Towards Accessible Autonomous Public Transport: Requirements of Transit Users with Visual Impairment and Autism Spectrum Disorder

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Abstract

People with physical or mental impairments are often disadvantaged in using mobility systems such as public transport. When it comes to automated on-demand shuttle services, the situation might get worse since no driver is aboard who could assist. This paper describes the results of a survey where visually impaired persons and individuals with autism spectrum disorder indicate their perception of using the status quo of public transport. Subsequently, we present visions towards accessible autonomous public transport. The results show that the requirements differ greatly or even contradict each other depending on the type of impairment. Therefore, an individualized vehicle setting in combination with an appropriate app-based service is recommended for launching accessible autonomous shuttle services.

1. Motivation

Mobility is a fundamental principle of social participation for every human being. Hence, innovative mobility solutions are crucial for persons with special needs. Besides, there are considerable ambitions to make vehicles drive autonomously. New mobility systems such as on-demand shuttle services operating in public transport (PT) may help society to solve social issues by developing Accessible Automated Vehicles (AAV) (Hwang et al., 2020; Riggs et al., 2022).

Today, operators of PT have to follow legal requirements and recommendations on how to accessibly design PT vehicles, stops, and stop approaches. This also applies to automated PT vehicles. These legal requirements for (fully automated) PT systems lead to several challenges. The automated vehicle must take over the tasks a human driver performs in the non-automated case. These tasks include safety-monitoring of the boarding process or assisting mobility-impaired passengers to enter/leave the vehicle, among several others. Regardless of the technical requirements and overtaking tasks of human vehicle operators, the passengers' needs must be met for high acceptance of a novel automated shuttle system.

To this end, we surveyed impaired individuals as well as experts/caregivers to identify the needs of passengers with limited mobility towards an automated shuttle service. The surveyed persons are chosen focusing on two groups: Visually Impaired (VI) and Autism Spectrum Disorder (ASD). This paper aims at analyzing two research questions: (1) identifying

barriers for individuals with VI and ASD related to PT infrastructure and their concerns on autonomous shuttle services, and (2) developing a vision for the design of novel autonomous shuttles as a part of on-demand mobility.

The paper is organized as follows. Section 2. gives a literature review, section 3. describes the methodology applied for the survey. Section 4. analyzes the results and findings while section 5. gives a discussion and describes the limitations of the methodology. Section 6. summarizes the paper and gives an outlook on future research.

2. Literature Review

Several pilot activities have been performed to understand the impact of automated shuttle systems (Avsar et al., 2022; Iclodean et al., 2020; Piatkowski, 2021). Many studies highlight that drivers or safety operators still plays an essential role in pilot activities to fulfill passengers' information needs or ensure safety (Avsar et al., 2022). This is also true for passengers with special needs (Riggs et al., 2022). But not only the time in the vehicle, also information, waiting, boarding, and alighting are essential to consider when talking about the accessibility of PT stops (Riggs et al., 2022). It must be understood in the early development phases of autonomous shuttle services how to address all the needs of various users. The needs of passengers are described as the four A's: availability, affordability, accessibility, and acceptability (Hwang et al., 2020; Millonig et al., 2018; Shrestha et al., 2017). This paper focuses on the accessibility aspect of particular user groups.

The authors of (Tabattanon et al., 2019) reported that there is no accessibility research for low-speed automated vehicles and only little for public transportation. In recent years, there has been development in accessibility research regarding AAVs. The study (Miller et al., 2022) investigates user acceptance of shared autonomous vehicles (AVs) among people with different mobility and communication needs in Singapore. According to the survey, trust in technology, safety concerns, accessible features, and simplicity of use are essential considerations for users with varying needs. Another study conducted in Singapore focused on individuals with ASD (Lim et al., 2021). The study aims to understand the challenges faced by this user group when using PT and proposes a design concept of an information terminal named ViCo (virtual companion) for future transport systems including driverless shuttles.

In (Schräder et al., 2022), strategies for handling tasks are proposed, which nowadays are performed by an accompanying person that an automated system will have to compensate. Their focus case is an autonomous family car. Existing measures on driverless and conventional vehicles, such as low-barrier interior designs, might partially compensate for the absence of a person who previously performed supporting tasks. The paper also notes that a low-barrier vehicle design can only partly contribute to the compensation for the absence of a required human companion for specific use cases.

The authors of (Hwang et al., 2020) try to answer the research question whether autonomous vehicles are a viable transportation option for people with disabilities. The study concludes that AV technology has the potential to significantly improve mobility and accessibility for individuals with disabilities. However, there are still concerns and anxieties about whether

automated vehicle technology is accessible to all people, and the built environment must be designed and maintained in an accessible way.

