [96] also found that Neuroticism negatively affected perceived Ease of Use when it came to the Acceptance of self-driving cars. People with a neurotic personality often experience frustration and depression quickly when faced with challenges [26], which in turn can make them feel less comfortable in a situation where they have to interact with an automated shuttle bus on their own and make decisions based on this.

H9: Higher levels of Conscientiousness correlate positively with perceived Ease of Use at the communication interface between automated shuttle buses and pedestrians

People with high levels of Conscientiousness tend to be more organised, responsible and goal-oriented than people with low levels of Conscientiousness [62]. Therefore, it is reasonable to assume that people with higher levels of Conscientiousness also tend to follow instructions more precisely and understand the interaction better. Their organised and responsible behavior could lead to a more efficient and positive interaction with the technology, which in turn contributes to a higher perceived Ease of Use. Previous studies confirm this assumption. Research has already shown that a majority of people perform better on tasks when they have a high level of Conscientiousness, both in job-related [17] and educational [31] achievements.

H10: Higher levels of Extraversion correlate positively with the perceived Ease of Use at the communication interface between automated shuttle buses and pedestrians

H13: Higher levels of Extraversion correlate positively with the perceived Usefulness at the communication interface between automated shuttle buses and pedestrians

Previous research [11] has shown that people with a high level of Extraversion tend to rate websites as easy to use, regardless of how they perceive their general level of complexity. Another study by Burnett and Ditsikas [20] found a similar result. Their study showed that extroverts are 40% more likely to find Usability problems than introverts. This could in turn be an indication that extroverts understand new systems faster and better and therefore rate the perceived Ease of Use and the perceived Usefulness higher, while introverts may have more difficulty communicating with the automated shuttle bus, which could lead to lower perceived Ease of Use and perceived Usefulness. Enthusiastic and Adventurous, characteristics attributed to people with high Extraversion [62], could also indicate the Acceptance of these two hypotheses. Their enthusiasm and sense of adventure may lead them to find new technologies exciting and interesting, and therefore easy to use and useful.

H11: Higher levels of Agreeableness correlate positively with the perceived Ease of Use at the communication interface between automated shuttle buses and pedestrians

H12: Higher levels of Agreeableness correlate positively with the perceived Usefulness at the communication interface between automated shuttle buses and pedestrians

The literature shows that people with high Agreeableness often value understanding, cooperation and supportive interactions [62]. This could mean that agreeable people are generally more positive about the new technology and may accept it more quickly. Shuttle buses should also improve mobility for all population groups and promote community and cooperation with their shared transportation, which in turn corresponds to the values of agreeable people. The positive correlation between Agreeableness and Acceptance has also been confirmed in studies from other contexts [126, 95], which in turn suggests that both perceived Ease of Use and perceived Usefulness should have a positive correlation in relation to the automated shuttle bus.

1.3. Research Model

In order to better understand the assumed correlations between the identified variables, a comprehensive research model is presented in figure 1. Paths that point directly from one variable to another are considered to be directly correlated according to the assumption. Positive correlations, where the increase in one variable is accompanied by an increase in another variable, are shown in the graph with a plus symbol (+). Negative correlations, where an increase in one variable is accompanied by a decrease in another variable, are indicated by a minus symbol (-).

By visualizing these hypotheses in a coherent research model, we intend to gain a deeper understanding of the fundamental mechanisms and connections in our study. Based on this theoretical foundation, an empirical study will be conducted to investigate the hypotheses and research question. If there is no connection between two variables, this indicates that not enough

evidence for this connection was found in the literature research conducted. Nevertheless, all connections are checked in the following work to ensure that no relevant connections have been overlooked.

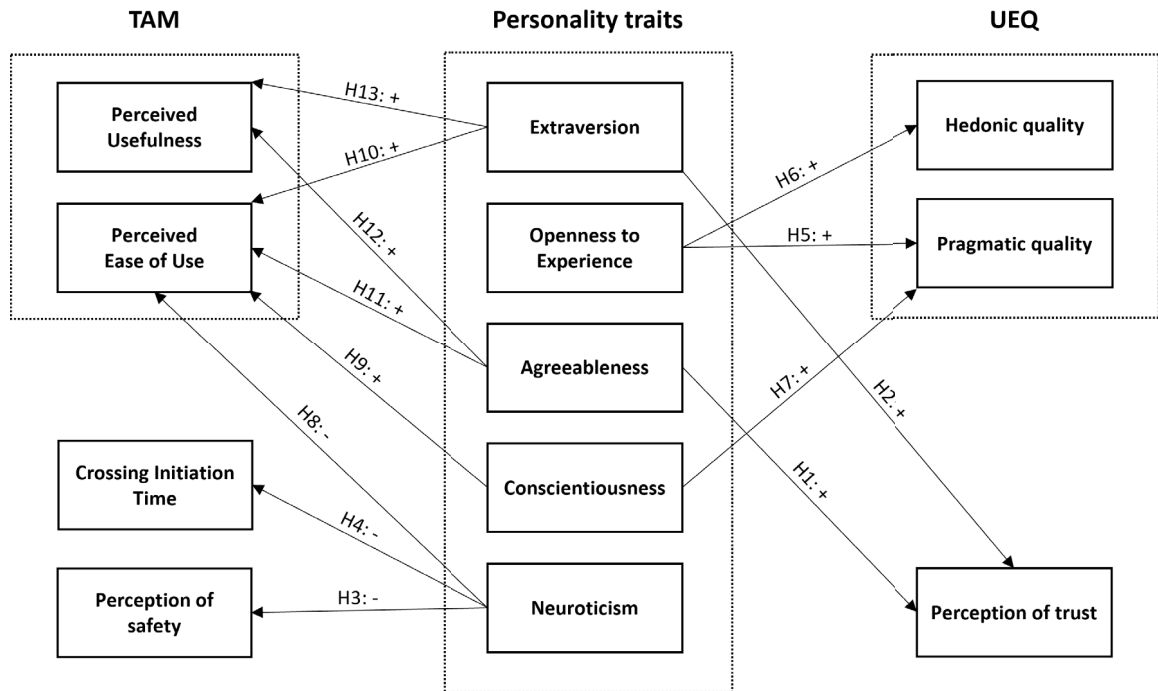


Figure 1: Hypothesis model. Positive correlation is marked with +. Negative correlation is marked with -.

1.4. Thesis Structure

The thesis is divided into a total of six chapters. An initial introduction to the topic and an explanation of the research question and hypotheses has already been provided in the previous section. The second chapter focuses on related work. This comprises the research and analysis of relevant studies from other scientists and economists, as well as results from self-conducted pre-studies as part of the Master's program. In this section, information from previous work on automated shuttle buses (see chapter 2.1), significant influencing factors in this context (see chapter 2.2) and a summary of personality models in general as well as the Big Five model of personalities used (see chapter 2.3.1) are presented. The relevance to the above-mentioned research question is then discussed. The aim of the first two chapters is to gain an overview of the above-mentioned topics and to understand the way they relate to each other. In addition, specific terms should be clearly defined in order to avoid possible misunderstandings.

The third chapter deals with the study design. This chapter deals with topics such as the implementation of the VR setting, the test environment, the recruitment of participants and the conduction and planning of the user study. Before referring to the concrete implementation in Unity, the derived measurement variables and methods are discussed, which were derived from the influencing factors from chapter 2.2. As described in the previous chapters, the user study is mainly conducted in the virtual CAVE of the HIKER laboratory at the University of Leeds. In order to keep the development and time expenditure as low as possible, a pilot study

was scheduled. This allowed the research design to be tested and validated before the actual main study began and to identify potential problems in advance.

The fourth chapter deals with the evaluation of the results. The main focus here is on the correlation matrix and the linear mixed effect model between personality traits and the measurement variables with the aim of recognizing significant correlations and patterns between two variables and revising the research model accordingly. The influence of the presence of the eHMI on the correlations found was also investigated. Furthermore, the results of the power analysis and the Cronbach's alphas for the questionnaires were examined. Together with chapter five, the discussion, the results are interpreted, their significance analyzed, the findings compared with the existing literature and possible implications discussed. A structure for this is provided by the hypotheses introduced at the beginning, which are also examined to see whether they can be accepted or rejected. Finally, chapter six provides a summary of the results and gives an outlook on possible future developments. Lastly, the limitations of this work are outlined.

2. Related Work

This work begins with a comprehensive review of the relevant literature in the field of automated driving with a focus on public, shared-use vehicles such as automated shuttle buses, introducing recent advances, challenges, and opportunities in this emerging sector. Next, we will discuss influencing factors that affect the general attitude towards automated shuttle buses. These factors are identified on the basis of preliminary studies (on-site investigations, literature research and other measurement methods). Furthermore, a brief introduction to the terms will be given in order to establish a common understanding. Finally, a concise overview into personality models and personality traits is given. In particular, the established Big Five Model of personality is examined in more detail. The structure of this literature review not only forms the basis for a well-founded analysis, but also provides information on how the selected influencing factors and personality traits are brought together, which makes a decisive contribution to the development of our research questions and hypotheses in the context of this work.

2.1. Automated Shuttle Buses: Development and Deployment

2.1.1. Level of Automation

A classification of the stage of automation in vehicles is often made according to the degree or level of automation. Here, the automation level refers to the extent of technical support in task execution [55]. The internationally valid standard here is SAE J3016 from the standardization organization SAE International [7]. It provides a taxonomy with detailed definitions for six levels of driving automation, ranging from no driving automation (SAE Level 0) to full driving automation (SAE Level 5). For better clarification, an illustration of the automation levels is provided in figure 2.

In general, most classification models of automation levels distinguish between assisted, automated and autonomous driving [4, 5]. Up to SAE Level 2, the system is referred to as assisted driving, where the functions support the driver, but the driver is responsible for continuously monitoring the system. At an SAE Level 3, the vehicle can drive independently at times, with the driver required to take the wheel again when prompted and with a lead time. Autonomous driving, also referred to as highly automated (SAE Level 4) or fully automated (SAE Level 5) driving, refers to vehicles that drive on their own without the intervention of the driver and make driving-relevant decisions independently during the journey.

Currently (state 2023), the concept of automated shuttle buses is being portrayed to the public as fully autonomous vehicles operating with no human drivers on board. This corresponds to the highest level of automation (SAE Levels 5). However, in many countries this vision is still far from being a feasible reality. The automated shuttle buses currently in operation can carry six to nine passengers and travel at a maximum speed of around nine mph (15 km/h) along predefined routes. These vehicles are equipped with a multitude of sensors that independently detect obstacles and respond reliably in case of any obstructions[105]. Additionally, all these vehicles are accompanied by a human operator who takes on various responsibilities during the journey [114], including intervening in vehicle control if the technology encounters challenges. This, in turn, suggests that the vehicles would be assignable to SAE Level 4 or even SAE Level 3.

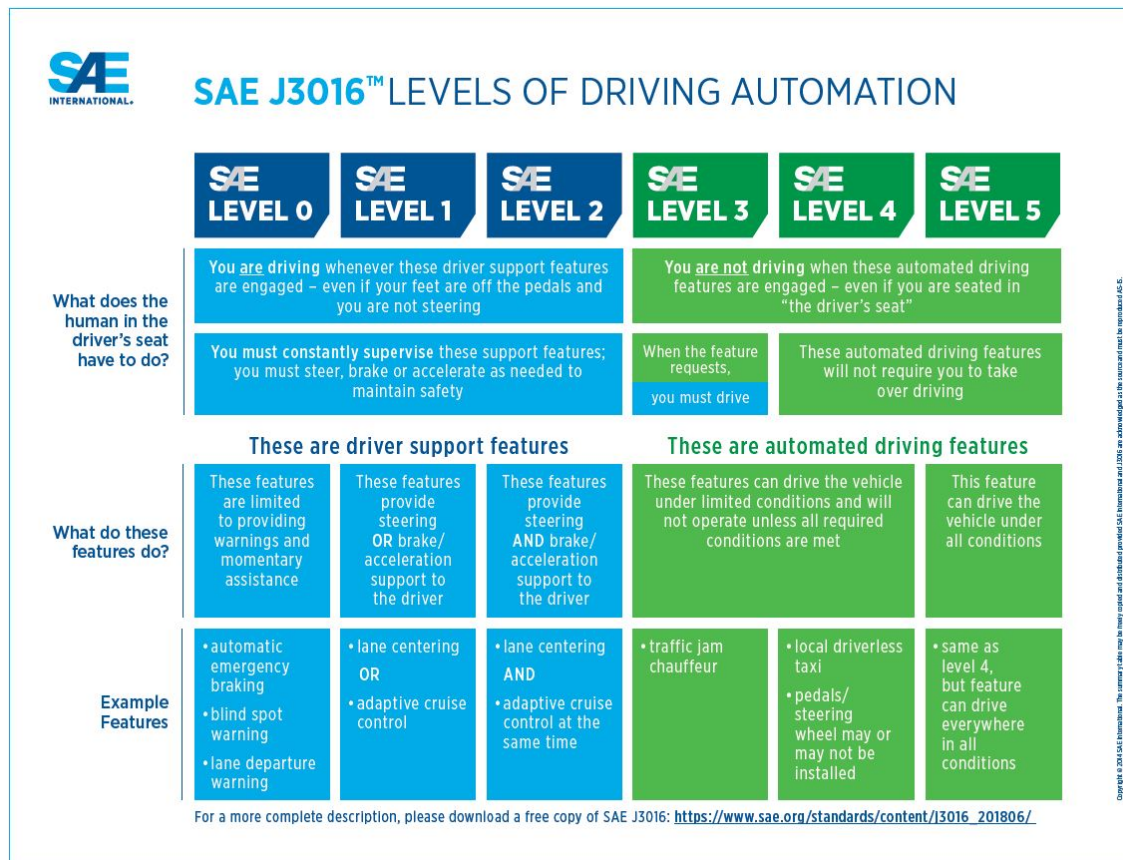


Figure 2: Levels of automation and their definition, Status 2021; Source: SAE International [7]

In this paper, we refer to “automated driving” when talking about driverless shared shuttle buses for simplicity, as this term is often used as an overarching term for all levels of automation as well. Additionally, as seen above, the distinctions in the current state of the art are often blurred to set a distinct classification.

2.1.2. Current State of Technology

Over recent years, the importance of automated driving has increased significantly. The numerous benefits arising from this technology are relevant to a wide range of stakeholders and sectors, including road users, automotive companies, cities, communities, and the government. This development is expected to continue to grow in importance in the coming years, influencing multiple aspects of society, business and technology. In automated driving, it is also necessary to differentiate between the vehicle operating models for automated driving, the type of use of the vehicles and whether the vehicles are private or shared can serve as the basis for this distinction. A distinction can be made between “private automated vehicles”, “shared automated vehicles” or “shared automated rides” [77]. The former case is the only concept where the user privately owns the vehicle. In the second, there is no private ownership, but a vehicle can be shared when needed and available. In the last, we are talking about an automated shared vehicle that is part of the public transportation system. In this work, we focus on the latter case. This means that, especially in this case, adapting user requirements to a specific target group is particularly challenging, as several individuals are simultaneously interacting with the vehicle

and with others during the ride.

From a legal standpoint, there is still work to be done before automated shuttle buses become seamlessly integrated into everyday life. These automated shuttle buses are classified as "special motor vehicles for passenger transport" under licensing law. Due to their unique design, obtaining type approval in accordance with Regulation (EU) 2018/858 is not possible. Therefore, their approval must be determined through the application of general regulations, such as national registration and approval laws [76]. The legal framework for the approval of automated and fully driverless vehicles in the EU was established by the General Safety of Vehicles (EU) 2019/2144 [39]. This was supplemented by the Commission Implementing Regulation (EU) 2022/1426 [38], which came into force on August 5, 2022. These regulations must be carefully followed, which complicates and extends the development process. Under previous laws, highly or fully automated vehicles could only be operated on private property without an attendant, as the road traffic regulations did not apply there. Due to the latest legislative amendments, highly automated vehicles are now also permitted to drive on public roads in certain operating areas. This established a ideal foundation for conducting pilot tests with highly automated trucks and buses on authorised routes. Additionally, according to a statement from the German Ministry of Transport, the goal is to have vehicles with higher automated driving functions in regular operation [67]. However, before fully automated driving can become a widespread reality, some testing and regulatory adjustments are still required.

