Proceedings of the Design Society, Volume 5: ICED25
https://doi.org/10.1017/pds.2025.10103

Challenges experienced by disabled people when traveling on and interacting with an autonomous bus

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ABSTRACT: Traveling on and interacting with an autonomous bus confronts disabled passengers with a handful of different and unknown challenges in terms of accessibility. To address this, a user journey was developed that includes the challenges for disabled passengers when traveling and interacting with an autonomous bus. The user journey provides a chronological list of occurring challenges for passengers with a disability. With the help of three qualitative studies in which four bus operators, ten bus drivers and 25 disabled passengers participated, the challenges of the user journey could be identified and some important requirements for possible solutions could be determined. By identifying the challenges, solutions can now be developed so that disabled passengers can travel on an autonomous bus and therefore the accessibility of autonomous buses can be increased.

KEYWORDS: user centred design, social responsibility, inclusive design, accessibility, public transport

1. Introduction

The topic of more efficient public transport is being studied worldwide, especially with regard to increasing its attractiveness compared to individual transport (Hirschhorn et al., 2020). In order to increase the attractiveness of public transport, a diverse and well-developed public transport network is required. In Germany, this aim is countered by the fact that there is a steadily growing shortage of qualified personnel in the public transport sector. This means that it is not possible to increase the number of vehicles in operation at any one time, as the drivers needed to drive the vehicles are not available (Buehler et al., 2024). Due to this shortage of bus drivers, the public transport network can only be improved through more efficient transport and connection planning. The increasingly efficient planning of public transport means that public transport vehicles are being used to ever greater capacity, as this is the only way to counteract the shortage of bus drivers. However, this makes the system more vulnerable to errors or failures that occur in a single vehicle, as the consequences are greater due to the high capacity utilization (Berdica, 2002).

This challenge is further exacerbated by the German government's new requirements for public transport. Among other things, the German government has determined that the public transport network must be extended to rural regions or be improved in such a way that reliable access is also available there, with a view to replacing individual transport in the future. In addition, public transportation is to be operated in an entirely accessible manner in the future (Kock, 2004). Because of these new requirements, the constantly growing shortage of bus drivers, the very high efficiency already being achieved in planning, and the associated vulnerability of the transportation system, new solutions which meet these requirements must be developed.

One approach to meeting the need for increased levels of accessibility in public transport and the expansion of this network involves autonomous electric buses, which can be used independently of the limits of a human driver (Federal Ministry for Digital and Transport (BMDV), 2024). Buses that can drive autonomously according to the SAE level 4 standard are better able to connect rural regions to the public transport network without having to build rails or tunnels first (BMDV, 2024). However, the use of such autonomous buses not only creates new opportunities, but also new challenges. In particular, new challenges arise in relation to the interaction of these autonomous buses with passengers and pedestrians. Such challenges are mostly due to the elimination of the driver, who has long assumed an important role in the interaction with passengers and pedestrians. (Seredynski et al., 2023)

In view of the need for accessible public transport, particular attention must be paid to passengers with disabilities and pedestrians who are currently dependent on the driver's assistance. For example, a wheelchair user has to ask the driver of a bus to unfold the manual ramp so that they can get on the bus and a blind passenger must ask the bus driver which bus they is boarding. Ultimately, the interaction must be rethought and solved with the help of new solutions in order to meet the legal requirement of accessible public transport.

For this reason, the challenges posed by the use of autonomous buses in public transport, especially for people with disabilities, must be identified so that they can then be systematically resolved in the future. The objective of this paper is therefore to identify the upcoming challenges that will be faced by passengers, especially those with disabilities, and to validate these challenges via interviews with experts and qualitative studies. Further analysis will be carried out to find out how these challenges can be solved. The research question is as follows: *What challenges arise when a disabled passenger wants to travel on an autonomous bus and what basic requirements must be met from the autonomous bus to solve these challenges?*

2. State of the art for disabled persons and autonomous buses

In order to identify the challenges of a disabled passenger when traveling with an autonomous bus, the individual terminologies must first be defined.