The article (Durand et al., 2023) investigates whether PT is an alternative travel option for users of special transport services in the Netherlands. The conclusion of the paper is that Special Transport Services (STS) play an important role in keeping people with impairments mobile, especially when no other option exists. Despite efforts to make PT more accessible, it is not a panacea for people with an impairment. Only 11% of STS users would have used public transport if STS was not available, and it is unlikely that more than 16% of all STS trips can be substituted by PT. The first and last miles in PT are major limiting factors for STS users.

The study (Zandieh et al., 2021) in Greater Manchester, UK, investigates the opportunities and challenges of autonomous vehicles for elderly adults' outdoor mobility. This user group is especially interesting because physical or mental disabilities are likely to arise at a higher age (Tabattanon et al., 2019). Thus, many effects are a combination of both this age group and disabilities. The study found that while older adults perceive opportunities in AVs as promoting social interaction, and offering stress-free door-to-door mobility, they also express concerns about safety, cost, and a lack of social interaction with a human driver.

In (Riggs et al., 2022), the authors conclude that while AV technology can help disabled individuals achieve high mobility, there are still gaps in accessibility policy that need to be addressed. They recommend that vehicle manufacturers, policymakers, and state and municipal agencies collaborate to integrate accessibility at this stage of the AV revolution. This would allow for the development of a transportation system that treats accessibility as a guiding principle, not as an afterthought.

Gaps in literature are, besides others, the boarding and alighting stage of AAVs with cognitive and/or developmental disabilities, like ASD, and the riding stage of AAVs with visual impairment. Within this paper, we want to address these research gaps. An essential factor on the acceptance of autonomous driving systems, which is not considered in the reviewed literature, is geographical and cultural diversity as well as differences in political decision making (European Commission, 2023). Pilot activities have already been conducted in Europe, but an in-depth analysis of passengers with special needs is still missing.

3. Methodology

This section describes the selected focus groups and their impairment, and gives an overview of the chosen survey participants.

3.1 Focus Groups

For the empirical study, we focus on three groups. One group is persons with Autism Spectrum Disorder (ASD), a second one those with visual impairment. As a third group, we asked experts, i.e. people not directly affected by an impairment but dealing with people with restricted mobility in everyday life such as parents, caregivers, or employees of disability facilities.

The group of autists is classified via the International Classification of Diseases (ICD). According to ICD-10, the autism-related disorders that we included in the study are *Asperger Syndrom* (belonging to the group of *other pervasive developmental disorders*), *Childhood Autism*, and *Atypical Autism*. The group of visually impaired is composed of people with *Low vision* (partial loss of vision that significantly impairs visual functioning according to ICD-10). This also implies that there were no participants 100% blind on both eyes. When recruiting survey participants we tried to find persons that only have one disability and as little bias as possible. However, this is not completely realizable due to different age groups, different traffic education, and unknown factors. **Figure 1** gives an overview of the surveyed persons and their typification.