Nevertheless, we are already witnessing the implementation of driving with higher levels of automation on public roads. The figure 3 shows examples of shared automated shuttle buses on current roads. Pilot buses are currently in operation in various cities, both with and without human assistance, although the majority of them are deployed with human assistance. Germany is one example of automated shuttle buses with human assistance. End of 2023, the Association of German Transport Companies (Verband Deutscher Verkehrsunternehmen, VDV) [122] has documented 45 cities in Germany with 63 automated shuttle bus projects. These projects encompass a wide range of initiatives, including the ongoing SMO project (Shuttle-Modellregion Oberbayern) [116] in Kronach, which features the Navya Arma vehicle type. Similarly, the Kel-Ride [66] funding project in Kehlheim utilises the EasyMile EZ10 vehicle type. Additionally, the Bad Birnbach Shuttle (Line 7015) [6] has been in operation since April 2017, also employing the EasyMile EZ10. Furthermore, there are historical shuttle bus projects like the EVA shuttle [8] in Karlsruhe, which provided passenger services from 2020 to August 2021. The CUBe (Continental Urban Mobility Experience) [83] was used on the Frankfurt university campus for students but ceased test operations in 2018. The former project also used the EasyMile EZ10. These projects collectively demonstrate the progressive adoption of automated transportation solutions in various urban settings.

On international roads, shared public vehicles such as robo-taxis or shuttle buses, are already allowed to drive without a human attendant. Locations such as the United States and China are at the forefront of passenger transport in public spaces. Notable international projects include Cruise [78, 36], which launched the first driverless cab service in California as part of a test program. Simultaneously, leading Chinese tech giants such as Baidu [99, 37, 92] are vigorously pushing to implement self-driving shuttle buses and robo-taxis within Chinese urban centers, including Chongqing.



(a) Autonomous Shuttle-Bus in the district: Karlsruhe, Exterior [8], Photographer: Paul Gärtner



(b) Autonomous Shuttle-Bus in the district: Karlsruhe, Interior [8], Photographer: Paul Gärtner



(c) Autonomous Shuttle-Bus in the district: Kronach, Exterior [116]



(d) Autonomous Shuttle-Bus in the district: Kronach, Interior [116]



(e) Autonomous Shuttle-Bus in the district: Kehlheim, Exterior [66]



(f) Autonomous Shuttle-Bus in the district: Kehlheim, Interior [66]

Figure 3: Indoor and Exterior from different autonomous shuttle bus projects

2.1.3. Chances and Risks

Automated vehicles are generally an enrichment for society, the economy and the environment. They can improve mobility, in terms of efficiency [90, 58, 57], safety [9, 90, 58], environmental performance [57, 58], and infrastructure improvements [3, 1]. To be more specific, converting transportation infrastructure to automated vehicles will lead to optimised route planning, fewer traffic accidents, cost savings in the economic sector [1], reduced mobility-related emissions, and a strengthening of rural and urban [3] transportation. In the public sector in particular,

shared automated vehicles can make a even bigger difference in terms of efficiency, environmental performance, and infrastructure improvements by reducing the number of vehicles on the road. This leads to an increase in the attractiveness of public transport, which in turn is particularly good for people who are dependent on public transport, such as older people, children, teenagers or people with disabilities.

However, they also bring new challenges, such as privacy concerns, ethnicity concerns and the need to adapt infrastructure and laws to realise their full potential. One of the biggest challenges is to find ways of making shared automated vehicles attractive to society and therefore to many different audiences. Even if a new technology is useful and offers potential, it loses its Usefulness if no one accepts and uses it. When we look at pilot projects for automated shared vehicles [114, 101, 124], it is obvious that while they arouse society's curiosity, there is also a certain amount of uncertainty about this new technology. This is often due to misunderstandings or lack of clarity about the actions of the driverless vehicle. The communication between vehicles and people is simply failing, with users' needs not being properly understood. Communication between humans and vehicles is a crucial factor. Here, the following applies: The more complex the traffic situation is, the more difficult it is for a person to react correctly to the action of the vehicle [57]. For this reason, it is particularly difficult for people to assess an encounter with an automated vehicle in the city or in situations without clear right-of-way rules. In the case of non-automated vehicles, other road users would make eye contact with the vehicle if they were unsure, in order to make sure that the other vehicle has the right of way. An automated vehicle must find other ways to communicate its intentions. Considering this, this study will specifically address this use case.

2.2. Influencing Factors: Defining Influences based on Preliminary Studies

Preliminary studies are helpful to develop a comprehensive understanding of the communication in the context of automated driving with shared shuttle buses. Some preliminary studies on this topic have already been conducted as part of the Master's program. These preliminary studies served as an indispensable foundation for the main study and helped to provide relevant insights and information to better understand user behavior and preferences as well as identify problem areas or factors that are potentially relevant in the context of communication with automated shared vehicles.

A literature review was conducted in an earlier (unpublished) report as part of the master's program to identify the influencing factors and challenges associated with the development of automated shuttle buses in real road traffic. In addition to the literature review, observations and open interviews were conducted at the shuttle bus pilot project locations in Kronach [116] and Kehlheim [66] to better understand the general attitude towards automated shuttle buses. This broad methodological approach made it possible to investigate various aspects of user behavior and interactions in real-life scenarios and in the context of in-depth discussions. These findings were summarised in detail in published papers [103, 114]. The findings gained from these preliminary studies provided valuable insights into factors and concerns that are important regarding the communication interface between pedestrians and automated shuttle buses. In this context, the preliminary studies have confirmed that the following factors are important for the investigation of eHMIs for automated shuttle buses: **Acceptance, Trust, User Experience, Usability and Safety**. These factors can also be expanded to include additional factors such as Accessibility or Comfort. However, in the context of analyzing the impact of personality on eHMIs in the exterior, these are only of marginal relevance, which is why they are not

considered in this paper.

Summarising, it can be said that the preliminary studies and the literature research narrowed down the choice of influencing factors considered for this study to five factors. These influencing factors have a significant impact on whether a positive or negative attitude towards automated shuttle buses develops. Building on these findings, the main study of this thesis extends the analysis of the impact of personality on those factors that shape attitudes towards automated shuttle buses. The following section provides a detailed analysis of the selected influencing factors, accompanied by a brief literature review to ensure a standardised definition and a comprehensive overview for this thesis. In the subsequent methodology chapter (see 3.1), the measurement of the selected influencing factors is explained in detail, including the subdivision into measurement variables.

In the field of user-centered design and research, the terms “User Experience”, “Usability”, “Trust”, “Safety” and “User Acceptance” are frequently encountered. Because of their significance in the subsequent discussion, this chapter will offer a more detailed elaboration on these aspects:

2.2.1. User Experience and Usability

User Experience represents according to ISO-9241-210 [33] the “person’s perceptions and responses resulting from the use and/or anticipated use of a product, system or service” before, during and after use. Law et al. [70] further narrows this definition by defining the focus of User Experience on the “interaction between a person and something that has a user interface”. The User Experience can be positive or negative. While positive experience provides the user with the necessary motivation to enjoy using a product, actively recommend it and even put up with minor defects, a negative experience has the contrary effect [88]. In this work, we always refer to a positive User Experience, as we want to improve the attitude of automated shuttle buses in general. User experience consists of the Pragmatic and Hedonic Quality. Pragmatic Quality measures the usefulness of a product in relation to its function, while Hedonic Quality measures the emotional experience and aesthetic pleasure of the product.

Usability, as defined by DIN EN ISO 9241-11 [32], is determined by the effectiveness, efficiency and satisfaction of user interaction with a product, system or service. Consequently, Pragmatic Quality is an important aspect of Usability. Pragmatic Quality specifically refers to the usefulness of a product or service from the user’s perspective, ensuring that the product or service fulfills the user’s practical needs, increases efficiency and is user-friendly.

It should be mentioned that the boundaries between User Experience and Usability usually overlap, as the two concepts are closely connected. However, the two concepts differ in the way they focus on measuring product interaction and perception. While Usability mainly focuses on efficiency, effectiveness and satisfaction with the product, User Experience covers a broader range of aspects, such as emotional and aesthetic impressions. It could therefore be suggested that Usability contributes to the User Experience of a product or service by ensuring that users can rely on the proper functioning.

2.2.2. Trust

Technology Trust is defined as the willingness to rely on a system in a situation of uncertainty and vulnerability in order to achieve personal goals [71]. According to Kohring [69], an act of

Trust does not consist of avoiding risky behaviour, it rather allows risky behavior to take place, because without risk there is no freedom of action and decision-making. It is important to keep the level of Trust at the optimal level, as both a low level of Trust (mistrust) and a high level of Trust (overconfidence) can lead the user to do things that we do not want. In the context of automated driving, mistrust tends to prevail [102], which can be reflected in the rejection of eHMIs. Trust in the context of automation can according to Kohn et al. [68] be examined in connection with passive and active behaviour. In passive behaviour, the user should not intervene in the action of the automation, as is the case with driver assistance systems, whereas in active behaviour, the user should consciously accept the action of the automation. The latter is particularly relevant for our case, as the participants are supposed to rely on the eHMI.

2.2.3. Safety

From previous studies [120], we see that most people are generally open to the idea of self-driving shuttle buses and recognise its potential for the public transport of the future [81]. However, the trustworthiness of this technology faces a major hurdle, mainly related to safety concerns. This includes both technical safety concerns such as accidents, technical failure and potential hacking attacks, as well as social safety concerns such as vandalism and potential threats from other passengers in the absence of an on-board safety driver [81]. In the case of eHMI of automated shuttle buses, the safety concern mainly relates to technical failure, such as the fear of the possibility that the automated shuttle will fail to detect a pedestrian or have an incorrect communication.

The aspects of Trust and Safety may sound similar at first, as they are closely linked. However, it should be noted that Trust refers to the expectation that the system will function flawlessly and efficiently and adequately meet the users' need. Safety, on the other hand, reflects the perceived safety during use or interaction with the automated shuttle bus. This includes technical aspects such as the avoidance of accidents or the functioning of the technology without failures, but also social aspects such as safe communication of intent between pedestrians and automated vehicles.

2.2.4. User Acceptance

The adoption way and manner in which automated driving technologies and services are adopted will be significantly influenced by user Acceptance. User Acceptance of technological products can be described as a user's willingness to use a particular system based on their internal attitude [29]. As stated by Davis [29] and Eden et al [35], social Acceptance is considered a key factor in the success of a technical system. Especially in the context of automated driving, we are striving for Acceptance so that new functionalities can be used and integrated into everyday traffic. We also need Acceptance to ensure that familiar patterns of behavior in road traffic can be replaced or supplemented by new ones that are necessary for automated technologies. Technology Acceptance is also of great importance, as only a few people had the opportunity to travel in a vehicle with a high level of automation (SAE 4 and above), while at the same time constant reports in the media on this topic influence their opinion.

It should also be noted that user Acceptance can be divided into two aspects: Acceptance and Accessibility. Acceptability pertains to the attitude, behavior, and response of users towards the subject of investigation after experiencing it, while Accessibility relates to users' anticipated attitudes before engaging with the subject of investigation [108, 113]. To facilitate understanding, we consider an new eHMI of an automated shuttle bus as the subject of investigation. Our goal

is to investigate people's attitudes towards the new eHMI. In this context, Acceptability refers to participants' attitudes and opinions after testing the eHMI, while Accessibility refers to participants' attitudes and opinions regarding the eHMI without prior testing experience. In the context of this study, we focus on the factor of Acceptability, as the participants will interact with an eHMI and subsequently evaluate it.

It is important to understand which factors influence Acceptance in general and in specific scenarios. Here, Acceptance models can serve as an instrument in this process. Already established frameworks such as the Technology Acceptance Model (TAM) [28], which is based on the Theory of Reasoned Action [45], provide more detailed insights into Acceptance. This model outlines the causal relationships among system design characteristics, perceived Usefulness, perceived Usability and attitudes toward rational reasons for hypothesised model relationships [47]. In addition, the model can also provide insight into the aspect of Trust that has evolved over the years.

2.3. Research on Personality

2.3.1. Personality Models and Traits

A person's personality is an important measurement criterion in research, allowing us to understand and predict human behavior [25], identify risk factors and explain the relationship to other variables. It explains why different people can act differently in one and the same context. Therefore, analyzing a person's personality can also provide predictions about the expected interaction with another person, a machine or a system. However, measuring personality is much more difficult than many other variables in research. Personality is subjective, and its perception varies across individuals. There are also a large number of characteristics and descriptions for personality. In addition, a person's personality is extremely complex and dynamic. It can change over a longer period of time and be influenced by many other factors, such as the social environment, education and personal experiences. For a quantitative comparison, a standardised measurement method is required. Personality models have been developed in order to create a standardised, valid measuring instrument. Personality models act as an essential tool to explore and understand the behavior, attitudes, and interactions of people. They attempt to structure the complexity of human personality by breaking it down into variables that can be used in research. These variables are called personality traits or personality dimensions. Personality traits are described as patterns of thinking, feeling, and behaving that generally extend across an person's lifespan and are relatively consistent [53]. In the academic community, research on personality traits is often challenged because it only approximates and simplifies reality. Nevertheless, modeling personality in measurable units (personality traits) is currently the best approach for a universal measurement model of personality. Due to ongoing research into personality traits, personality models are constantly evolving and have been used and tested in different contexts, cultures and languages [54, 104, 96, 119, 111, 84, 85].

Various models attempt to understand personality using different approaches [24, 52]. The Myers-Briggs Type Indicator (MBTI) [98] is a personality test for identifying individual preferences and behavioral patterns. The MBTI categorises personalities into different types based on four dichotomous dimensions: Extraversion vs. Introversion, Sensing vs. Intuition, Thinking vs. Feeling, and Judging vs. Perceiving. Another personality model is the Dark Triad, which was first published by Paulhus et al. [91]. This model refers to three negative personality traits: Narcissism, Machiavellianism and Psychopathy. The personality dimensions are used to identify negative effects on interpersonal relationships and the social environment. However, these

two personality models do not cover a wide range of personality characteristics and are less scientifically validated, so they are not suitable for our study. One of the best-known and most widely used personality models is the five-factor model of personality (also known as the Big Five) [49, 50], consisting of Openness (to experience), Conscientiousness, Extraversion, Agreeableness, Neuroticism. It is therefore not surprising that there are many variations of this model, for example, the HEXACO model of personality [14], which expands the dimensions of the Big Five by adding the Honesty-humility dimension. There is also an abbreviated version, which was published in 1985 by Eysenck et al. [40], that consists of only three personality dimensions: Extraversion, Neuroticism and Psychoticism. It is advisable to use this abbreviated version with caution, because according to the Big Five theory, five factors are required to explain most of the observed variations in personality. Since then, the Big Five has been used in numerous studies and contexts and is constantly being improved, so it is not surprising that the Big Five is seen as "the central model for personality research". Although it is widely recognised in other areas, the Big Five model has received less attention and use in the automotive sector. For this reason, we decided to use the Big Five personality dimensions in our study. In the following subchapter, the personality traits and the origin of the Big Five are discussed in more detail.

2.3.2. Big Five Model of Personalities

The Big Five (also referred to as the OCEAN model) is an established personality model from psychology that divides a person's personality into five personality dimensions. The foundation for the Big Five was laid with the so-called "lexical hypothesis" (also called "lexical approach") in the 1930s. This is based on the idea that people have a linguistic coding for everything that is important to them and worth describing. Accordingly, relevant personality traits tend to be encoded as a single word in language [13, 23, 61]. This led to the establishment of the five-factor model [49, 50] and the five main dimensions of personality, known as the Big Five, into which every person can be classified on scales: Openness (to experience), Conscientiousness, Extraversion, Agreeableness, Neuroticism. In the years that followed, this approach was refined and substantiated by continuous research [51, 30, 34, 64, 72, 82, 107]. The Big Five was also shown to be an extremely useful measuring instrument of the personality in different languages and in different cultures [119, 111, 84, 85]. As a result, the Big Five model can be considered one of the most important and well-founded models for capturing human personality, and it can be regarded as the "universal standard model" in personality research.

The Big Five describe five basic dimensions or personality traits that are used to characterise how people differ in personality. Each of these dimensions is a spectrum on which people move to some degree. It is important to note that people are on a range for each dimension and cannot be assigned exclusively to one dimension. Within the research community, there is a general agreement on the number of personality dimensions, but the meaning of these may vary slightly as they are interpreted differently by different researchers and cultures. To avoid ambiguity in this paper, brief definitions of the five personality dimensions are therefore provided below. The basis for this is the Big-Five Trait Taxonomy by John et al. [62]. The five dimensions in this work are described as follows:

Openness to Experience This dimension describes how open a person is to new experiences, ideas and creativity. People with a high level of Openness to Experience are curious, clever, imaginative and insightful. People with a low Openness score tend to be more commonplace, simple and less open to experimentation.

Conscientiousness This dimension refers to a person's organization, sense of duty, and self-

control. People with high Conscientiousness are described as organised, reliable, practical, and conscientious in their actions. People with low Conscientiousness can be rather irresponsible, forgetful and careless.

Extraversion Extraversion refers to the extent to which a person is sociable, outgoing, and energetic. Extroverts feel comfortable in social situations, are talkative, adventurous, enthusiastic and tend to be active. In contrast, less extroverted people (introverts) tend to be quiet, shy and reserved and prefer a less stimulating environment.