The United Nations Convention on the Rights of Persons with Disabilities has the following definition of persons with disabilities in Article 1 (UN, 2006, p. 4) of its Protocol:

> *"Persons with disabilities include those who have long-term physical, mental, intellectual or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others."*

This definition already provides several different types of impairments that people with disabilities may have and which may limit them when interacting with an autonomous bus. This categorization is further detailed by the Association of German Transport Companies (VDV, 2012) by differentiating between physically disabled, visually impaired, hearing impaired and cognitively and mentally impaired passengers. In addition, the VDV also considers people who are temporarily restricted in their mobility due to special circumstances, such as having a cast on their foot. This is referred to as mobility-impaired "in the broader sense", while the mobility impairments described above are referred to as "in the narrower sense". According to the VDV, these types of disability should be considered for an accessible vehicle, which is why this categorization is considered in the following. (VDV, 2012)

Autonomous vehicles are categorized into 6 different categories of automation according to the ISO/SAE PAS 22736 (2021) standard. Level 0 stands for no driving automation and level 5 for full driving automation. An autonomous bus that drives in accordance with level 4 is defined as a vehicle which has high driving automation. The difference to level 5 is that a level 4 vehicle can only drive in a fully automated manner on known routes and is therefore limited in this respect. However, since a bus travels on predefined routes and therefore the roads to be traveled are known, a bus with level 4 is sufficient. Furthermore, the bus considered in this study is a low-floor regular-service bus, commonly used in public transport in Germany. It is important to distinguish this from a shuttle bus, as there are significant differences in size, capacity, and legal requirements. According to EU Regulation 2018/858 (2018), a shuttle bus can have a maximum of eight seats, no standing places, and must weigh less than five tons. In contrast, a regular-service bus significantly exceeds this capacity, offering both seated and standing places, and has a much higher weight.

As a result, existing research projects focusing primarily on autonomous shuttle buses with smaller capacity and different structural characteristics cannot serve as a direct basis for this study. While some findings, such as communication between an autonomous shuttle bus and pedestrians (Verma et al.,2019), may be transferable, the substantial differences in transport capacity and legal requirements necessitate a separate examination of autonomous regular-service buses.

As stated in the research question, the requirement for complete accessibility is particularly important here, which is why three different qualitative studies were conducted to identify the challenges faced by people with disabilities when traveling with an autonomous bus. These qualitative studies are presented below.

3. Methodology and study design

In order to identify the resulting main challenges for disabled passengers in relation to autonomous buses, a total of three studies were conducted to cover different perspectives. All three studies are qualitative empirical studies based on a primary analysis of interviews with a guideline as a data collection instrument and were all conducted in the greater Munich area, which has both urban and rural areas to reflect these two different types of public transport. The three perspectives considered here are the challenges that disabled passengers themselves experience when traveling on an autonomous bus, the challenges that bus drivers experience, and the challenges that bus operators experience when disabled passengers travel on an autonomous bus. These three different perspectives were used to extract, analyze, and summarize the findings relevant to answering the research question. This method of obtaining the challenges is visualized below (Figure 1). The individual studies are presented in the following chapters.