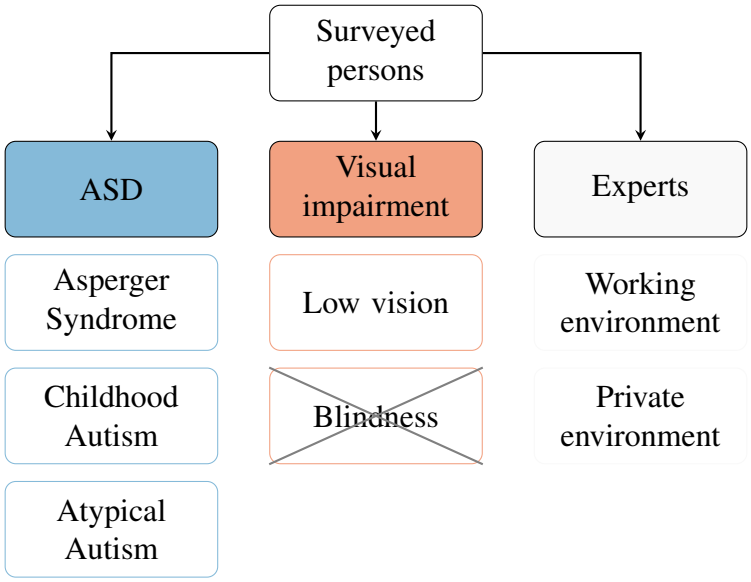

Figure 1: Overview of Surveyed Persons

3.2 Data Collection

For each of the three groups, ten people took part in our survey. A detailed list of the participants and their characteristics can be found in **Table 1**. Participants with autism are indicated by *'ASD'*, those with visual impairment with *'VI'*, and those who are an expert/caregiver with *'E'*. The age of all participants is between 16 and 90, males and females are equally distributed among the participants. Furthermore, it is indicated how often each individual uses PT. All study participants live in the metropolitan area of Munich, Germany. The guided interview includes three types of questions. At the beginning of the interview, the interviewees are introduced to the topic with introductory questions. Subsequently, the interview consists of guided questions and ad-hoc questions. The latter are questions that arise during the interview. The former represent the core of an interview. The questions are both open and closed questions. In the case of closed questions, they can only answer *'yes'* or *'no'*, whereas the answers to open questions can be answered in any way. Therefore, open questions also lead to different answers, from which the core information must then be filtered (Hussy et al., 2010). In this survey, the questions are answered both written and orally.

Table 1: Participants Characteristics

Participant	Age	Gender	Type	Frequency of PT use
ASD1	31	Male	Asperger Syndrome	often
ASD2	24	Male	Asperger Syndrome	regularly
ASD3	16	Female	Asperger Syndrome	never
ASD4	40	Female	Asperger Syndrome	never
ASD5	32	Male	Asperger Syndrome	never
ASD6	53	Male	Atypical Autism	regularly
ASD7	18	Male	Atypical Autism	never
ASD8	37	Male	Childhood Autism	never
ASD9	29	Female	Childhood Autism	rarely
ASD10	48	Male	Childhood Autism	never
VI1	27	Female	Visually Impaired (since birth)	often
VI2	53	Male	Visually Impaired (since birth)	regularly
VI3	38	Female	Visually Impaired (since birth)	regularly
VI4	72	Female	Visually Impaired (since birth)	regularly
VI5	18	Female	Visually Impaired (since birth)	never
VI6	90	Female	Visually Impaired (since 40 yrs)	never
VI7	75	Male	Visually Impaired (since 25 yrs)	often
VI8	34	Female	Visually Impaired (since birth)	regularly
VI9	47	Male	Visually Impaired (since birth)	rarely
VI10	22	Male	Visually Impaired (since birth)	regularly
E1	40	Male	Driving Service for Individuals with Disabilities	
E2	26	Male	Driving Service for Individuals with Disabilities	
E3	48	Female	Facility for Individuals with Disabilities	
E4	27	Male	Facility for Individuals with Disabilities	
E5	31	Female	Facility for Individuals with Disabilities	
E6	42	Female	Facility for Individuals with Disabilities	
E7	50	Female	Accompanying Person	
E8	40	Female	Parent	
E9	48	Female	Pedagogue	
E10	39	Male	Transport Company	

4. Results

This section summarizes the answers of the survey and presents visions on the design of novel automated shuttle services.

4.1 Barriers in Public Transport

The survey results show that individuals with visual impairments and autism face very different barriers in public transport (**Figures 2** and **3**, for visually impaired and autists, respectively).

4.1.1 Barriers for Individuals with Visual Impairment

The group of visually impaired individuals describe that information (notices and display boards) on PT stops or vehicles is difficult to read because of missing visual contrasts or auditory aids. Infrastructure aspects such as stairways are not sufficiently highlighted visually as well. Tactile highlighting of infrastructure elements via floor indicators at PT stops is reported to be insufficient or missing. Participants frequently describe issues when identifying stairs or exact boarding locations.

When using underground services,VI persons and experts report that lighting conditions in underground infrastructure leads to orientation problems. Besides visual and tactile senses, visually impaired individuals highly rely on auditory perception. That is why speaker announcements are crucial in PT use for this user group. It is reported that speaker announcements are missing at many bus/tram stops in the study area. If a bus stop or a vehicle is equipped with speakers, the announcements at a platform or in the vehicle should be more frequent and repeated more often.

Another issue reported is that PT stops are difficult to access. This poor accessibility is caused by above-described problems of insufficient highlighting (visual or tactile) of infrastructure elements but also conflicts with other road users. Widespread bus stop designs in Germany can lead to conflicts between boarding passengers and cyclists, because bike lanes are next to waiting areas or must be crossed to enter a PT vehicle.

4.1.2 Barriers for Individuals with Autism Spectrum Disorder

Barriers for individuals with ASD face different issues in PT. Autists and experts report that this passenger group perceives irregularities and delays in PT operations as disruptive. The same applies to high people density both at PT stops and in vehicles. They point out too small waiting areas for passengers, frequent and long waiting times due to delays, and body contact with foreign persons.