Agreeableness This dimension relates to the extent to which a person is cooperative, kind, and considerate. People with high Agreeableness are trusting, helpful, and harmony-oriented. They are also sensitive. On the other hand, people with low Agreeableness tend to be cold, competitive, and unfriendly.

Neuroticism Neuroticism describes the extent to which a person experiences emotional instability and negative emotions. People with high Neuroticism are more likely to be fearful, nervous, anxious, insecure, and self-pitying. In contrast people with low Neuroticism tend to be emotionally stable, calm and more resistant to stress.

There are several standardised questionnaires for the Big Five. We decided to use the freely available Big Five Inventory published by John et al.[63] (see appendix A.2).

3. Study Design

This section covers the essential aspects of planning and conducting a user study. This includes the preparation and implementation of the study design and the environment, the selection and recruitment of participants and the actual study procedure. The section also includes an introduction to the relevant measurement variables and applied methods that resulted from the derived influencing factors. The data collected provides a basis for analyzing and deriving practical findings, which will be discussed in more detail in the following chapters.

This study was designed and conducted in collaboration with the University of Leeds in the United Kingdom. This involved collecting a large amount of data. It should be noted that only the data described in chapter 3.1 are relevant for the analysis of this work in order to answer the research question and test the hypotheses. However, for a better understanding and reproducibility of the study, the entire study setting is described in the following chapter. The study was conducted in compliance with ethical guidelines. An ethics application was submitted and approved.

3.1. Methodology

The following chapter provides a detailed description of the measurement variables and the research methodology used. To simplify the analysis, the factors identified in chapter 2.2, which influencing attitudes and perceptions towards automated shuttle buses, were subdivided into measurement variables. Table 1 illustrates the connection between the influencing factors, the measurement variables derived from them and the measurement methods used. These explanations are intended to provide a clear overview of the methodological approach of this thesis and lay the foundations for the subsequent analysis and discussion.

Influencing factors	Measurement variables	Measurement Method
Acceptance	Perceived Usefulness	TAM
	Perceived Ease of Use	TAM
Trust	Trust Scale	Trust Questionnaire
User Experience	Pragmatic Quality	UEQ
	Hedonic Quality	UEQ
Usability	Pragmatic Quality	UEQ
Perception of Safety	Safety Scale	Single-item scale
	Crossing Initiation Time	Head-Tracking

Table 1: Influencing factors and their derived measurement variables and methods used in the evaluation of automated shuttle buses

3.1.1. User Experience Questionnaire

In order to evaluate the Usability and User Experience for our experiment, we decided to use the User Experience Questionnaire (UEQ) [2] in English (see appendix A.1). In previous studies investigating Usability and personality, the SUS questionnaire was often selected, but Schmidt et al. [110] recommended choosing a questionnaire that does not focus solely on Usability, but encompasses a broader picture of the respondent's subjective experience. Due to time constraints

and the multiple use of the questionnaire in one session, a abbreviated version of the UEQ was chosen, known as the “User Experience Questionnaire Short” (UEQ-S). It consists of 8 items instead of the original 26 items. In addition, the UEQ-S enables a comprehensive analysis of the Pragmatic and Hedonic Quality (in contrast to the UEQ, which focuses on individual characteristics of the User Experience), which is essential in this study and therefore also an advantage.

The UEQ-S is a measurement method that determines the mean values for the Pragmatic and Hedonic Quality, as well as the overall score of the system. In this way, it considers aspects of User Experience as well as Usability. For the overall quality, both qualities are weighted equally, in contrast to related questionnaires (e.g. SUS [60] and UMUX [44]), where the focus is strongly on the Pragmatic Quality [112]. All items were rated on a bipolar 7-point Likert scale, where each attribute is evaluated using opposing adjectives. An Excel template [2], which is freely available online and provides a simplified analysis of the data, was used to evaluate the mean scores for the Pragmatic and Hedonic Quality.

3.1.2. Perceived Usefulness & Perceived Ease of Use

The evaluation of technology Acceptance is based on the theoretical framework of Davis’ TAM [28]. The model is based on the idea that perceived Usefulness and perceived Ease of Use are key factors that influence a person’s attitude towards a technology and their willingness to use it. Consequently, the higher the perceived Usefulness and perceived Ease of Use, the more likely it is that a person will accept the technology. The two factors are defined as follows:

Perceived Usefulness Perceived Usefulness refers to a user’s perception of whether a technology or system will improve their performance or productivity. Acceptance is increased by the usefulness of the technology or system.

Perceived Ease of Use Perceived Ease of Use refers to the user’s perception of whether a technology or system is easy and user-friendly to use. Acceptance increases if the technology or system is uncomplicated to use.

In this study, an adapted version of the TAM questionnaire was used to measure perceived Usefulness (PU) and perceived Ease of Use (PEoU). This modification was based on the questionnaire by Rahman et al. [97] which in turn was based on the original questionnaire by Venkatesh & Davis [121]. Rahman et al. [97] showed that the items measuring PU and PEoU can be validly used in the context of driver assistance. The questionnaire items were verbally adapted to ensure that the content was suitable for the use case of the interaction between pedestrian and automated vehicle (see Table 2). A native English speaker also reviewed and improved the questionnaire. All items were rated on a 7-point Likert scale, structured with the following gradations: 1 = Strongly disagree, 2 = Moderately disagree, 3 = Somewhat disagree, 4 = Neither disagree nor agree, 5 = Somewhat agree, 6 = Moderately agree, and 7 = Strongly agree. To measure PU and PEoU, the participants’ ratings for the corresponding items on each scale were averaged.

3.1.3. Trust Scale

The level of Trust in the automated shuttle bus and its communication was determined using a adapted version of the questionnaire based on the work of Merritt [86]. This questionnaire consists of 6 questions, each rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), and is widely recognised in studies dealing with Trust in automation. In our study,

Adapted Questionnaire	Adapted from Rahman et al. [97]
Perceived Usefulness (PU)	
(1) Using the automated shuttle bus improves my decision-making performance when crossing the road.	Using the system would improve my driving performance.
(2) Using the automated shuttle bus increases my safety.	Using the system in driving increases my safety.
(3) Using the automated shuttle bus increases the decision-making effectiveness when crossing the road.	Using the system enhances effectiveness in my driving.
(4) I find the automated shuttle bus useful when crossing the road.	I would find the system useful in my driving.
Perceived Ease of Use (PEoU)	
(5) My interaction with the automated shuttle bus is clear and understandable.	My intention with the system would be clear and understandable.
(6) I find the automated shuttle bus difficult to use. (reverse-scaled item)	I would find the system difficult to use (reverse-scaled item).
(7) Interacting with the automated shuttle bus does not require a lot of my mental effort.	Interacting with the system would not require a lot of mental effort.
(8) I find it easy to get the automated shuttle bus to do what i want it to do.	I would find it easy to get the system to do what I want it to do.

Table 2: Adapted questionnaire with items focussing on perceived Usefulness (PU) & perceived Ease of Use (PEoU) with reference to the original questionnaire from Rahman et al. [97]. The term "shuttle bus" was substituted with "car" for the questions regarding the car model.

Adapted questionnaire	Adapted from Merritt [86]
Trust Scale	
(1) I believe the automated shuttle bus is a competent performer.	I believe the AWD is a competent performer.
(2) I Trust the automated shuttle bus.	I Trust the AWD.
(3) I have confidence in the communication given by the automated shuttle bus.	I have confidence in the advice given by the AWD.
(4) I can depend on the automated shuttle bus.	I can depend on the AWD.
(5) I can rely on the automated shuttle bus to behave in consistent ways.	I can rely on the AWD to behave in consistent ways.
-	I can rely on the AWD to do its best every time I take its advice.

Table 3: Adapted questionnaire with items focussing on perceived Trust with reference to the original questionnaires from Merritt [86]. AWD stands for Automatic Weapons Detector. The term "shuttle bus" was substituted with "car" for the questions regarding the car model.

question three was slightly adjusted and question six was completely removed to ensure a better fit with pedestrian interaction with the automated shuttle bus and to avoid potential ambiguity. The questionnaire was also reviewed and improved by a native English speaker. The table 3 shows the results of the adapted questionnaire compared to the original version. The first column contains the modified version of the questionnaire, while the second column shows the original version. The average score serves as an indicator of the level of Trust, with higher scores reflecting a higher level of Trust.

3.1.4. Safety Scale and Crossing Initiation Time

Safety was assessed using two approaches: a single-item scale and behavioral measurements. After each trial, the participants were asked about their immediate perception of Safety (PS) in the given situation in order to record their authentic perceived Safety as accurately as possible. To measure the perception of Safety, a single-item scale was used, which asked the following question: "I felt safe during this road-crossing situation, both while standing and walking". The Likert scale consisted of four answers: 1 - Disagree (I felt notably unsafe at least once during this road crossing situation), 2 - Mostly disagree, 3 - Mostly agree and 4 - Agree (I felt completely safe during this entire road crossing situation). The mean value of the data from the cases that were recorded exclusively using the bus model and human deceleration was then calculated. In addition to the single-item scale, the participants' behavior is also systematically recorded. Here, the Crossing Initiation Time (CTI) was measured, i.e. the duration it takes for

the participant to decide whether they intend to cross the road. For this purpose, the time was recorded from the point at which the tracked head moved towards the road after the start tone ("beep tone"), which officially begins the test, sounded. Here, faster decisions are indicators for a higher perceptions of Safety, while slower decisions imply a lower perceptions of Safety. Based on the assumption that participants think longer about their decision and the scenario if they have a lower perception of safety in automation [125].

3.2. Apparatus

The user study was conducted in the HIKER laboratory (Highly Immersive Kinematic Experimental Research lab) [75] at the University of Leeds in the institute for transport studies, in a CAVE-based simulator with the functionality to recreate an immersive pedestrian environment. In the user study, particular emphasis was placed on method triangulation (measurements, questionnaires and interviews) in order to increase the reliability and validity of the results [22]. For this purpose, the study setting was divided into two main experimental environments (referred to below as the experimental sections). These included a virtual environment for measurements and direct interaction with the scenarios and an non-virtual environment in which participants could answer questions about their personality, intentions and perception of the scenarios presented.

The virtual experimental section included a VR study in the CAVE-based HIKER simulator in which the participants were asked to experience various scenarios. The HIKER simulator allows participants to interact with a variety of urban environments and vehicles in a 9×4 metre space, at a level that is not possible with head-mounted virtual reality devices. The participants can move very freely in the CAVE, which is ideal for scenarios that require movement, such as crossing scenarios. The HIKER simulator consisted of glass walls with rear projection from a series of 4k projectors, with the entire scene responding to the participants' head position and gaze. It should be emphasised that the result reproduces VR without the participants having to wear a spear-shaped VR headset. Only light glasses are required. This allowed fine movements to be captured in real time without compromising the experiment. In order to get a better idea, the HIKER simulator is shown in figure 4. The other experimental environment consisted of a quiet environment with a seating place in which the beginning and end of the study was conducted. In this experimental setting, participants were asked to fill out questionnaires on a tablet about their personality and demographic data before the study. This was followed by an open interview in which the participants explained their behavior and perception in relation to the previously seen scenarios after the part of the study in the virtual environment. Care was taken to create a comfortable and calming atmosphere to minimise stress or discomfort.

Figure 4: The Highly Immersive Kinematic Experimental Research (HIKER) pedestrian laboratory at the University of Leeds; Source: University of Leeds [75]

3.3. Implementation of the VR Environment and Scenarios

In the following, the development and implementation of the VR environment used is described. The Unity game engine was used as the game development environment. The University of Leeds provided a VR environment that had already been used in previous studies [74] to investigate eHMIs on automated, privately used cars and the "crossing behavior" of pedestrians. The scenario of their studies was similar to our study in terms of environmental conditions and experimental design. In both cases, the focus was on creating a controlled environment to study the crossing behavior of pedestrians interacting with automated vehicles. A test scenario in the virtual environment looked as follows: *Several vehicles, without and with eHMI, moved at different distances along a straight road without junctions and performed stopping maneuvers from time to time. The participants had to decide for themselves whether to cross the road or not.* For the eHMI, we chose a design (cyan-colored lightband) and light pattern (fast pulsing) that had already been validated and updated in previous studies [73, 74] at the University of Leeds in a similar context like our study. We made adjustments to the light pattern, after Lee et al. [73, 74] indicated that a faster flashing light led to earlier crossings during vehicle deceleration than the variant with the slower pulsing lightband.

A few changes had to be made to the environmental conditions for our study. A bus stop has been added to our scenario. The participants were standing at a bus stop at the beginning of the



(a) Starting point of the participants: Bus stop with oncoming vehicles



(b) Participant crossing the road in the CAVE after acoustic signal

Figure 5: VR simulation - Two images showing the study environment in virtual reality

study (see figure 5b), which initially obstructing their view of the road's end, from where the vehicles were coming. The pedestrians were informed by an acoustic signal about 3 seconds before the vehicle reached the bus stop to walk towards the road and decide whether and when to cross the road. This decision was based on whether the oncoming vehicle stopped or not. Figure 5b shows an example interaction between participant and automated vehicle in which the participant crosses the road after the automated vehicle has stopped. For this work, another feature had to be adapted in the code: the automated vehicles used in the simulation were car models, primarily used for private rides. Therefore, the purchased 3D Navya Shuttle Bus model [15] was added to the simulation. The "lightband" eHMI concept used and evaluated in an earlier study with a similar study setting [74, 73] as well as the driving behavior and the vehicle dynamics also had to be transferred to the automated shuttle bus model. In figure 6, both models can be viewed side by side with the "lightband" switched on. The programming of this part was conducted by an experienced developer.



Figure 6: VR models used with lightband eHMI (car vs. bus)

3.4. Selection of Participants

The participants in the study consisted of men and women between the ages of 18 and 64. This age group was selected due to its presumed relevance to the research topic. It was also expected that participants would already be familiar with driving on the left-hand side of the road, so care was taken to only have participants who had lived in the UK for at least one year. A participant pool from the University of Leeds was used to recruit the participants. During recruitment, care was taken to inform the participants about the duration and purpose of the study and to reject unsuitable participants in advance. In order to achieve an equitable distribution of personality traits, the balance of personality traits was checked from half of the recruited participants for the first time. A total of 40 participants aged between 20 and 64 ($M(SD) = 37.2(13.7)$, Median = 34) took part in the study. This number was considered appropriate in order to ensure sufficient variance in the data and at the same time take into account the feasibility of data collection. The demographic data of the survey participants revealed a balanced gender distribution, with 23 men and 17 women. There was also a wide range of prior knowledge in the field of self-driving vehicles, ranging from not informed (have never read or watched articles/videos about automated vehicles) to well informed (often engage with articles/videos about automated vehicles).