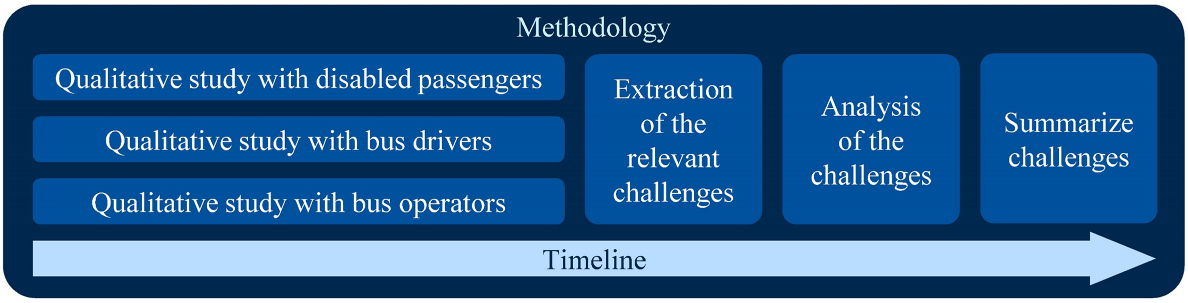

Figure 1. Method for obtaining the challenges

3.1. Qualitative study with disabled passengers

In this qualitative study, a total of 25 disabled participants in the German city of Munich were interviewed individually with the help of a guideline between January 20 and January 25, 2024. Of these 25 participants, 12 were female and 13 male. The youngest participant was 19 and the oldest 62, with 19 of the participants being between 30 and 50 years old. 23 were physically impaired, 16 were mentally or intellectually impaired, and 4 had sensory impairments. Accordingly, some of the participants had multiple impairments. Since it is not feasible to carry out the study with a guideline for very severely mentally or intellectually impaired people, the mental or intellectual impairments represented here are not severe cases. Since people with such severe cases of mental or intellectual impairment travel by other means of transport anyway, this is not an issue here.

The guideline used for the interview is divided into several blocks. In the first block, the study participant is given a brief explanation of what this study is about – finding the main challenges for disabled passengers when driving with autonomous busses. They are then asked in the second block about their demographic characteristics, such as age, gender, and occupation. In the third block, the disabilities of the study participants are determined in order to be able to assign them to the different types of disabilities. In the following, a discussion is held with the study participants about the challenges they might experience on a journey with an autonomous bus. As the participants have no previous experience with autonomous buses, the usage of a conventional bus is taken as a basis. From there, the participants are interviewed about the steps they go through when traveling on a bus and the challenges they anticipate when traveling on an autonomous bus. The discussion aimed at identifying the challenges was limited to the journey with the autonomous bus, i.e. from boarding to exiting the autonomous bus. Challenges such as finding or reaching the bus stop are therefore not added here, as these are not part of the research question. At the end, the challenges identified and discussed are summarized for the participant. As no strict list of questions was worked through during the interviews, but rather the challenges and concerns of the interviewees were addressed during the conversation, it is not possible to provide a list of the questions asked here.

The qualitative content analysis method according to Mayring (2019) was applied to systematically evaluate the interviews. The analysis followed a structured, multi-step approach to ensure a comprehensive interpretation of the data. First, the collected interview transcripts were summarized, meaning that key statements were extracted while eliminating redundancies and irrelevant details. This step ensured that only the most relevant aspects related to the research question remained. Next, an explication process was conducted to clarify ambiguous or unclear statements by considering their context. Additional literature and background information were used where necessary to enhance the understanding of specific responses. Finally, the data was structured by categorizing key themes and patterns into overarching categories. These categories were developed inductively based on the interview content and iteratively refined to ensure a meaningful classification. The structured results were then analyzed in relation to the research objectives and are presented in Chapter 4. This methodological approach ensures that the findings are systematically derived, transparent, and grounded in the perspectives of the interview participants.

3.2. Qualitative study with bus drivers

A total of 10 male bus drivers from the city of Munich were interviewed from January 23 to January 25, 2024. The bus drivers were between 38 and 64 years old and had varying lengths of professional experience, ranging from six months to 32 years.

A guideline was also used in the bus driver interviews, which were divided into 7 areas. First, an introduction was given as to what the interviews were about, followed by the question of how the bus driver likes their job and what notable incidents there have been in past journeys. The third area addressed the interaction of the bus driver with the passengers: When do these interactions take place and for what reason? The fourth area dealt with the problems that bus drivers face during their journey. The following area discussed the special challenges that need to be considered for disabled passengers. The sixth section considered the future of bus drivers in relation to autonomous buses, with the final step involving the collection of the demographic characteristics of the bus drivers who were interviewed. For the interviews, the entire bus journey of a bus driver was considered and also analyzed using the same qualitative content analysis method according to Mayring (2019) and therefore went through the same steps as described above.

3.3. Qualitative study with bus operators

In the interviews with bus operators, a total of four experts from Munich bus operator organizations were individually interviewed online from 29 January to 22 February 2024. Three of these experts were male and one was female. The four experts each had extensive professional experience in different areas of Munich's transportation and operator system, with each having worked in their respective fields for over a decade. One expert specialized in the automation of local public transport, focusing on the development and implementation of autonomous mobility solutions. Another expert worked in transport planning, optimizing routes, schedules, and infrastructure to improve efficiency and accessibility. A third expert was dedicated to innovation development in public transport, integrating new technologies and sustainable mobility concepts. The fourth expert had a strong background in market and mobility research, analyzing passenger numbers, travel behaviour, and emerging mobility trends to support data-driven decision-making. Collectively, these experts play a crucial role in shaping the future of Munich's bus network, as they are responsible for defining its long-term strategic development. For this reason, they were specifically chosen for this study. While additional expert interviews would have strengthened the study’s validity, these four individuals represent the only specialists in Munich operating at this strategic level.