Another aspect mentioned by the surveyed persons is too many visual stimuli, noise from their environments, as well as strong and varying odors. This is also related to high people densities, which increases all impressions to be processed by the affected persons. A high noise level, changing background sounds (e.g., speaker announcements), high color contrasts,

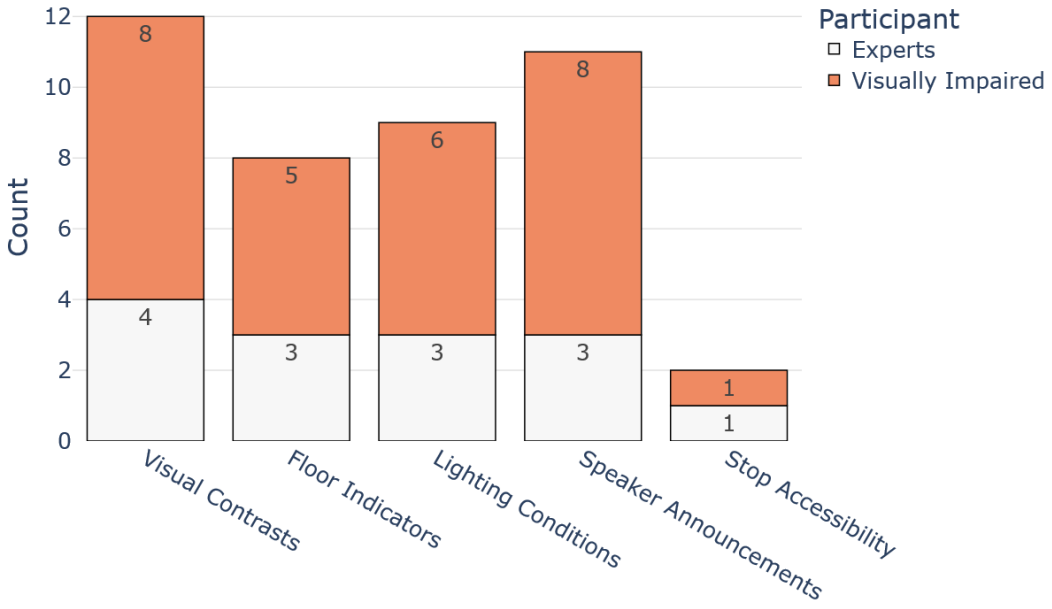

Figure 2: Barriers for individuals with visual impairment

and chaotic scenes with many moving persons and objects are challenging for this user group. Autists also feel uncomfortable in environments with unpleasant or unfamiliar odors.

Some limitations and challenges reported by visually impaired people disagree with those perceived by autists. While the former highly rely on speaker announcements and prefer to increase their frequency, it is considered as a barrier for autists. Visual stimuli are similar to auditory stimuli in this regard. While visually impaired people prefer higher contrast between information inside and outside the vehicle, more visual stimuli are undesirable to autists.

4.2 Visions on Accessible Autonomous Vehicle Design

When it comes to autonomous shuttles, which drive without a guiding and assisting person, visually impaired and autistic persons face the above mentioned challenges. Based on the indicated perception of the surveyed persons, in the following, we present some visions on how to design an accessible automated shuttle.

4.2.1 Comfort

As a first point, we recommend to individualize settings. This can be done via a mobile application on private or on-board devices. This app can modify the settings in the vehicle to adjust ambient lighting, speaker announcements etc. according to the passenger's needs. Since impairments are very individual, these settings should not be fixed. A passenger should be able to adjust the settings in the shuttle in real-time and save settings via a personal user profile. This type of customization system can lead to conflicts when other passengers do not