3.5. Study Procedure

The study design consisted of a within-subject design to avoid the negative influences of individual differences and to establish a direct comparison between the different concepts depending on the type of the vehicle (car or bus), the deceleration type (Human-Like Deceleration (HL), Old AV-equivalent Deceleration (Old AV), New AV-equivalent Deceleration (New AV)) and if they have an eHMI (lightband) or not. Therefore, each of our participants evaluated all concepts one after the other. To minimise the training and fatigue effect, we randomised the order of the eHMI scenarios. Therefore, in one condition, some users first evaluated the concept with the lightband eHMI and then the baseline concept with no eHMI. While the other users saw the baseline concept first. The three braking profiles (HL, Old AV, New AV) were developed on the basis of preliminary studies by the University of Leeds [74]. They differ firstly in terms of the distance they brake from the participant, whereby HL and New AV brake slightly further away from the participant (9.95 m), while Old AV brakes significantly closer to the participant (2.5 m). Secondly, they differ in the braking speed and the way in which the vehicles brake (constantly or gradually). Old AV and New AV have the same deceleration speed and constant deceleration, while HL comes to a standstill in two steps with different deceleration speeds. The entire study consists of seven blocks with a total duration of 1h 15min per participant, whereby only blocks two to six were conducted in the virtual environment in the CAVE and blocks one and seven in a non-virtual environment. Each block focused on a different aspect of the study, while the same set of trials from block three (but not always all trials) was used. The blocks are presented and explained in more detail in the following. Furthermore, a comprehensive overview of the entire study design is illustrated in figure 7

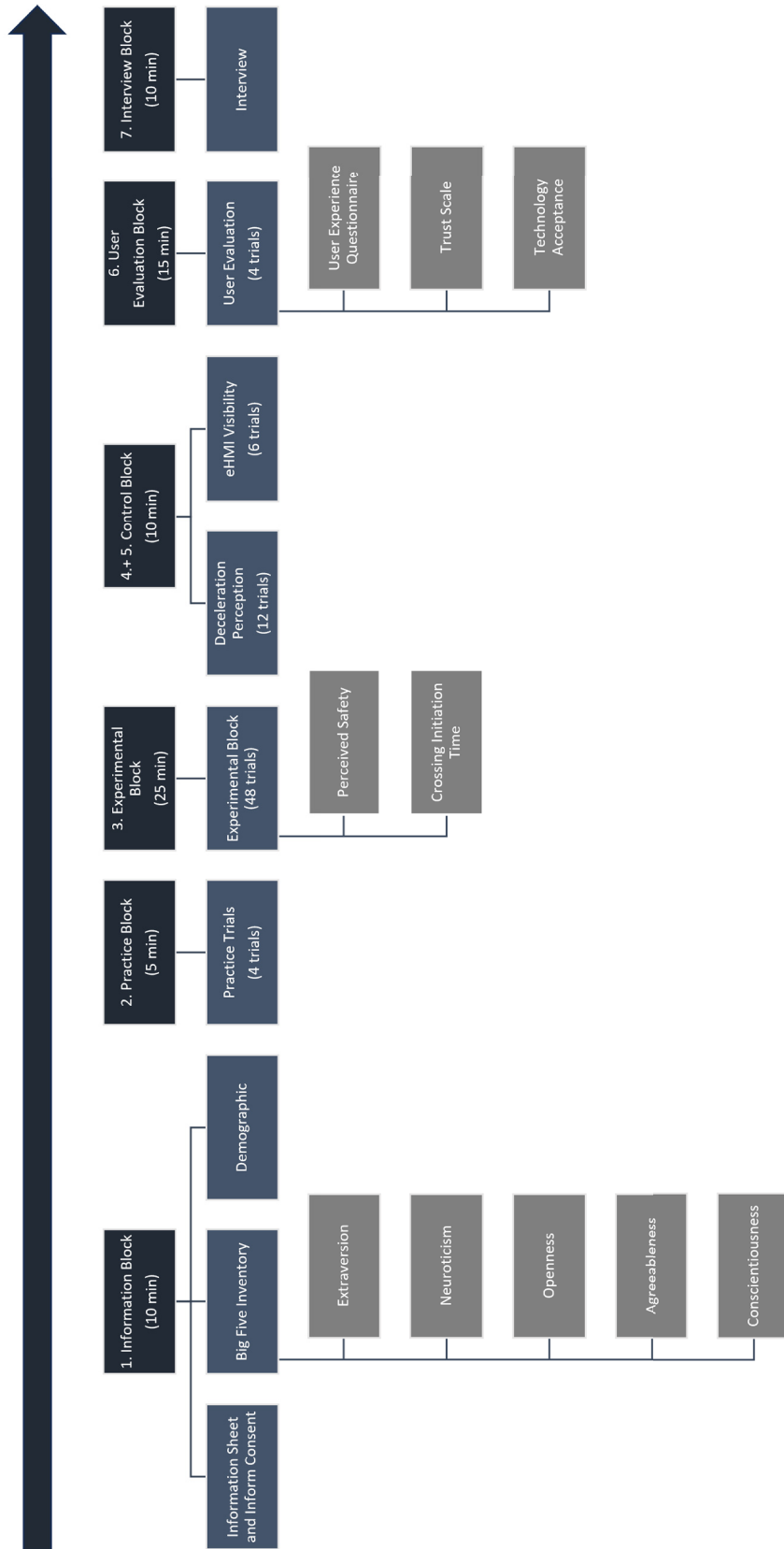


Figure 7: Study Design

Before taking part in the study, participants received detailed information about the study, including the purpose, the expected time required and possible risks. Participants gave their written consent after having the opportunity to ask questions and express concerns. All data was pseudonymised and treated confidentially. Furthermore, the participants were asked to complete a questionnaire on a tablet that contained both demographic questions and questions based on the Big Five Inventory. The latter was used to measure the extent of participants' personality traits in terms of Openness (to Experience), Conscientiousness, Extraversion, Agreeableness and Neuroticism within a range.

Before starting the trials in the VR environment, the participants were again verbally briefed on the instructions, including what their **task** is, the **mindset** they should be in, what the **eHMI means**, the **PS** rating, and what happens if they decide to cross the road or in the case of choosing not to cross the road. The specific task for the participants was formulated as follows: *"You will start the experiment standing at the edge of the road, marked by an X in tape on the HIKER floor. You should look straight ahead, until you hear a short beep tone, at which point, you should turn your head to the right. You then need to decide whether or not to cross in front of the approaching vehicle (car/bus). Please remember that you should stay safe, but that you are also in a hurry to a meeting. Sometimes the approaching vehicle will have a cyan lightband which is used to communicate 'I am yielding'. Each time you cross, you should provide a rating of how safe you felt from one to four, where one represents i feel very unsafe and four represent i feel very safe. If you don't cross, you should look straight ahead again and wait for the next trial."* This was followed by a practice session with four trials to familiarise the participants with the equipment, the virtual environment and the experiment. The participants were able to ask questions during this session. The measurement times and the PS ratings from the practice session were not included in the data collection.

After completing the practice block, the actual experimental block began. The instructions and tasks remained identical to those in the practice block. The experimental block consisted of a total of 48 trials in which three different deceleration profiles (HL, Old AV, New AV), two different vehicle types (bus/car) and scenarios with or without eHMI (cyan-colored lightband) were presented. Each combination was shown twice. In addition, 24 trials were also integrated, 12 of them with a car and 12 with a bus, in which the automated vehicle did not decelerate. This corresponds to exactly half of the trials. This is intended to encourage participants to think carefully about their decisions and to ensure that the participants did not know in advance whether the vehicle would brake or not. A detailed overview of the trials with the corresponding braking behavior for the experimental block can be found in the table 4. To avoid any influences from a predefined order, all 48 trials were presented in randomised order. After each crossing, participants were directly asked to rate their PS on a scale from 1 to 4 (1 - disagree/unsafe, 2 - Mostly disagree, 3 - Mostly agree, 4 - agree/safe).

After the experimental block, two control blocks, consisting of blocks 4 and 5, were integrated. The purpose of these was to investigate how quickly the participants perceived the deceleration (block 4) and the eHMI (block 5). For this purpose, firstly 12 trials were initially repeated, showing all possible deceleration profiles. The task was relatively similar to the previous block. The participants were still asked to look straight ahead until they heard a signal tone and were only then allowed to look to the right. However, they were no longer asked to cross the road or to give a PS rating. Instead, the participants were asked to confirm by pressing a button as soon as they noticed the vehicle's braking in block 4. Subsequently, the task was slightly modified in block 5, here the participants were asked in six further trials (only those with the eHMIs) to

Experimental Block (N=48)

Number of scenarios	Deceleration Profil	eHMI (Y/N)
2 trials (car, shuttle bus) x 2 rep	Human-Like Deceleration (HL): - Step 1 (31m to 23m): 13.8m/s (30.87mph) to 13.3m/s (29.75mph), rate = -0.85 - Step 2 (23m to 9.95m): 13.3m/s (29.75mph) to 0m/s (0mph), rate = -8.89	Y
2 trials (car, shuttle bus) x 2 rep	Human-Like Deceleration	N
2 trials (car, shuttle bus) x 2 rep	New AV-equivalent Constant Deceleration (New AV): - Step 1 (31m to 9.95m): 13.8m/s (30.87mph) to 0m/s (0mph), rate = -4.52	Y
2 trials (car, shuttle bus) x 2 rep	New AV-equivalent Constant Deceleration	N
2 trials (car, shuttle bus) x 2 rep	Old AV-equivalent Constant Deceleration (Old AV): - Step 1 (31m to 2.5m): 13.8m/s (30.87mph) to 0m/s (0mph), rate = -3.34	Y
2 trials (car, shuttle bus) x 2 rep	Old AV-equivalent Constant Deceleration	N
2 trials (car, shuttle bus) x 12 rep	no Deceleration	

Table 4: Overview of the arrangement of the trials (N=48) for the experimental block with varying deceleration profiles and the integration of eHMI (Yes/No). The deceleration profiles differ in the distance to the participant at complete stop and the deceleration speed as well as the way of deceleration (constant or gradual).

press the button as quickly as possible when they perceived the eHMI on the vehicle.

The final task in the CAVE was the User Evaluation Block. The aim of this was to evaluate the concept of the automated vehicles in relation to the vehicle type and the presence of an eHMI. A total of four trials were presented, consisting of a bus with eHMI, a bus without eHMI, a car with eHMI and a car without eHMI. As the evaluation of the deceleration profiles was not the main focus in this example, Human-Like Deceleration was selected in all four cases. The exact task was explained to the participants as follows: *“In the previous trials, you have decided whether to cross or not in front of different automated vehicles. In this block, you will provide ratings on your experience of each automated vehicle, including the impact of vehicle type and the presence of a lightband. Please watch the automated vehicle carefully until it comes to a full stop, at which point you will answer the questionnaire. In this case, the deceleration does not have to be taken into account.”* The questionnaire was completed on a tablet after each trial and consisted of the User Experience Questionnaire, which was designed to measure Pragmatic and Hedonic Quality, a Trust Scale and a technology Acceptance Scale.

After the user evaluation block, the participants were guided out of the CAVE and brought back into the non-virtual environment. Lastly, an open interview was conducted in which the topics of Safety, Trust, User Experience, Usability and Acceptance were addressed again. This approach made it possible to collect additional qualitative data, which led to a deeper insight into the perspectives of the interviewees. This method made it possible to gain a more comprehensive understanding of the participants’ viewpoints and opinions.

4. Evaluation of Results

In the following section, the data is analyzed and evaluated. In addition to the results used to analyze the hypotheses, the statistical methods were also checked for validity. The Cronbach's alpha was calculated for all adapted questionnaires and a power analysis, which was carried out before the actual study, was explained in more detail. It should be emphasised that although the data was collected for each vehicle model (car and bus) and for each deceleration type (HL, New AV, Old AV), only the data for the bus models and for the human deceleration was used in the analysis part for this work. This was done to minimise the impact of external influences and random effects.

4.1. Power Analysis

In this VR study, the focus was on investigating the influence of personality traits on the factors influencing attitudes towards automated shuttle buses. The relationships were analyzed using a regression model. In this context, a power analysis was previously conducted to evaluate the statistical power of the study, i.e. the probability of finding a significant effect if such an effect actually exists. The analytical tool used for these calculations was G*Power [43, 42], a software widely utilised for conducting power analyses in research.

According to industry standards and research literature guidelines, a target power of 0.8 was considered appropriate. This power makes it possible to detect effects of medium size and is recognised as an appropriate measure of the statistical strength of a study. Since the literature did not provide a clear definition of the actual effect size, the standard effect sizes of 0.3 and 0.5 were used for the calculation. The power analysis conducted showed that for a one-sided test with a significance level of 0.05 (usual standard) with a medium effect size of 0.3, a total sample size of 67 participants is required. In the case of a large effect size of 0.5, only 23 participants are required. Considering these sample size requirements, a sample size of 40 participants was finally chosen. This number seems appropriate for conducting a virtual study with a duration of 75 minutes per participant and still maintains a high likelihood of attaining statistically significant effects.

4.2. Cronbach's Alpha-Coefficient

In the study, slightly modified versions of standardised questionnaires were used in most cases to measure the measurement variables. Consequently, these were also checked for internal consistency and reliability. This enabled a careful assessment of the accuracy and reliability of the measurements taken. To verify this, we used the reliability measure Cronbach's alpha coefficient [27], which indicates how well the different items of a questionnaire correlate with each other, which can indicate the homogeneity of the questionnaire. Items that belong to the same scale should generally have a high correlation. An alpha coefficient is generally considered good if it reaches a value of 0.7 or higher, while values of 0.8 and above are considered very good [118]. With the exception of the perceived Ease of Use scale items, all scales (Perceived Usefulness, Trust, Pragmatic Quality and Hedonic Quality) achieved an alpha coefficient of over 0.8, which can be considered very good. Perceived Ease of Use achieved an alpha coefficient of almost 0.7, which can also still be considered good. Perceived Safety and Crossing Initiation Time are not listed here, as the former is a single-item scale and the latter is a behavioral measurement.

Scale	Number of Items	Alpha-Coefficient
Perceived Ease of Use	4	0.69
Perceived Usefulness	4	0.93
Trust	5	0.91
Pragmatic Quality	6	0.91
Hedonic Quality	6	0.87

Table 5: Cronbach's Alpha-Coefficient (total N = 40 for all variables)

4.3. Correlation Analysis

The correlation matrix was created using the Spearman method. This approach was chosen to meet the requirements of the data. Each data set was analyzed using the Shapiro-Wilk test to confirm a normal distribution. In a graphical analysis using Q-Q plots and histograms, our data appears to be normally distributed, which could also indicate a Pearson correlation. The descriptive statistics occasionally reveal a deviation from the normal distribution, supporting the decision to use Spearman's correlation. In addition, many of our data are based on Likert scales, which are often assigned to ordinal and thus non-metric data. In such cases, the literature recommends using the Spearman correlation. Another advantage of Spearman is that it is more robust to outliers as it is based on ranks. The data was analyzed using the programming language R.

A correlation analysis was performed to test the hypotheses discussed previously. Consequently, the correlation matrix contains the variables for the personality traits (Extraversion = EXT, Conscientiousness = CON, Openness = OPE, Agreeableness = AGR and Neuroticism = NEU), the measurement factors (perceived Usefulness = PU, perceived Ease of Use = PEoU, Trust, Safety, Hedonic Quality = UEQ_Hed, Pragmatic Quality = UEQ_Pra, Overall Quality = UEQ_Ove and Crossing Initiation Time = CIT) as well as supplementary variables for later interpretation, consisting of age and prior knowledge of automated vehicles (in short: KnowAD). First, the hypotheses were analyzed separately for the repeated measurement (bus with/without eHMI). Table 9 presents the descriptive statistics and correlation patterns between the model variables for the bus concept with the eHMI (the dataset is abbreviated as BY), while Table 8 shows the same results for the bus concept without eHMI (the dataset is abbreviated as BN). Significant correlations were highlighted to show the relationships between all model constructs. Whereby a significant result ($p < 0.05$) is marked with one asterisk (*), a highly significant result ($p < 0.01$) with two asterisks (**) and three asterisks (***) indicate an even higher significance level, with a $p < 0.001$. If the results are not statistically significant, this is marked with "ns". A detailed examination of the correlations between the personality traits with other personality traits are not examined in detail as they do not correspond to the purpose of this work. The same applies to the measuring variables with other measuring variables. Nevertheless, they can be seen in the correlation matrices. The correlation matrices were created using the programming language R.

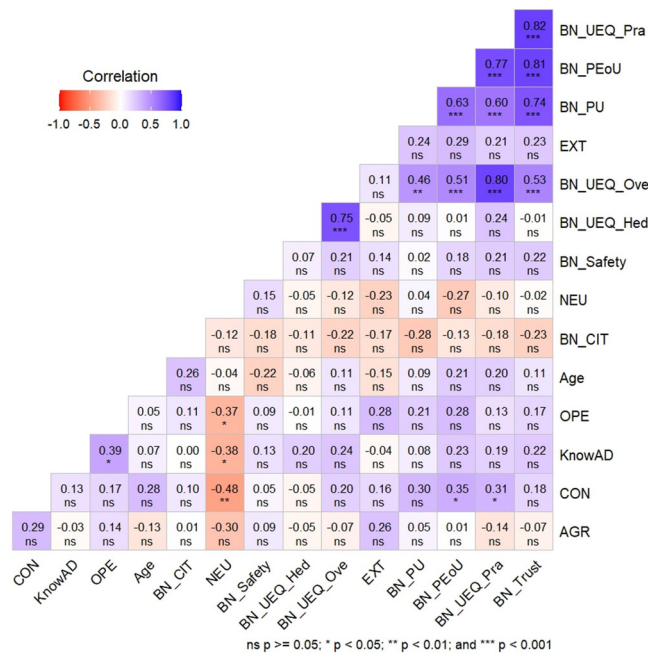


Figure 8: Note. EXT=Extraversion; AGR=Agreeableness; OPE=Openness to new Experience; CON= Conscientiousness; NEU=Neuroticism; PU=Perceived Usefulness; PEOU=Perceived Ease of Use; UEQ_Hed=Hedonic Quality; UEQ_Pra=Pragmatic Quality; CIT=Crossing Initiation Time; KnowAD=Knowledge of automated vehicles. Correlation Matrix: Bus without eHMI (BN). Ns indicates $p \geq .05$. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.

The correlation matrix with the data set without eHMI shows a significant positive correlation between Openness to Experience and knowledge of automated vehicles ($r=0.39$, $p < 0.05$) as well as a significant negative correlation between Neuroticism and knowledge of automated vehicles ($r=-0.38$, $p < 0.05$). Furthermore, there was a positive correlation between the personality trait Conscientiousness and Pragmatic Quality ($r=0.31$, $p < 0.05$) and Perceived Ease of Use ($r=0.35$, $p < 0.05$), indicating that conscientious people rate Pragmatic Quality and perceived Ease of Use better than people with a low level of Conscientiousness.