In the guideline used for this study, there were a total of four different parts. The first part examined the interaction between passengers, drivers, and bus operators. The second part dealt with future trends and developments in the bus industry. The third part addressed the topic of automated driving in order to discuss the potential and the challenges of autonomous buses, as well as requirements for future passengers and the ecosystem of autonomous buses. The last part dealt with the challenges for disabled passengers and what needs to be in place in autonomous buses to make them fully accessible. These four thematic areas were discussed with the experts interviewed and worked through one after the other. New questions that arose during the discussion were always addressed directly. This study considered the journey of an autonomous bus from its starting bus stop to its destination bus stop. Mayring's (2019) method was again chosen to analyze the data collected with the same methodical approach as described above.

4. Findings

The findings of the three qualitative studies conducted will be explained in this chapter. The results of the various interviews presented here are limited to discussions of the challenges faced by disabled people in relation to autonomous buses, as only this part is relevant for answering the research question.

4.1. Findings of the qualitative study with disabled people

The interviews with people with disabilities revealed several different challenges when using and interacting with autonomous buses. With 21 mentions, the use of the ramp, which the bus driver has to fold out manually to enable wheelchair users to board, is one of the main points of interaction and therefore one of the main challenges posed by a future autonomous bus from the perspective of a physical disabled passengers. To enter the bus, the wheelchair user tells the bus driver that they want to get on the bus, the driver unfolds the ramp, and the disabled passenger is then helped over the ramp onto the bus. With 15 mentions, the second most common interaction is informing the bus driver of the exit bus stop. This is either because the disabled passenger does not realize what the next stop is – since their disability means they cannot see or read the display panel – or because they have difficulty telling the bus driver from their wheelchair seat that the manual ramp must now be folded out again in order for them to exit. The other challenges that have been mentioned are identifying the right bus, locating the door area and a seat, recognizing the arrival at the desired destination stop, and receiving feedback on the successful communication of an exit request. Respondents reported that the presence of high-contrast accents on handrails, stop buttons, and other important aspects help them when use buses independently. However, these aids can still be improved. In addition, assistance is often required when driving up the ramp, as it can be too steep due to different curb heights, and when clearing the designated wheelchair user area so that the wheelchair user can position themselves in accordance with safety requirements during the journey. For mentally and intellectually impaired passengers, the main challenge is that information must be easy to understand.

4.2. Findings of the qualitative study with bus drivers

Bus drivers also cited making boarding possible as their main challenge with disabled passengers. However, the bus drivers here also mentioned passengers with walkers and baby carriages as a challenge that an autonomous bus has to overcome. According to the specifications described by the bus drivers, the ramp in Munich is not folded out for walkers and baby carriages, but assistance is still provided for boarding and exiting the bus if necessary. The second most frequently cited challenge is providing information about the next stop, the bus route, and the final stop, even though the bus drivers themselves report that this level of information is rarely provided. The bus drivers cite the sale of tickets in Munich exclusively via ticket machines, websites, and an app, as well as the ban on speaking to the bus driver while driving and the plexiglass barriers installed due to COVID-19 as reasons for this. Other challenges mentioned by individual bus drivers include correctly positioning the bus at the curb and bus stop so that disabled passengers can board and making announcements that inform passengers of special incidents, for example that a road is closed due to an accident and therefore a bus stop cannot be approached. The bus drivers argue that the autonomous bus must also have the tools to pass on corresponding information in such cases.