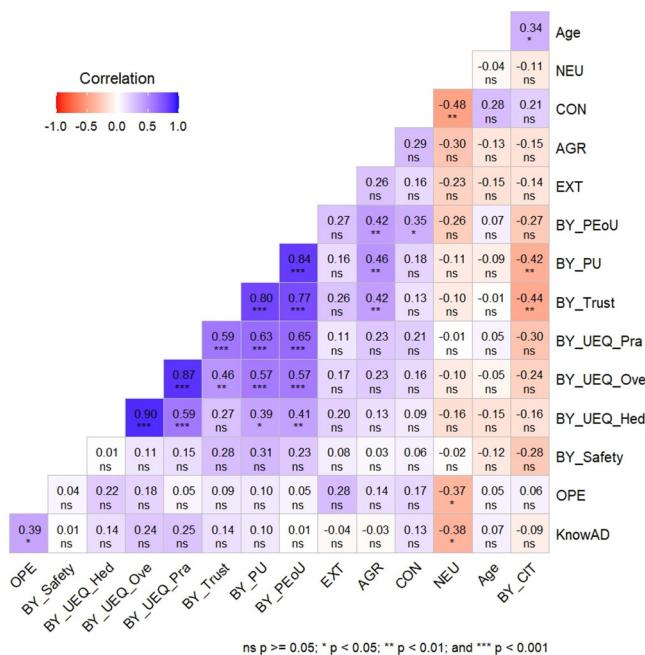


Figure 9: Note. EXT=Extraversion; AGR=Agreeableness; OPE=Openness to new Experience; CON= Conscientiousness; NEU=Neuroticism; PU=Perceived Usefulness; PEOU=Perceived Ease of Use; UEQ_Hed=Hedonic Quality; UEQ_Pra=Pragmatic Quality; CIT=Crossing Initiation Time; KnowAD=Knowledge of automated vehicles. Correlation Matrix: Bus with eHMI (BY). Ns indicates $p \geq .05$. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.

In contrast to the dataset without eHMI, the correlation matrix based on the dataset with eHMI shows three significant positive correlations between Agreeableness and Trust ($r=0.42$, $p<0.01$) as well as Agreeableness and perceived Usefulness ($r=0.46$, $p<0.05$) and Agreeableness and perceived Ease of Use ($r=0.42$, $p<0.05$). This indicates that agreeable people trust the automated shuttle bus more, find it easier to understand and more useful than people with a low level of Agreeableness. Furthermore, we were able to find a positive correlation between the personality trait Conscientiousness and perceived Ease of Use with $r=0.35$, $p<0.05$, similar to the correlation matrix without eHMI. In addition, knowledge of automated shuttle buses correlates positively with Openness to Experience ($r=0.39$, $p<0.05$) and negatively with Neuroticism ($r=-0.38$, $p<0.05$).

So far, the repeated measurements under the two conditions (bus with eHMI and bus without eHMI) have been considered separately in two correlation matrices in order to analyze the significant correlations according to their context. In the following, the measurements with the two conditions (the dataset is abbreviated as BNB) are considered together (see table 10).

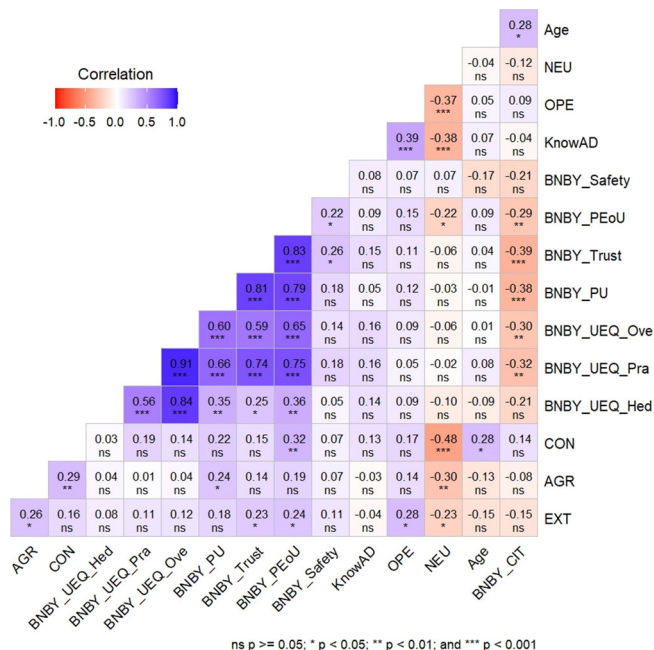


Figure 10: Note. EXT=Extraversion; AGR=Agreeableness; OPE=Openness to new Experience; CON= Conscientiousness; NEU=Neuroticism; PU=Perceived Usefulness; PEoU=Perceived Ease of Use; UEQ_Hed=Hedonic Quality; UEQ_Pra=Pragmatic Quality; CIT=Crossing Initiation Time; KnowAD=Knowledge of automated vehicles. Correlation Matrix with two conditions: Bus with/without eHMI (BNBY). Ns indicates $p \geq .05$. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.

Like the other correlation matrices, a significant positive effect between Conscientiousness and perceived Ease of Use can be recognised with $r=0.32$, $p<0.01$. Furthermore, a significant positive correlation between Agreeableness and perceived Usefulness ($r=0.24$, $p<0.05$) indicates that agreeable people perceive the automated shuttle bus to be more useful than less agreeable people. This was already observed in the dataset containing only the eHMI concepts, but the effect was stronger. The personality trait Extraversion has a significant positive correlation effect with Trust ($r=0.23$, $p<0.05$) and a positive correlation effect with perceived Ease of Use ($r=0.24$, $p<0.05$). These results indicate that extroverted people rate the automated shuttle buses more trustingly and perceive them to be easier to use than introverted people. Furthermore, a significant negative correlation was found between Neuroticism and perceived Ease of Use ($r=-0.22$, $p<0.05$), which in turn leads to the conclusion that neurotic people tend to perceive the automated shuttle bus as more complicated and more difficult to use than more emotionally stable people. Also worth mentioning are the significant correlations associated with knowledge about automated vehicles. The Spearman correlation showed a significant positive correlation with Openness to experience $r = 0.39$ ($p < 0.001$), indicating that open-minded people tend to have a higher knowledge of automated vehicles than people with a low Openness to experience score. In contrast, neurotic people show a significant negative correlation with knowledge about automated vehicles ($r = -0.38$, $p < 0.001$), which means that these people tend to have less knowledge about automated vehicles. Another interesting correlation was found between age and Conscientiousness. The Spearman correlation showed a significant positive correlation with Conscientiousness $r = 0.28$ ($p < 0.05$), which indicates that conscientious people tend to be

older than careless people.

Figure 11 shows a visual representation of the research model with the correlation effects from the dataset that includes all concepts (with and without eHMI). In a further step of the analysis, we thus examine and analyze the effect of the presence of an eHMI on our correlations using a linear model. A mixed effects modeling approach was chosen to consider the repeated measurement and random effects in our analyses. In addition, this method takes into account both categorical (e.g. group with/without eHMI) and continuous variables (e.g. Extraversion or Trust score) in the data set. The participant number (PNr) was selected as the random factor. This ensures that the individual differences in repeated measurements on the same person are adequately taken into account in the data.

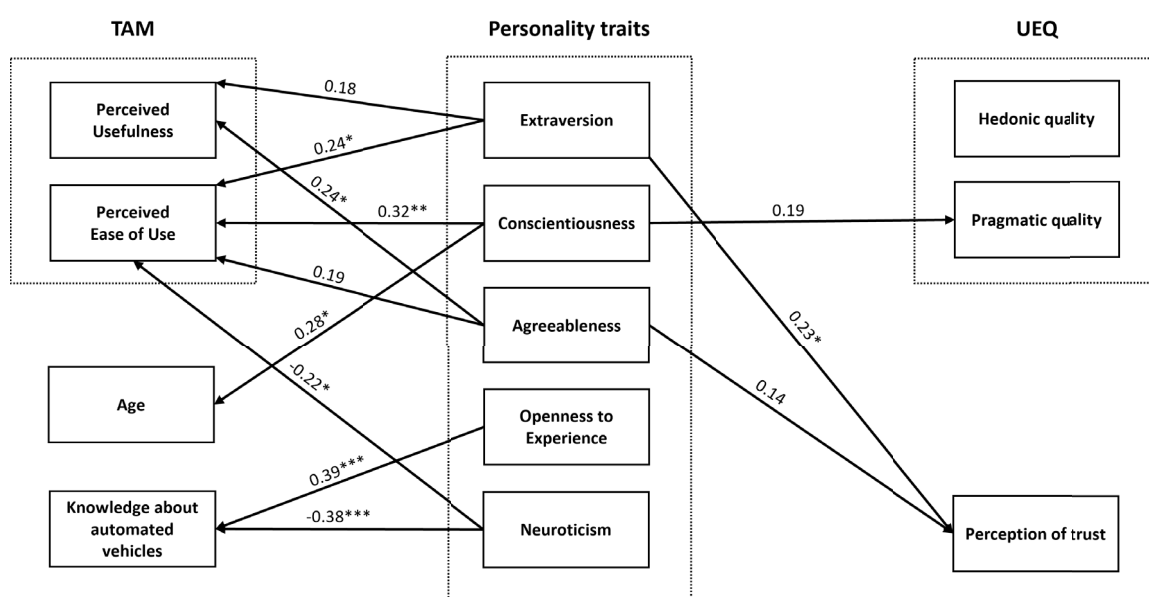


Figure 11: Research model with correlation values. Positive correlation is marked with +. Negative correlation is marked with -. Solid lines are fully accepted hypotheses. Dashed lines are partially accepted hypotheses.

4.4. Linear Mixed Effects Model

Linear Mixed Effects Model were created to analyse the collective impact of different personality traits on the individual variables measured. The "lmer" function in R, which is included in the "nlme" package, was used for the linear mixed effects model. In order to determine the influence of an eHMI on the correlation between personality trait and measurable variable, the data was formatted in a long format and an additional variable (Mod_eHMI) was added to indicate whether the data collected belonged to a concept with (1) or without (0) eHMI. In our model, this variable served as a moderator variable, with the personality traits acting as predictors and the measurable variables as dependent variables. In R, a moderate relationship (e.g. between EXT and Trust) with c Mod_eHMI was represented as follows (see function 1):

$$model = lmer(BNBY_Trust \sim EXT * Mod_eHMI) \quad (1)$$

In order to better understand the relationships between one dependent variable and several independent variables, the model was extended (see function 2). For a better understanding of

the model, the individual components of the model are explained in more detail in the table 6. This model could have been extended by further variables. In order to avoid over-fitting and to achieve an appropriate model complexity, we decided against an even more complex model with additional variables.

$$\begin{aligned} model = lmer(BNBY_PEoU \sim & EXT * Mod_eHMI \\ & + OPE * Mod_eHMI + NEU * Mod_eHMI + AGR * Mod_eHMI \\ & + CON * Mod_eHMI + (1|PNr), data = long, REML = FALSE) \quad (2) \end{aligned}$$

Model Components	Description
BNBY_PEOU	This is the dependent variable (response variable Y) that is predicted in the model (e.g. Trust, PEOU, PU,...).
EXT:Mod_eHMI, OPE:Mod_eHMI, NEU:Mod_eHMI, AGR:Mod_eHMI, CON:Mod_eHMI	This component contains the independent variables (predictors X) and the moderator variable (M). This is an interaction between the variables EXT, OPE, NEU, AGR, CON and Mod_eHMI. This part captures both the main effects of the independent variables and how the effect of the independent variables changes depending on Mod_eHMI. These are fixed effects.
(1 PNr)	This component of the model defines the random effects. The variable PNr stands for the participant number. This means that repeated measurements on the same person are considered in the model (group effects).
data = long	This is the data set in which the variables are contained.
REML = FALSE	This part specifies that the maximum likelihood method (Maximum Likelihood) is used for parameter estimation instead of the restricted maximum likelihood method (REML). This has the benefit of improving the analysis of prediction accuracy.

Table 6: Description of the model components

To improve the model, we performed a backward elimination, i.e. all potential effects are first included in the model and then non-significant effects are gradually removed. We then obtain a simplified model with the most important variables. This process is applied to all dependent variables. In the model used, both the main effects of the independent variables EXT, OPE, NEU, AGR, CON and Mod_eHMI are examined as well as the interaction (EXT:Mod_eHMI, OPE:Mod_eHMI, NEU:Mod_eHMI, AGR:Mod_eHMI, CON:Mod_eHMI) between EXT, OPE, NEU, AGR, CON and Mod_eHMI. The results of the linear mixed effects model are examined in more detail in the following subchapters according to their dependent variable.

4.4.1. Correlation Between Personality Traits and Trust Score

For the dependent variable Trust, the backward elimination of fixed effects shows that the independent variable of AGR and the presence of an eHMI have an influence on Trust (see table 7. In this context, both the main effects of "AGR" and "Mod_eHMI" as well as the interaction

	Eliminated	Sum of Sq	F value	Pr(>F)
Mod_eHMI:NEU	1	0.00032	0.0008	0.97704
Mod_eHMI:OPE	2	0.07092	0.1846	0.66974
OPE	3	0.07897	0.2046	0.65346
NEU	4	0.09639	0.2498	0.61997
Mod_eHMI:CON	5	0.38494	0.9974	0.32394
CON	6	0.21184	0.5356	0.46855
EXT:Mod_eHMI	7	0.72226	1.8259	0.18420
EXT	8	1.28330	3.1026	0.08581
Mod_eHMI:AGR	0	2.76547	6.6861	0.01347

Table 7: Fixed-Effects Elimination: Trust

effect between these two variables ($F(1, 40) = 6.6861, p = 0.01347$) show a statistically significant deterioration of the model during the elimination process. It should also be noted that the main effect of EXT, with an F-value of 3.1026 and a p-value of 0.08581, almost significantly affected the model at elimination. Eliminating the random effect significantly degrades the model ($p=0.009067$), therefore the random effect should be considered in the simplified model. The simplified model for Trust is as follows:

$$BNBY_Trust \sim Mod_eHMI + AGR + (1|PNr) + Mod_eHMI : AGR \quad (3)$$

4.4.2. Correlation Between Personality Traits and Safety Score

	Eliminated	Sum of Sq	F value	Pr(>F)
Mod_eHMI:AGR	1	0.00010	0.0006	0.9814
Mod_eHMI:OPE	2	0.01516	0.0833	0.7744
Mod_eHMI:NEU	3	0.08573	0.4702	0.4968
EXT:Mod_eHMI	4	0.11961	0.6485	0.4254
EXT	5	0.00477	0.0255	0.8740
AGR	6	0.14869	0.7933	0.3784
OPE	7	0.21890	1.1678	0.2863
Mod_eHMI:CON	8	0.24913	1.3291	0.2558
CON	9	0.16603	0.8573	0.3600
NEU	10	0.14412	0.7441	0.3935
Mod_eHMI	11	0.37812	1.9524	0.1700

Table 8: Fixed-Effects Elimination: Safety

For the dependent variable Safety, all main effects of the personality traits and the influence of eHMI could be eliminated without causing a significant deterioration in the model (see table 8. Eliminating the random effect significantly degrades the model ($p=5.485e-05$), therefore the random effect should be considered in the simplified model. The simplified model for Safety is as follows:

$$BNBY_Safety \sim (1|PNr) \quad (4)$$

4.4.3. Correlation Between Personality Traits and Crossing Initiation Time

	Eliminated	Sum Sq	F value	Pr(>F)
Mod_eHMI:NEU	1	0.0029	0.0018	0.9661
EXT:Mod_eHMI	2	0.0754	0.0475	0.8286
NEU	3	0.2642	0.1663	0.6856
Mod_eHMI:OPE	4	0.3205	0.2018	0.6557
OPE	5	0.5766	0.3611	0.5513
EXT	6	0.3191	0.1999	0.6572
Mod_eHMI:AGR	7	5.0620	3.1703	0.0826
AGR	8	0.5035	0.2922	0.5918
Mod_eHMI:CON	9	3.0621	1.7770	0.1901
CON	10	0.4445	0.2470	0.6219
Mod_eHMI	0	15.4809	8.6015	0.0055

Table 9: Fixed-Effects Elimination: CIT

In the model for crossing initiation time, all main effects of the personality traits could be eliminated without having a significant deterioration of the model (see table 9). A significant deterioration of the model was observed by eliminating the "Mod_eHMI" variable ($F(1, 40) = 8.6015, p = 0.0055$). Eliminating the random effect significantly degrades the model ($p=0.002147$), therefore the random effect should be considered in the simplified model. The simplified model for the Crossing Initiation Time is as follows:

$$BNBY_CIT \sim Mod_eHMI + (1|PNr) \quad (5)$$

4.4.4. Correlation Between Personality Traits and Pragmatic, Hedonic and Overall Quality

	Eliminated	Sum of Sq	F value	Pr(>F)
Mod_eHMI:OPE	1	0.0057	0.0073	0.93205
OPE	2	0.0511	0.0670	0.79650
Mod_eHMI:NEU	3	0.0702	0.0933	0.76091
NEU	4	0.3501	0.4717	0.49445
Mod_eHMI:CON	5	0.5527	0.7500	0.38934
EXT:Mod_eHMI	6	1.3340	1.8167	0.18188
EXT	7	1.3393	1.8040	0.18334
Mod_eHMI:AGR	8	1.3425	1.7891	0.18508
AGR	9	0.0209	0.0276	0.86849
Mod_eHMI	0	30.0125	40.0913	1.485e-08
CON	0	3.0825	4.1176	0.04589