4.3. Findings of the qualitative study with bus operators

The interviews with the bus operators primarily revealed challenges relating to the safety of a disabled person's journey. For example, it was mainly discussed how a disabled person could request help if there is no longer a bus driver who can assist with medical care or other challenges. The advantage of the standard bus, namely that the driver is available as a direct contact person, does not apply to buses that operate autonomously. The bus operators also referred to the challenge of having an autonomous bus check whether a disabled passenger is correctly positioned before the bus sets off. The concern that the ramp could no longer be folded out correctly due to bad weather conditions such as lots of snow or grit, which would make it impossible for wheelchair users to get on and off, was also mentioned in this context. There was also concern that the absence of a bus driver could lead to violence on an autonomous bus, with disabled passengers less able to protect themselves. However, some experts also stated that there is no direct contact with the driver in other means of public transport.

5. Predicted challenges for user journeys on autonomous buses

In order to systematically record the challenges faced by disabled passengers when interacting with an autonomous bus as mentioned in these various studies, a reference user journey on an autonomous bus was created. This represents the user journey in a chronological order where possible. This user journey starts at any bus stop that is served by autonomous buses and at which the disabled passenger wants to board, it ends when the disabled passenger has exited the autonomous bus. During the studies, it emerged that physically impaired passengers who are in particular need of assistance are primarily wheelchair users, as the ramp on the bus is only extended for them due to legal requirements (DPAC, 2024). Sensory impaired passengers who need assistance primarily have impaired hearing or sight, as other sensory impairments do not affect travel with a bus – this is in accordance with the VDV (2012) definition of restricted mobility. For the two remaining types of disabilities according to the UN definition, mental and intellectual, no separate challenges were identified in the studies – these have therefore been summarized as cognitive impairment for the purpose of the reference user journey. The following user journey is therefore primarily for people with these types of disabilities.
The user journey is set up for the individual passenger, who goes through the three main phases of boarding the bus, riding on the bus, and exiting the bus. Individual challenges are listed for these main categories, but do not have to occur for every disabled passenger. The order in which they occur can also change depending on how the passenger acts. It must therefore be ensured for the autonomous bus that these challenges can be solved independently of the disabilities of the passenger and the order in which they occur.
In the following graphic (Figure 2), the user journey with its three parts is shown in chronological order. The various identified challenges are assigned to the individual parts of the journey, as are the disabled

Direction of the user journey timeline

1. Boarding - at the bus stop:				
Identifying the right bus	X	X		X
Locating the bus entrance	X			
Request unfolding of a ramp			X	
Door opening/feedback that you can now safely enter	X	X		X
Ensure that the ramp can be safely driven on			X	
Finding a seat/for standing place also possible	X		X	
Wheelchair space must be cleared of other passengers			X	
Ensure that the disabled passenger is safely positioned			X	
Warning before folding in the ramp and closing the door	X	X	X	X
Warning of departure	X	X	X	X
2. Traveling - on the road:				
Make emergency calls	X	X	X	X
Receive information about the next bus stops	X	X		X
Receive information about any special events (delays…)	X	X		X
Request to stop	X		X	X
Request to fold out the ramp for the next bus stop			X	
Provide feedback on the different requests	X	X	X	X
Announce arrival to the next bus stop	X	X		X
3. Exiting - at the bus stop:				
Inform about door opening	X	X		X
Inform that the ramp is unfolding	X	X	X	X
Feedback that you can now safely exit	X	X	X	X
Locating the bus exit	X			
Ensure that the ramp can be safely driven on			X	

Figure 2. User journey of a disabled passenger on an autonomous bus

passengers primarily affected by these challenges. The symbols denote the respective disability: The eye stands for visually impaired passengers, the ear for hearing impaired passengers, the person with a walking stick for physically impaired passengers, and the brain for cognitively impaired passengers. Within one of the three parts of the user journey, the individual challenges may differ from the chronological sequence. As a result, they are not numbered but instead listed in an example order.
This user journey incorporates the findings from the three qualitative studies listed above to identify the challenges that passengers with disabilities face when interacting with and using an autonomous bus. It should also be noted that during the journey of an autonomous bus, several parts of the user journey can be active at the same time. For example, a disabled passenger may board the bus at one stop while another passenger wants to exit the bus and a third passenger continues to sit on the bus before they exit at another stop. It must therefore be ensured at all times that the challenges for each individual disabled passenger can be successfully resolved without simultaneously hindering another passenger. It should also be pointed out here that the challenges listed for passengers with reduced mobility in an autonomous bus must be solved in such a way that they can operate independently of the weather or other environmental influences.