Table 10: Fixed-Effects Elimination: Pragmatic Quality

In the case of Pragmatic Quality, the backward elimination of fixed effects shows that the main effects of CON and the presence of an eHMI have an impact on Pragmatic Quality (see table 10). The F-value of 4.1176 and the p-value of 0.04589 indicates that the elimination of "CON" leads to a significant change in the model fit ($F(1,40)=4.1176, p=0.04589$). This also applies to the

elimination of the main effect of "Mod_eHMI", which leads to an extremely high significant change with, $F(1,40) = 40.0913, p = 1.485e - 08$. There is no significant interaction effect between CON and Mod-eHMI ($F(1,40) = 0.75, p = 0.38934$). The p-value for the likelihood ratio test is 0.1323, which is above the usual significance level of 0.05. This means that the elimination of "(1 | PNr)" is not considered statistically significant. The simplified model for Pragmatic Quality is as follows:

$$BNBY_UEQ_Pra \sim Mod_eHMI + CON \quad (6)$$

	Elimated	Sum Sq	F value	Pr(>F)
Mod_eHMI:NEU	1	0.0765	0.1746	0.6783
Mod_eHMI:CON	2	0.0677	0.1538	0.6970
EXT:Mod_eHMI	3	0.0806	0.1823	0.6717
EXT	4	0.0007	0.0016	0.9686
CON	5	0.0986	0.2221	0.6400
NEU	6	0.1942	0.4374	0.5122
Mod_eHMI:AGR	7	0.3557	0.8013	0.3761
AGR	8	0.0123	0.0272	0.8698
Mod_eHMI:OPE	9	0.6713	1.4824	0.2305
OPE	10	0.3004	0.6397	0.4286
Mod_eHMI	0	10.1531	21.6204	3.588e-05***

Table 11: Fixed-Effects Elimination: Hedonic Quality

In the case of Hedonic Quality, the backward elimination of the fixed effects clearly shows that the main effects of the personality traits have no significant influence on Hedonic Quality. The simplified model $BNBY_UEQ_Hed \sim Mod_eHMI$ was chosen due to the significant improvement, with the F-value for the F-test in the reduced table ($F(1,40) = 21.6204, p = 3.588e - 05$) indicating the statistical significance of the remaining fixed effects (see table 11). Eliminating the random effect leads to a significant degradation of the model with $p=0.04554$, therefore the random effect should be considered in the simplified model. The simplified model for Hedonic Quality is as follows:

$$BNBY_UEQ_Hed \sim Mod_eHMI + (1|PNr) \quad (7)$$

For the overall Quality, which is calculated from the Hedonic and Pragmatic Quality combined, the elimination of the main effect of the "Mod_eHMI" variable also has a significant change in the model fit ($F(1,40) = 36.7513, p = 4.488e - 08$). The personality traits or their interaction effect with "Mod_eHMI" shows no significant change (see table 12). The p-value for the likelihood ratio test is 0.1307, which is above the usual significance level of 0.05. This means that the elimination of "(1 | PNr)" is not considered statistically significant. The simplified model for the Overall Quality is as follows:

$$BNBY_UEQ_Ove \sim Mod_eHMI \quad (8)$$

	Eliminated	Sum of Sq	F value	Pr(>F)
Mod_eHMI:CON	1	0.0099	0.0182	0.8932
Mod_eHMI:OPE	2	0.1136	0.2106	0.6477
Mod_eHMI:NEU	3	0.0609	0.1142	0.7365
NEU	4	0.0021	0.0040	0.9498
EXT:Mod_eHMI	5	0.0979	0.1886	0.6654
OPE	6	0.1007	0.1961	0.6592
EXT	7	0.5602	1.1030	0.2970
CON	8	0.7039	1.3840	0.2431
Mod_eHMI:AGR	9	0.8865	1.7344	0.1918
AGR	10	0.1017	0.1971	0.6583
Mod_eHMI	0	18.7695	36.7513	4.488e-08

Table 12: Fixed-Effects Elimination: Overall Quality

	Eliminated	Sum of Sq	F value	Pr(>F)
Mod_eHMI:CON	1	0.1143	0.1844	0.66992
Mod_eHMI:NEU	2	0.0983	0.1579	0.69321
NEU	3	0.0155	0.0248	0.87559
Mod_eHMI:OPE	4	0.3527	0.5643	0.45692
OPE	5	0.0011	0.0018	0.96648
EXT:Mod_eHMI	6	1.4847	2.3426	0.13375
EXT	7	2.0257	3.0193	0.08997
CON	0	4.3229	6.4432	0.01513
Mod_eHMI:AGR	0	3.5347	5.2684	0.02704

Table 13: Fixed-Effects Elimination: PEoU

4.4.5. Correlation Between Personality Traits and Perceived Usefulness and Perceived Ease of Use

In the case of the dependent variable perceived Ease of Use, the backward elimination of fixed effects shows that the independent variables of AGR, CON and Mod_eHMI have an impact on the PEoU (see table 13). The F-value of 6.4432 and the p-value of 0.01513 indicates that the elimination of the main effect "CON" leads to a significant change in the model fit ($F(1, 40) = 6.4432, p = 0.01513$). The same applies to the main effects of AGR and Mod_eHMI as well as the interaction effect between both of them ($F(1, 40) = 5.2684, p = 0.02704$). There is no significant interaction effect between "CON" and "eHMI" ($F(1, 40) = 0.1844, p = 0.66992$), therefore "CON:eHMI" is not included in the simplified model. It should also be noted that the main effect of EXT, with an F-value of 3.0193 and a p-value of 0.08997, almost significantly affected the model at elimination. Eliminating the random effect significantly degrades the model ($p=0.03484$), therefore the random effect should be considered in the simplified model. The simplified model for the perceived Ease of Use is as follows:

$$BNBY_PEoU \sim Mod_eHMI + AGR + CON + (1|PNr) + Mod_eHMI : AGE \quad (9)$$

In the case of the perceived Usefulness, the backward elimination of fixed effects shows that the independent variables of AGR, and the presence of an eHMI have an impact on Pragmatic

	Eliminated	Sum of Sq	F value	Pr(>F)
Mod_eHMI:OPE	1	0.0766	0.0911	0.764310
Mod_eHMI:NEU	2	0.3024	0.3588	0.552557
OPE	3	0.4582	0.5388	0.467192
NEU	4	0.7941	0.9338	0.339674
Mod_eHMI:CON	5	1.3619	1.6016	0.212997
CON	6	0.8814	0.9967	0.324123
EXT:Mod_eHMI	0	4.0646	4.5961	0.038178
Mod_eHMI:AGR	0	9.1390	10.3340	0.002584

Table 14: Fixed-Effects Elimination: PU

Quality (see table 14). It is evident that the main effects of AGR and Mod_eHMI as well as the interaction effect Mod_eHMI:AGR between the two variables ($F(1, 40) = 10.3340, p = 0.002584$) lead to a significant change in model fit. The same is the case for the main effects EXT and Mod_eHMI and their interaction effect EXT:Mod_eHMI ($F(1, 40) = 4.5961, p = 0.038178$). The main effect of EXT should be considered with caution, as no significant effect was found in the correlation matrices. It is assumed that the main effect of EXT appears in the simplified model due to the moderate relationship. Eliminating the random effect significantly degrades the model ($p=0.001744$), therefore the random effect should be considered in the simplified model. The simplified model for the perceived Usefulness is as follows:

$$BNBY_PU \sim EXT + Mod_eHMI + AGR + (1|PNr) + EXT : Mod_eHMI + Mod_eHMI : AGR \quad (10)$$

4.5. Interview

In the present study, an open-ended interview (see appendix A.3) was conducted to investigate whether the participants give different statements and prioritise different aspects depending on their personality profile. The previous results (correlation matrices and linear mixed effects model) indicated that certain factors for the perception of automated shuttle buses correlate with certain personality traits. However, the analysis of the interviews did not reveal any notable differences in the statements made by the participants depending on the level of a certain personality trait. Regardless of their personality profile, the participants said that Trust and the feeling of Safety could be influenced by the type of vehicle (smaller vehicles increase Trust and Safety), the presence of an eHMI (concepts with an eHMI increase Trust and Safety) and the distance at which the vehicle comes to a stop (vehicle stops further away from the participant increase Trust and Safety). These results suggest that other factors may have a greater influence on participants' priorities and that, despite different evaluation patterns of the influencing factors, they still see similar opportunities for improvement.

5. Discussion

In the discussion of this thesis, the results of the study are critically examined in the context of the research questions and hypotheses. This section contains a comprehensive reflection on the results obtained and compares them with the existing literature in order to better understand the overall context of the study. Each hypothesis is discussed in detail one by one. To better visualise the results, the relationship between personality trait and measured variable was presented as a plot for each hypothesis (see figures 12, 13, 14, 15). For a better interpretation of the results and the interaction effect of the eHMI, the connection was also shown once for the concepts with eHMI (as a whole line) and once for the concepts without eHMI (as a dashed line). The alternative hypotheses are then accepted, partly accepted or rejected. The research model is then revised and presented based on the actual results.

5.1. Impact of the Personality Traits on the Influencing Factor Trust

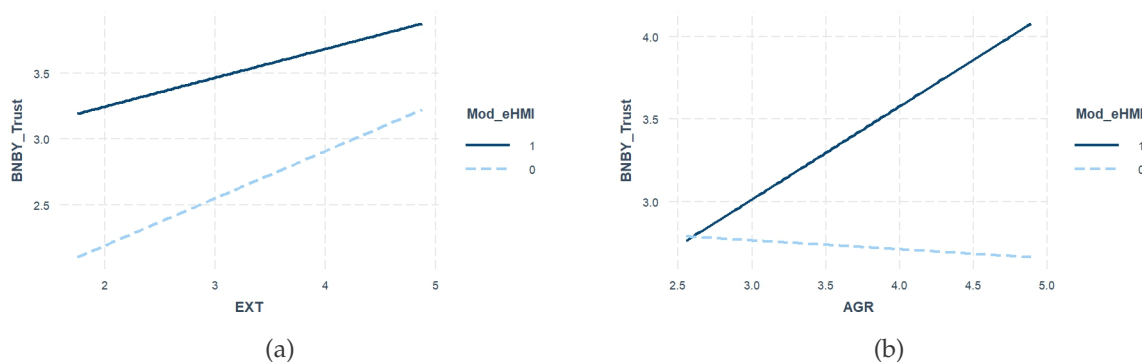


Figure 12: Exploration of Main and Interaction Effects on Safety: Two plots depict the impact of Extraversion (a) and Agreeableness (b) on Trust.

A significant positive correlation was found between Extraversion and Trust, suggesting that extroverts tend to have a higher level of Trust towards automated shuttle buses compared to introverts. This is also visible in the graph 12a, where both the concepts with and without eHMI show a positive slope between Extraversion and Trust. This is in agreement with the high level of confidence and enthusiasm attributed to Extraversion [62]. According to Behrenbruch et al. [19] this nature often results in an open-minded willingness to embrace new technologies, while less extraverted people often show reluctance and little interest in building Trust in new technologies. Other studies from other fields [19, 126], such as mobile applications and services, have also recognised this positive correlation. However, this correlation should be considered with care, as only a very small effect could be identified and the backward elimination also no longer includes the personality dimension Extraversion in the simplified model. Based on the present research, the alternative hypothesis **H1** can only be partially accepted.

The results of the correlation matrices indicate that there is a significant positive correlation between Agreeableness and Trust only for the concepts with an eHMI. This is also confirmed by the significant interaction effect of the eHMI from the linear mixed effects model. For the concepts without an eHMI, the interaction between Agreeableness and Trust even appears to be slightly negative, but this effect is not significant. These results can be visually seen in figure 12b. To summarise, we can confirm that people who tend to be agreeable when interacting

with an automated shuttle bus with an eHMI also have a higher level of Trust in the concept of the automated shuttle bus. Agreeable people place a high value on social interactions, helpful and cooperative behavior [62], which leads to the assumption that in terms of user interfaces, they are likely to prefer a user-friendly design with clear information that encourages positive interaction. The preference for a visual, well-designed interface and a centralised arrangement of information [89], such as the eHMI used in our study, could indicate that the concept with the eHMI is perceived as more accessible and collaborative. This suggests that agreeable people may place more Trust in a user interface that supports their social needs and has a better communication interface. Based on the results, the alternative hypothesis **H2** can be accepted.

5.2. Impact of the Personality Traits on the Influencing Factor Safety

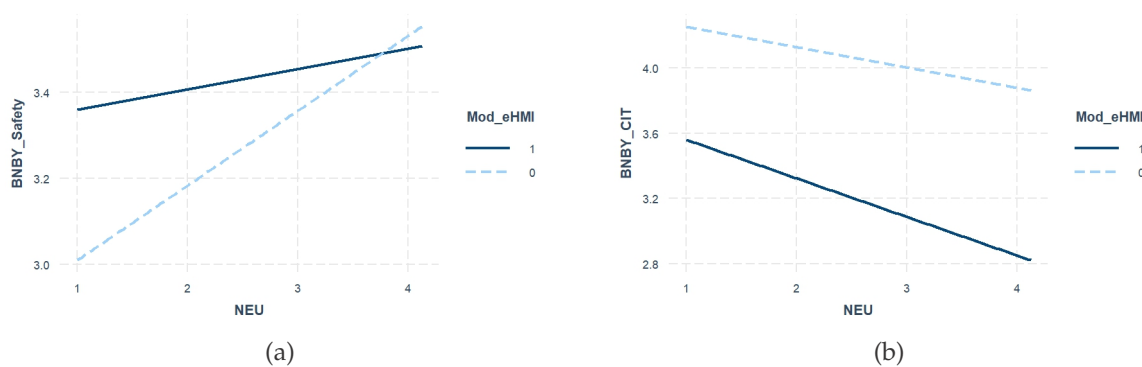


Figure 13: Exploration of Main and Interaction Effects on Safety: One plot depict the impact of Neuroticism on the perceived Safety (a). Another plot depict the impact of Neuroticism on the Crossing Initiation Time (b).

Surprisingly, Neuroticism and the perceived Safety did not show a significant correlation. Also unexpected is the (non-significant) tendency for the concept without eHMI in figure 13a, which shows that the more neurotic a person is, the higher they rate the feeling of Safety in the situation. This speaks against our hypothesis, although literature suggests that neurotic people tend to be more stressed [123] or feel insecure more quickly in many situations [18]. An explanation for the results of this study could be that the fear of social interaction with a human driver [117], as is the case with non-automated vehicles, outweighs the fear of failure with new technologies. However, further research is needed in future studies to investigate this in more detail. It was also unexpected that the Crossing Initiation Time did not show a significant correlation with Neuroticism (see figure 13b). Especially as Lommen et al. [79] have already found that people with a high level of Neuroticism prefer to be cautious rather than feel regret later, especially in the case of imminent danger, to which the tested scenario of crossing the road may also belong. A possible explanation for the result could be that crossing the road in a simulated environment is not perceived as an immediate danger. Neurotic people may therefore have behaved differently in the experiment than in a real situation. The current findings and data led to the rejection of both the alternative hypotheses for **H3** and **H4**. This indicates that the initially assumed deviations or effects were not proven to be statistically significant, but further studies should be conducted in a real environment.

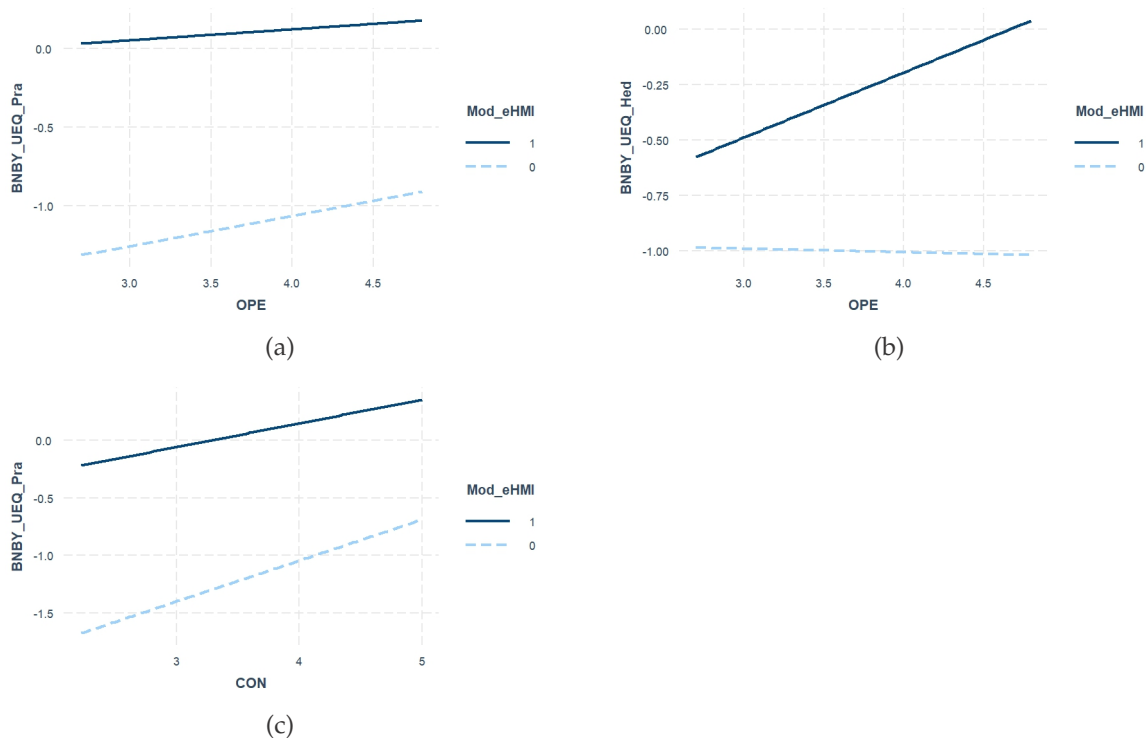


Figure 14: Exploration of Main and Interaction Effects on User Experience and Usability: Two plots depict the impact of Openness to Experience (a) and Conscientiousness (c) on the Pragmatic Quality. Another plot depicts the impact of Openness to Experience (b) on the Hedonic Quality.

5.3. Impact of the Personality Traits on the Influencing Factor Usability and User Experience

It was unexpected to find that Openness (to Experience) did not significantly influence neither the Pragmatic nor the Hedonic Quality of the automated shuttle bus. It was expected that people with a high level of Openness, who are described as intelligent, curious and interested in many things [62], would tend to rate the useful, functional, aesthetic and emotional aspects of automated shuttles more highly, as they are generally more open to new technologies. The graphs for the Pragmatic Quality (see figure 14a) and the Hedonic Quality (see figure 14b) clearly reaffirm this point. There is hardly any noticeable incline. Therefore, the alternative hypotheses for both **H5** and **H6** could be rejected based on the available data and results, indicating that the originally hypothesised deviations or effects were not statistically significant. This is in contrast to the study by Kortum et al. [93], which found a positive correlation between Usability and Openness to Experience. In this case, the literature does not provide an explanation for this observation. This could mean that the present study makes a contribution to a less researched area and offers new insights. It may be necessary to conduct additional research to increase understanding of the underlying interactions. Furthermore, sample variation or sample size could also have an influence.

The results of our correlation matrix indicate that we found a significant correlation between Conscientiousness and Pragmatic Quality, but only for the concept without eHMI. The graph 14c also shows a greater increase for the concept without eHMI, which indicates a greater main

effect between Conscientiousness and Pragmatic Quality. The simplified model also indicated a significant main effect, but not a significant interaction effect. There is a possibility that the actual relationship between the variables is more complex than assumed in the linear model. The correlation matrix could provide evidence of these relationships that are not captured by the interaction effect in the linear model. In the study on the design of graphical user interfaces based on Conscientiousness, Alves et al. [12] found no significant correlation between the personality dimension of Conscientiousness and perceived Usability. However, they did find differences between the preferences of the user interface. For example, people with low Conscientiousness tend to prefer the user interface designed for them, while people with high Conscientiousness prefer the interface customised for their needs. This would confirm the idea that the chosen interface of the eHMI has an high influence on the correlation between Conscientiousness and Pragmatic Quality despite the non-significant result of the interaction effect in backward elimination. The correlation matrices also indicate that although there is no significant correlation between the measured Pragmatic Quality for the concept with an eHMI and Conscientiousness, there is a significant correlation between the measured Pragmatic Quality for the concept with no eHMI and Conscientiousness. Based on the present results, we can assume that conscientious people rate the Pragmatic Quality of automated shuttle buses without eHMI higher than people with a low level of Conscientiousness. We can therefore accept the alternative hypothesis **H7**.

5.4. Impact of the Personality Traits on the Influencing Factor Technology Acceptance

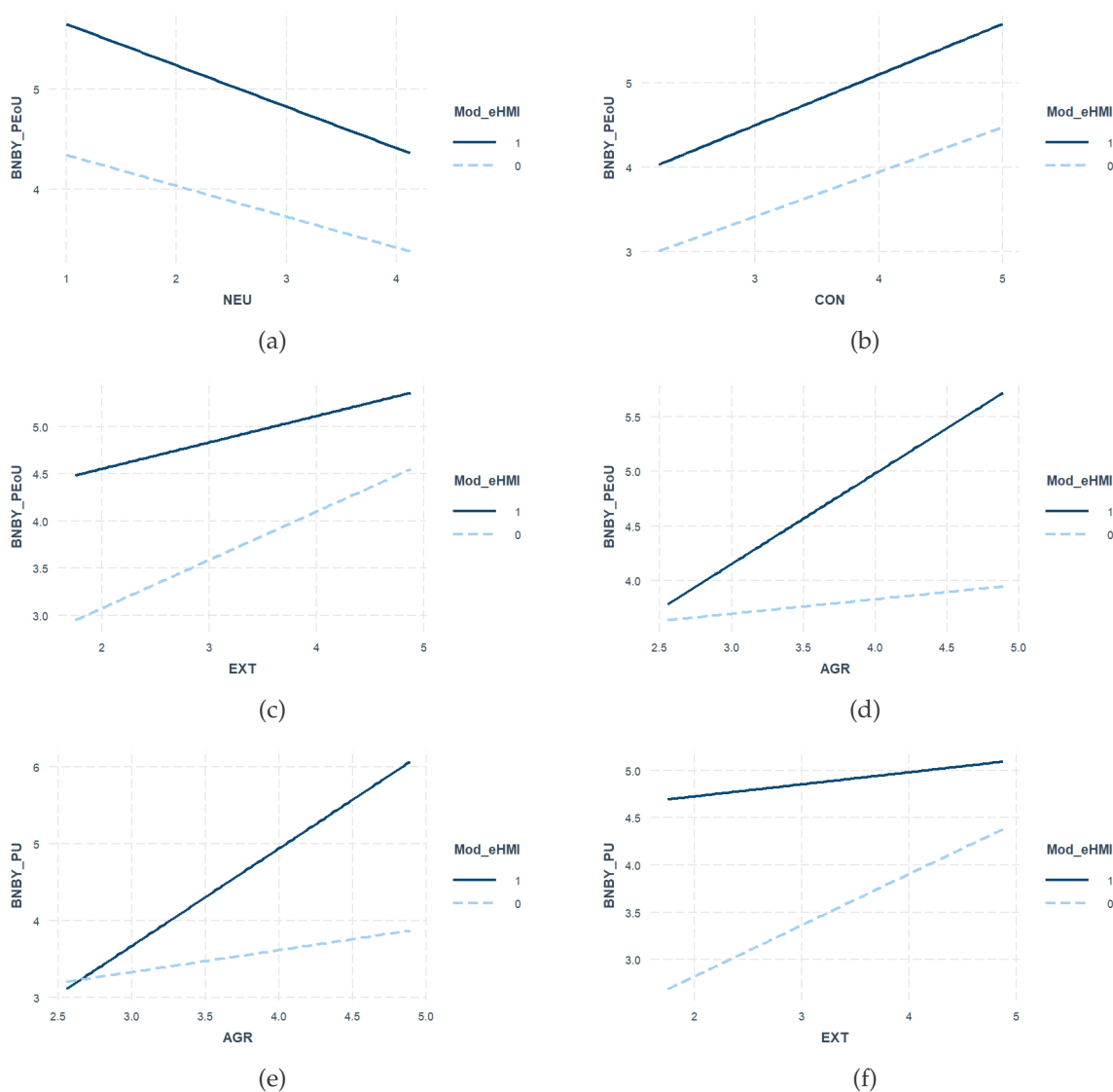


Figure 15: Exploration of Main and Interaction Effects on User Experience and Usability: Four plots depict the impact of Neuroticism (a), Conscientiousness (b), Extraversion (c) and Agreeableness (d) on the perceived Ease of Use. Two Plot depict the impact of Agreeableness (e) and Extraversion (f) on the perceived Usefulness.

The results of the correlation matrix indicate a negative, significant effect between Neuroticism and perceived Ease of Use for both concepts (with and without eHMI). This is also clearly visible in the graph 15a, as both lines run almost parallel downwards. Backward elimination also indicated no significant interaction effect. It can therefore be assumed that the presence of an eHMI has no influence on the relationship between Neuroticism and perceived Ease of Use. It is also worth mentioning that in the simplified model, the main effect of Neuroticism did not show any significant deterioration when the variable was removed. Nevertheless, the graph and correlation matrix indicate a significant effect. It is possible that the simplified model does

not have sufficient statistical power to detect a significant effect, which can be seen in the graph and the correlation matrix. The literature also supports the hypothesis that there is a negative correlation between Neuroticism and perceived Ease of Use. Studies such as Salam et al. [106] or Qu et al. [96] also show a negative effect of Neuroticism on perceived Ease of Use in the context of technologies and systems. This is due to the fact that people with neurotic personality traits often quickly experience frustration and depression when confronted with new challenges [26] and generally interact more anxiously and insecurely than people who are emotionally stable [62]. This also affects their perception of technologies. It is therefore not surprising that we found in our study that the more neurotic a person is, the lower they rate the perceived Ease of Use during interaction and communication with an automated shuttle bus. Based on the data and the supporting literature, the alternative hypothesis **H8** can be accepted.

A very high positive and significant correlation was found between perceived Ease of Use and Conscientiousness. Both the results of the correlation matrices and the backward elimination, which would estimate the perceived Ease of Use model as significantly worse without taking into account the direct main effect of Conscientiousness, point to this. A significant interaction effect between the sense of responsibility and the presence of an eHMI could not be found, so the presence of an eHMI does not appear to have any influence on the relationship between perceived Ease of Use and Conscientiousness. These findings are also visible in the graph 15b. In this context, a positive correlation between perceived Ease of Use and Conscientiousness suggests that users who perceive the technology as easy to use may also have a higher propensity to interact with these technologies responsibly and safely and tend to behave responsibly when crossing the road. It could also be an indicator that users who have a conscious and responsible behavior will find the technology easy to use. One reason for this could be that people with a high score in Conscientiousness tend to have a goal-oriented and responsible behavior [62], which could lead to a more efficient and positive interaction with the technology. This, in turn, enhances the overall perceived Ease of Use. This is in agreement with the work by Digman et al. [31], who referred to the personality dimension of Conscientiousness as "Will to Achieve", as this dimension correlated consistently and notably with educational achievements. Barrick et. al [17] work, also came to the conclusion that people with a high level of Conscientiousness were better at performing tasks. Based on the results, we can accept the alternative hypothesis **H9**.

Ease of learning is inversely related to the amount of risk (such as the risk of failure) associated with the decision to learn or use a new technology. The easier a potential user perceives the system to be, the lower they perceive the risk associated with attempting to learn [80]. People with a high level of Extraversion are adventurous, active and ethustatic people with a high level of self-esteem [100, 41]. They also tend to rate systems and technologies as easy to use, regardless of how they rate the overall level of complexity of these things [11]. This in turn suggests that they are more likely to engage with new technologies and systems than introverts. This is also reflected in the results. The correlation matrix shows a positive and significant correlation between Extraversion and perceived Ease of Use. This indicates that higher level of Extraversion tends to be associated with higher perceived Ease of Use. The slope of the lines depicted in the graph 15c also indicates a stronger effect. Also noticeable is the slightly steeper slope for the concept without eHMI. However, the results of the backward elimination showed that Extraversion was removed from the model for perceived Ease of Use. This could indicate that the inclusion of Extraversion in the simplified model did not make a significant contribution to the explanation of perceived Ease of Use compared to other variables. Nevertheless, it should not be ignored that Extraversion was rated slightly below the significance threshold. The value

just below the significance threshold could indicate sample fluctuations. The statistical analysis leads to the partial acceptance of **H10**. No significant correlation was found in the correlation matrix between Extraversion and perceived Usefulness. Nevertheless, the graph 15f suggests that Extraversion has a strong effect on perceived Usefulness, but only for the concepts without eHMI. It is also noticeable from the backward elimination that removing the interaction effect in this context leads to a significant deterioration of the model. Summarising, it can be said that the presence of an eHMI leads to a decrease in the correlation between Extraversion and perceived Usefulness. In this way, the statistical analysis leads to the partial assumption of **H13** which should be investigated in more detail in further studies.

The correlation matrices show that Agreeableness has a significant correlation with both perceived Ease of Use and perceived Usefulness. The simplified model of perceived Ease of Use and perceived Usefulness also shows that ignoring the main effect of Agreeableness leads to a significant deterioration of the model. Not to be neglected is also the significant interaction effect in the backward elimination of how the eHMI affects the relationship between Agreeableness and perceived Ease of Use and perceived Usefulness. This becomes even more obvious when looking at the graphs of perceived Ease of Use (see figure 15d) and perceived Usefulness (see figure 15e). In both models, the slope is significantly steeper for the automated shuttle bus concept with an eHMI, which indicates a stronger effect between Agreeableness and perceived Ease of Use as well as perceived Usefulness. The correlation matrices also show a significantly higher effect for the concept with eHMI. Nevertheless, the correlation between Agreeableness and perceived Usefulness appears to be slightly less influenced by the moderation variable of eHMI. Summarising, it can be said that people who tend to be agreeable see the automated shuttle bus with an eHMI as easier to use than people with a low level of Agreeableness. At the same time, people with a high level of Agreeableness generally see the technology of the automated shuttle bus as a practical, beneficial and useful technology compared to people who are less agreeable. This effect is reinforced by the presence of a suitable eHMI. This is in agreement with the literature, which states that people with high levels of Agreeableness often value harmony, collaboration and supporting social interaction [62]. The positive correlation between Agreeableness and Acceptance has also been confirmed in other areas [126, 95], which is consistent with our results. In terms of user interfaces, this could mean that they are more likely to prefer a design that is user-friendly, provides clear information and encourages positive interaction. The preference for a communication-enhancing eHMI, such as the lightband used, could be due to the fact that such a design is perceived as more accessible and collaborative [89]. In summary, it can be confirmed that **H11** and **H12** are both accepted.

5.5. Revision of the Research Model

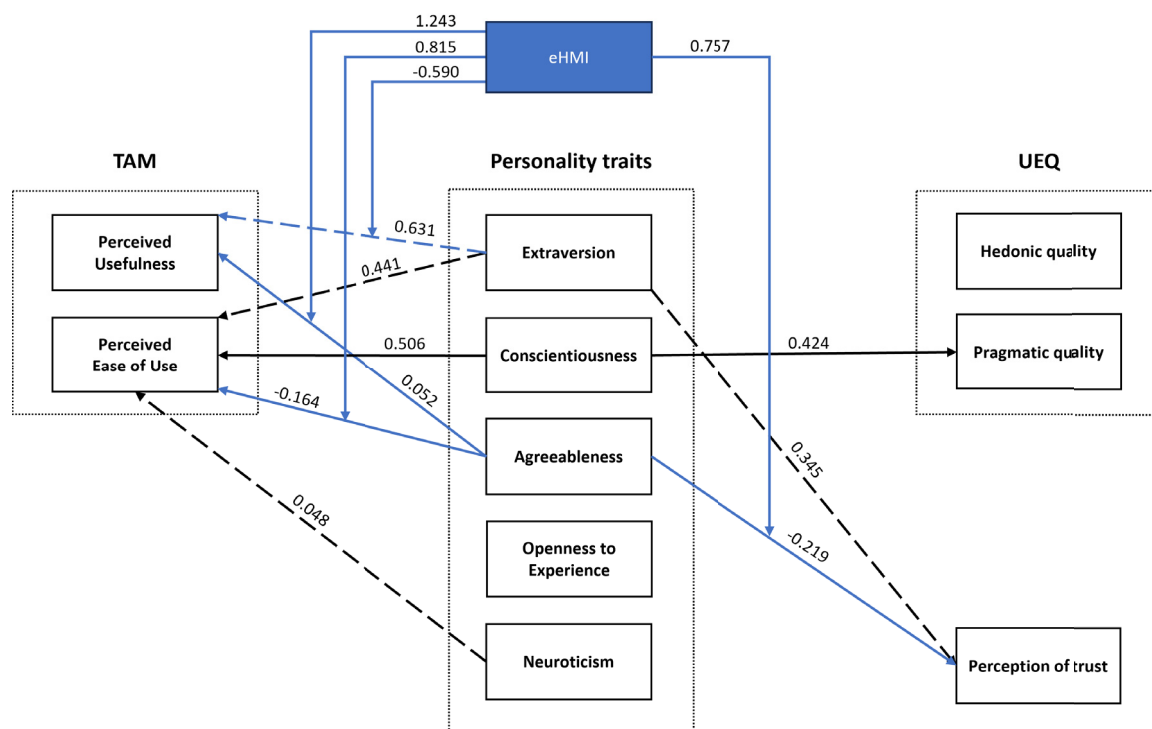


Figure 16: Research model with unstandardised Estimates (from the simplified model). Moderator variables are shown with an arrow pointing to the influenced relationship. Solid lines are fully accepted hypotheses. Dashed lines are partially accepted hypotheses.