6. Requirements for possible solutions to these challenges

The challenges of the user journey are discussed below in a summarized manner as there are identical or similar solution principles for many of the challenges shown above. Potential individual solutions are presented as illustrative examples, following established solution principles already used in other transport systems, such as rail. This approach increases the likelihood that these solutions can be efficiently adapted for use in autonomous buses in a cost-effective and time-efficient manner.

6.1. Transfer of information

To improve information transfer for passengers with disabilities in autonomous buses, solutions should follow the two-senses principle (2SP), ensuring information is always conveyed through at least two different sensory channels (e.g., visual and auditory signals) (Schneider, 2024). This approach helps visually impaired passengers through audio signals and hearing-impaired passengers through visual cues. Additionally, information should be accessible from any seat, including for passengers facing backward, and should be designed simply for cognitively impaired individuals. Key challenges and potential solutions include:

- Identifying the correct bus and locating the entrance:
  - High-contrast colors, lighting elements, and acoustic signals (e.g., a clicking sound similar to pedestrian crossings) could help visually impaired passengers locate the entrance (Dalke et al., 2010).
  - Visual impairments often still allow for the perception of strong contrasts, making bright LED indicators around doors and inside the bus effective.
- Finding the door and understanding door status:
  - LED strips around door frames, similar to those used on Frankfurt’s streetcars, could indicate whether doors are opening, closing, or locked.
  - This would benefit both visually impaired and hearing-impaired passengers by providing clear visual cues in addition to audio signals.
- Interacting with buttons (e.g., stop request, emergency, ramp activation):
  - Buttons could include LED rings with different colors or flashing patterns to indicate their function.
  - Braille labeling should be added for blind passengers.
  - Haptic feedback (e.g., vibrations) could confirm successful button presses, addressing potential challenges in noisy environments.
  - An audio confirmation could further support the 2SP by signaling when a button has been successfully activated.
- Receiving feedback and ensuring safe positioning before departure:
  - The bus driver currently ensures that passengers with mobility impairments are safely positioned before the bus departs. In an autonomous bus, a solution must be developed to provide equivalent feedback to ensure passenger safety before movement.

- Finding a free seat:
    - Currently, visually impaired passengers must rely on bus drivers or manually feel around to locate an available seat. A solution could involve reserved seating areas for blind passengers or seat indicators that signal availability through audio or visual cues. (Bareria et al., 2012)

For information transfer in autonomous buses, audio and visual signals should always be combined to improve accessibility. Additionally, haptic feedback can serve as an extra sensory channel where needed, such as in buttons. Established solutions from other transport modes, like high-contrast visuals, braille labeling, and LED indicators, should be adapted to autonomous buses. By ensuring that passengers with sensory or cognitive impairments receive information in an accessible manner, barriers should be significantly reduced, making autonomous public transport more inclusive.

6.2. Physical support for impaired passengers

For physically impaired passengers, the challenges are getting on and off the autonomous bus safely and finding a seat. While visually impaired passengers cannot see a free seat and therefore have problems initially finding a seat, physically impaired passengers have problems reaching the seat already reserved for them in the special seating area of a bus. This seat is not only reserved specifically for wheelchair users, but also for passengers with walkers or baby carriages, as this is the only place where there is sufficient space on the bus. If this seat is blocked by an unauthorized passenger, it must be cleared by informing this passenger.

For physically impaired passengers who are sitting in a wheelchair traveling up the ramp is one of the biggest challenges. A way must be found to make it easy and safe for wheelchair users to enter the bus. Given that a manual ramp, as currently installed, is not fit for purpose in the context of an autonomous bus, it must be replaced by another suitable solution like an automatic ramp. It must be ensured that this automatic ramp extends reliably so that a wheelchair user can always get off the autonomous bus no matter what the weather or other conditions are like. To enable the wheelchair user to use the ramp, there must be a way to tell the autonomous bus that it needs to extend the ramp or provide a different potential solution. It is important to ensure that this notification option also complies with the requirements listed the previous section in terms of transferring information, since wheelchair users often have multiple disabilities. As an example, a specific button could be placed on the outside of the bus, on the corresponding door and at the wheelchair space in the bus, which activates the extension of the ramp. In general, it is important that physically impaired passengers are enabled to get on and off the bus safely, reliably, and quickly.

6.3. Security concerns

The transition to autonomous buses introduces significant changes in public transport operations, particularly regarding passenger safety. One primary concern is the absence of a human driver, who traditionally plays a crucial role in ensuring both operational safety and passenger security. Addressing these concerns requires a combination of technological advancements, system monitoring, and passenger support measures.

The absence of a driver raises understandable safety concerns, particularly regarding passenger security in emergencies such as vandalism, altercations, or medical incidents. Traditionally, bus drivers serve as both a deterrent to misconduct and a first responder in critical situations. Without them, alternative measures must ensure passenger safety.

A key solution is remote monitoring, where control centers equipped with real-time surveillance can intervene if needed. Emergency buttons and voice-activated systems would allow passengers to report incidents directly. AI-powered security cameras could detect suspicious behavior, automatically alerting authorities if necessary. Additionally, automated incident response systems could assess situations and trigger appropriate actions, such as notifying emergency services or stopping the bus in a safe location. For medical emergencies, the bus could integrate real-time health alerts, allowing passengers to call for assistance via onboard communication systems. Clear audio-visual guidance would inform riders about emergency procedures, ensuring that help is requested swiftly when needed.

While the lack of a driver presents new challenges, a combination of AI surveillance, remote supervision, and emergency response systems can ensure a high level of passenger safety, making autonomous buses a secure alternative for public transportation.

7. Discussion

With the studies conducted, numerous challenges related to different types of disabilities were identified. Physically and sensory-impaired passengers, in particular, face a wide range of difficulties. Examining these challenges from multiple perspectives—those of disabled passengers, bus drivers, and bus operators—has provided a comprehensive set of observations, contributing to the identification of key challenges. However, some studies had a relatively small number of participants, such as the study involving bus operators. Generally, this can reduce the reliability of a study. Nevertheless, since the interviews were conducted with experts who have extensive experience in their respective fields and possess significant subject matter expertise, the validity of their statements remains high. This ensures the quality of the study results despite the limited number of participants.

Presenting the identified challenges in the form of a user journey makes them easy to comprehend and visualize. However, this simplified representation omits certain details, such as the frequency of specific challenges. Given that the occurrence of these challenges depends heavily on the distribution of different types of disabilities across various locations, it was decided not to incorporate this additional information into the user journey but instead to prioritize clarity and accessibility. By categorizing different types of disabilities within the user journey, weightings can still be assigned and evaluated effectively. As a result, the first part of the research question posed at the beginning of this study is addressed through the user journey.

The identified requirements and potential solutions demonstrate that there are numerous ways to support passengers with sensory and cognitive impairments when traveling on an autonomous bus. Simple measures, such as additional displays and announcements, LED lighting, and haptic feedback, can significantly improve accessibility. Assisting physically impaired passengers, however, requires more extensive modifications to the design of autonomous buses, particularly in developing systems that enable wheelchair users to board and exit the bus independently, as well as ensuring a safety system for passengers in designated seating areas. Despite these challenges, such measures are feasible.

Therefore, the second part of the research question is addressed through the analysis of challenges faced by passengers with disabilities and the identification of fundamental requirements needed to overcome these barriers. However, these requirements—especially the proposed solutions—have not yet been tested for their practical implementation or precise impact on improving accessibility in autonomous buses. Additionally, crucial factors such as cost considerations and legal regulations have not yet been incorporated into this analysis, as the primary focus has been on identifying the most significant challenges. Future research must further investigate these aspects and develop concrete solutions to test their feasibility and effectiveness in real-world scenarios.

8. Outlook

In the future, the identified challenges for different types of disabilities must be addressed by evaluating various potential solutions based on feasibility, cost, speed, and ease of implementation. Both existing and new approaches will be considered, assessing their impact on accessibility. Additional factors like cost and space requirements may also play a role in selecting the best solutions. This process will enable a prioritization of implementations while aiming to ultimately resolve all challenges.

Acknowledgments

This research was funded by the Federal Ministry for Digital and Transport of Germany (BMDV) on the basis of a decision of the German Bundestag with roundabout 12.7 million euros as part of the project MINGA in the framework of the funding guideline “autonomous and connected driving in public transports”.

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