Based on all results (correlation matrices and the linear mixed-effects models), the research model derived from the hypotheses was revised using the actual results. A graphical representation of the results with the unstandardised estimates (from the simplified model) in relation to our hypotheses is shown in figure 16. Hypotheses that are fully accepted are shown with a solid line, while partially accepted hypotheses are shown with a dashed line. A moderation by the eHMI is represented by an arrow pointing to the influenced relationship. The fully accepted hypotheses showed a significant result for both the correlation matrix and backward elimination. The partially accepted hypotheses indicated that a significant correlation was only found in the correlation matrix, but that these did not occur in the simplified model after backward elimination. One exception is the correlation between Extraversion and perceived Usefulness. Here, the interaction effect and the main effect were shown to be significant in the backward elimination, but no significant correlation was found between the two variables in the correlation matrix. Table 15 summarises the main results of all analysis methods.

Path	Linear mixed effects model		Correlation matrix			Hypotheses results
	Regression Estimates (from simplified model)	In the simplified model	Correlation coefficients from BN	Correlation coefficients from BY	Correlation coefficients from BNB	
EXT→Trust		N			0.23*	H1 partly supported
AGR→Trust	-0.054	Y		0.42**		H2 supported
AGR:Mod_eHMI→Trust	0.616	Y				
NEU→Safety		N				H3 rejected
NEU→CIT		N				H4 rejected
OPE→PRA		N				H5 rejected
OPE→HED		N				H6 rejected
CON→PRA	0.280	Y	0.31*			H7 supported
NEU→PEoU		N			-0.22*	H8 partly supported
CON→PEoU	0.484	Y	0.35*	0.35*	0.32**	H9 supported
EXT→PEoU		N			0.24*	H10 partly supported
AGR→PEoU	-0.029	Y		0.42**		H11 supported
AGR:Mod_eHMI→PEoU	0.697	Y				
AGR→PU	0.145	Y		0.46**	0.24*	H12 supported
AGR:Mod_eHMI→PU	1.147	Y				
EXT→PU	0.516	Y				H13 partly supported
EXT:Mod_eHMI→PU	-0.614	Y				

Table 15: EXT=Extraversion; AGR=Agreeableness; OPE=Openness to new Experience; CON=Conscientiousness; NEU=Neuroticism; PU=Perceived Usefulness; PEoU=Perceived Ease of Use; UEQ_Hed=Hedonic Quality; UEQ_Pra=Pragmatic Quality; CIT=Crossing Initiation Time; :Mod_eHMI=Moderation with eHMI. Y=Yes; N=No. BN=Dataset bus without eHMI. BY=Dataset bus with eHMI. BNB=Dataset bus with and without eHMI. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.

6. Conclusion

This section addresses the summary of the findings, the outlook for future studies and the identification of the limitations encountered in the research. The summary of the findings critically analyses the research and highlights possible implications and connections. The outlook for future studies outlines potential research directions and in-depth approaches to broaden the understanding of the topic. Furthermore, the identified limitations of the study are analysed in detail in order to transparently present the limitations of the study and discuss possible consequences for the interpretation of the results.

The present work focused primarily on the impact of personality in the context of the interaction, perception and communication between a person and an automated shuttle buses. In order to measure a construct as complex as personality, we used the standardised Big Five with the five personality dimensions: Openness (to experience), Conscientiousness, Extraversion, Agreeableness, Neuroticism. This model has already proven its validity in various technological areas [16, 59, 106]. We conducted a user study with 40 participants that simulated the interaction of the participants with an automated shuttle bus during a road crossing scenario in a virtual environment. This was followed by an investigation of the correlations between personality traits and factors influencing the perception and attitude towards automated shuttle buses. We also analysed the moderate influence of the presence of an eHMI in relation to the correlation between personality trait and measurement variable. A total of 13 hypotheses were formulated, while four hypotheses had to be rejected, four partially accepted and five fully accepted. The user studies have shown that there is a significant correlation between some personality traits and the influencing factors of Trust, Usability and Acceptance. No significant correlation was identified between the personality traits and the User Experience (especially in terms of Hedonic Quality). The same applies to the perception of Safety. Four significant interaction effects were found where the presence of an eHMI influenced the correlation between personality trait and measurement variable. In relation to the research question, this means that the personality of the user is a non-negligible factor in the evaluation of the perception and attitude of automated shuttle buses. With regard to the influencing factors, this means the following:

From the literature it is known that people who rate perceived Ease of Use and perceived Usefulness of a technology very highly are also more likely to accept and use it immediately [56]. Based on the results of this study, it can be deduced that people with high levels of Agreeableness, Extraversion and Conscientiousness are more likely to approve of the automated shuttle bus, while Neuroticism has a negative impact on technology Acceptance. This is in agreement with studies from the literature investigating technology Acceptance [96, 126, 106, 17], which in other contexts have also found a positive correlation between Agreeableness, Extraversion and Conscientiousness and found a negative correlation with Neuroticism.

Considering the influencing factor "Trust", there is a positive correlation with people who have a high level of Agreeableness and Extraversion. This is also strongly supported by the literature. The study from Jacques et al [59] and Zhou et al. [126] found that people with a high level of Extraversion and/or Agreeableness have a positive propensity for Trust. People with high Extraversion tend to be open and sociable, while agreeable people are characterised by their friendliness and willingness to cooperate. Both traits are characterised by strong communication skills, which in turn could make a positive contribution to strengthening Trust by promoting clear and positive communication.

With regard to Usability, which we measured by looking at Pragmatic Quality, we can only find a correlation with the personality trait of Conscientiousness. Interestingly, there are also studies that speak against these results, for example Alves et al. [12] found no significant correlation between the personality dimension of Conscientiousness and perceived Usability. However, the study by Alves et al. [12] also showed that the design of the human-machine interface can have a major influence on how conscientious people perceive it. Which in turn suggests that it can be very context-dependent. As Usability can be seen as part of the User Experience, it would be reasonable to assume that conscientious people would also rate the User Experience more positively. However, no significant correlation was found for Hedonic Quality (the emotional aspect of the User Experience). Therefore, it is advisable to approach this assumption carefully.

Agreeableness is the only personality trait for which the presence of an eHMI shows a clear moderating influence on the correlation with the measurement variables. Regarding this, the relationship between Agreeableness and the measurement variable was either strongly strengthened into a positive correlation when an eHMI was present, or was showing an effect only when an eHMI was present. Al-Samarraie et al. [10] analyzed eye movement predictors to investigate individual preferences for visual design elements in relation to personality dimensions. In particular, the predictive accuracy of Agreeableness and Conscientiousness varied between trials. This suggests that people with these personality traits could be strongly influenced by the characteristics of the visual design elements. Agreeable people may be naturally more open to using new technologies, especially if these technologies help to enhance communication [62]. This in turn could be an explanation for the moderate effect of eHMI on Agreeableness. In the case of Extraversion, a moderate effect could only be seen in the relationship in connection with perceived Usefulness, although this was very small in comparison to Agreeableness. All other personality traits did not appear to show a significant interaction effect, which in turn leads to the conclusion that the correlation between these personality traits and the measurement variables is not influenced by the presence of an eHMI.

6.1. Significance and Future Prospect

We were able to confirm that four of the five dimensions of the Big Five have a significant influence on how people experience the interaction with an automated shuttle bus. Particularly with regard to Trust, Usability and Acceptance, these personality dimensions have a recognisable impact on the perception and evaluation of these factors. The insights gained from this research represent a significant step towards adapting technologies even more precisely to the different personality profiles of users. These findings can enrich many different areas of application and have the potential to improve our understanding not only of human personality models, but also of people's interaction with technology. The areas of application discussed are examined in more detail below:

Personalised User interface design The results of the study could help to design user interfaces for automated shuttle buses that are designed to satisfy a specific need. By precisely adapting the technologies to specific personality traits, assistance is offered for those factors where there is an obvious necessity. These adaptations take particular account of factors that have a strong positive or negative correlation with individual personality profiles to ensure an optimal User Experience.

Encourage understanding of other studies Understanding the influence of personality and integrating this into future studies could help to understand inconsistencies between studies. For example, the sample of participants with an unbalanced distribution of a personality trait could be the reason why results differ. This could also be relevant for studies with a between-subjects design.

Defining appropriate requirements for automated shuttle buses Understanding the relationship between personality traits and influencing factors helps to develop more effective requirements and better measures that promote Acceptance, Trust and other factors in automated shuttle services. This could help the integration of such technologies into society.

Psychological insights into human-machine interaction The study could also contribute to the overall understanding of the psychological aspects of human-machine interaction. Furthermore, it can strengthen theoretical models that explain the relationship between personality traits and automated vehicles.

For future studies, it would be interesting not only to look at single personality traits, but also to examine the combination of several personality characteristics. It can be assumed that this would make the prediction even more precise, as the interaction of several personality traits could have its own dynamics. Furthermore, this is closer to reality, as a person does not have just one trait per personality, but several personality traits with different levels of expression. In the context of this Master's thesis, it would have been too extensive to analyze the influence of multiple personality traits with each other and the other factors. Nevertheless, the work already lays a solid foundation and provides insights into which personality traits could be considered useful as a combination.

6.2. Limitations

Although this master's thesis provides significant insights into the topic, it is important to recognise the limitations associated with it. Understanding the limitations is important for a proper understanding of the scope and interpretation of the results. The present work is a VR study that simulates a realistic environment without exposing the participants to real danger. However, the awareness of a danger-free situation could lead the participants to interact differently than in a real situation. Nevertheless, the virtual CAVE is one of the best ways to create an immersive environment that comes very close to a real situation. In order to minimise this effect, the participants were told in advance that they should react as they would in real life, even though it was a simulation.

A further limitation resulted from the limited sample size of the study, which was also due to the VR study. In accordance with common standards and the guidelines of the research literature, a power analysis was performed with a power of 0.8. This power allows the detection of effects of medium size and is considered a suitable measure of the statistical strength of a study. Unfortunately, due to resource constraints and other practical challenges, it was not possible to achieve the recommended number of participants for small (616 participants) and medium (67 participants) effects at a power of 0.8. However, with a sample size of 40 participants, this was still well above the recommended number for larger effects (23 participants). The calculated sample size illustrates that the study may not be able to detect smaller effects that could be detected by a larger number of participants. A survey study would be more suitable for such an investigation than a VR study. However, this compromise was consciously accepted, as a

higher value was placed on immersion. A conscious decision was therefore made to accept the limitation of smaller effects.

It should also be noted that in this study we focused exclusively on the dimensions of the Big Five (Openness to Experience, Conscientiousness, Extraversion, Agreeableness, Neuroticism) and ignored other well-known personality models and attributes, such as Self-awareness, Self-Efficacy, Technology Affinity or Need for Achievement. Nevertheless, the Big Five were chosen because they have been rarely used in the automotive sector, while other personality-related data can be taken from the metadata of other studies. However, these additional personality dimensions could have a significant impact on the models of factors influencing positive attitudes towards automated vehicles. It would be advisable to explore the interactions between these and other factors in subsequent studies in order to gain a comprehensive insight into the general communication and influencing factors.

Despite these limitations, the study recognises the importance of its findings and strives to provide valuable insights. A comprehensive description of the results and the use of appropriate methods ensure a thorough and detailed analysis. The outlook suggests possible follow-up studies or extensions that could build on the results of this study. They could specifically help to address the gap in research investigating how personality has an impact on the communication with automated vehicles.

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A. Appendix

A.1. User Experience Questionnaire (Short Version)

Items of the short version of the User Experience Questionnaire (UEQ)

This document lists the items and their order for all the available languages of the UEQ.

English version

obstructive	o o o o o o o	supportive
complicated	o o o o o o o	easy
inefficient	o o o o o o o	efficient
confusing	o o o o o o o	clear
boring	o o o o o o o	exciting
not interesting	o o o o o o o	interesting
conventional	o o o o o o o	inventive
usual	o o o o o o o	leading edge

A.2. Big Five Inventory

Scale:

The Big Five Inventory (BFI)

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

Disagree strongly 1	Disagree a little 2	Neither agree nor disagree 3	Agree a little 4	Agree Strongly 5
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I see Myself as Someone Who...

- | | |
|--|--|
| ___ 1. Is talkative | ___ 23. Tends to be lazy |
| ___ 2. Tends to find fault with others | ___ 24. Is emotionally stable, not easily upset |
| ___ 3. Does a thorough job | ___ 25. Is inventive |
| ___ 4. Is depressed, blue | ___ 26. Has an assertive personality |
| ___ 5. Is original, comes up with new ideas | ___ 27. Can be cold and aloof |
| ___ 6. Is reserved | ___ 28. Perseveres until the task is finished |
| ___ 7. Is helpful and unselfish with others | ___ 29. Can be moody |
| ___ 8. Can be somewhat careless | ___ 30. Values artistic, aesthetic experiences |
| ___ 9. Is relaxed, handles stress well | ___ 31. Is sometimes shy, inhibited |
| ___ 10. Is curious about many different things | ___ 32. Is considerate and kind to almost everyone |
| ___ 11. Is full of energy | ___ 33. Does things efficiently |
| ___ 12. Starts quarrels with others | ___ 34. Remains calm in tense situations |
| ___ 13. Is a reliable worker | ___ 35. Prefers work that is routine |
| ___ 14. Can be tense | ___ 36. Is outgoing, sociable |
| ___ 15. Is ingenious, a deep thinker | ___ 37. Is sometimes rude to others |
| ___ 16. Generates a lot of enthusiasm | ___ 38. Makes plans and follows through with them |
| ___ 17. Has a forgiving nature | ___ 39. Gets nervous easily |
| ___ 18. Tends to be disorganized | ___ 40. Likes to reflect, play with ideas |
| ___ 19. Worries a lot | ___ 41. Has few artistic interests |

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___20. Has an active imagination

___21. Tends to be quiet

___22. Is generally trusting

___42. Likes to cooperate with others

___43. Is easily distracted

___44. Is sophisticated in art, music, or literature

Scoring:

BFI scale scoring (“R” denotes reverse-scored items):

Extraversion: 1, 6R, 11, 16, 21R, 26, 31R, 36

Agreeableness: 2R, 7, 12R, 17, 22, 27R, 32, 37R, 42

Conscientiousness: 3, 8R, 13, 18R, 23R, 28, 33, 38, 43R

Neuroticism: 4, 9R, 14, 19, 24R, 29, 34R, 39

Openness: 5, 10, 15, 20, 25, 30, 35R, 40, 41R, 44

A.3. Interview Questions



This is the third part of this study.

Please answer the following questions thoughtfully, and your responses will contribute to a better understanding of this subject. Thank you for your participation.

If you have any questions: alice.rollwagen@carissma.eu

Section A: Number of participant

- A1. Please enter the participant number you received from your experimenter.

Section B: Interview

- B1. Would you feel safer with a human driver? Please explain your answer.

Yes

No

No Answer

- B2. How strongly do you agree with the following statements (1 - strongly disagree, 7 - strongly agree):

1 - Strongly disagree 2 - Moderately disagree 3 - Somewhat disagree 4 - Neither disagree nor agree 5 - Somewhat agree 6 - Moderately agree 7 - Strongly agree

I feel safer when a human drives the shuttle bus.

- B3. Did you feel safer crossing the road when the vehicle was communicating with a Light Band? Please explain your answer.

Yes

No

No Answer



[Empty rectangular box for response]

B4. Can you explain to what extent the Light Band creates positive experiences such as joy or satisfaction?

[Empty rectangular box for response]

B5. Could the intention of the automatic vehicle be better visualized? If so, how?

[Empty rectangular box for response]

B6. What could increase trust for you in the scenario shown earlier (road crossing)?

[Empty rectangular box for response]

B7. What could increase acceptance for you in the scenario shown earlier (road crossing)?

[Empty rectangular box for response]

A.4. Data carrier