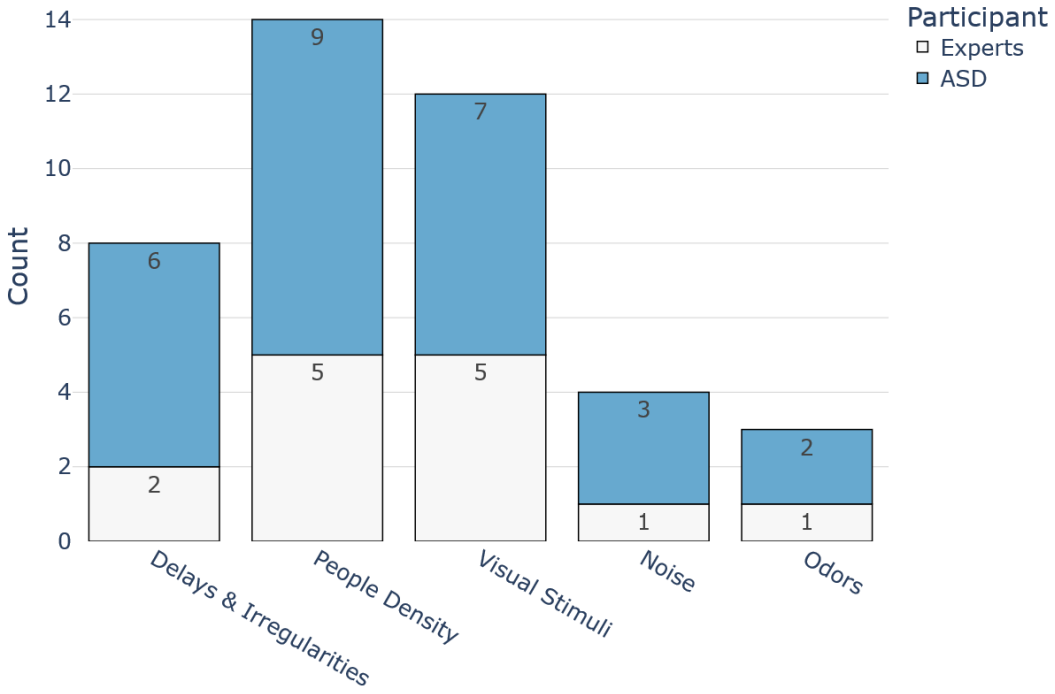

Figure 3: Barriers for individuals with Autism Spectrum Disorder

agree with current settings or have different needs. A solution can be different customizable compartments in the vehicle, which can only be implemented for certain vehicle sizes and types.

4.2.2 Travel Information

Another important aspect of user acceptance of autonomous shuttles is the information needs of passengers. Some user groups have particular needs, for example, the information on the occupancy rate of vehicles is important for autists. This pre-trip information could be communicated via an app. On-trip information is also important for passengers as proven by pilot activities of autonomous shuttle services (Avsar et al., 2022). Again private or on-board devices are necessary to answer certain questions like the duration to the next stop or the reason why the AV takes an alternative route. The communication with the automated vehicle is an essential point to increase acceptance and perceived safety on a trip.

4.2.3 Safety

Not only indirect safety measures like communication are important for passengers, also direct safety measures as indicated by the survey. Security cameras can be installed to ensure personal safety and as indicated by all surveyed passenger groups, the possibility to interrupt the trip via emergency stop or ask for help via emergency call are essential parts

of autonomous shuttle systems. **Figure 4** shows all the aspects mentioned by the surveyed people.

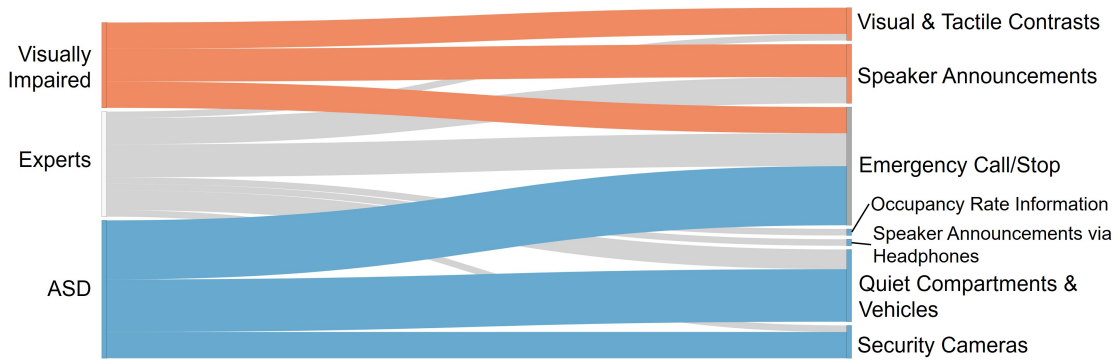

Figure 4: Design Recommendations for Accessible Autonomous Vehicles

5. Discussion and Limitations

The survey results show that the requirements of the two passenger groups with special needs vary significantly. For visually impaired people, it is necessary to give indicators for the border between sidewalk and street. For autists, a minimum of noise, sounds, and odors is requested whereas for visually impaired people, speaker announcements are decisive. Therefore, vehicle interior elements should be customizable to optimize user acceptance and meet passengers information and needs. In this paper, we only gave a vision on how to optimize the vehicle. For fixed stops, like in most of today's PT, also infrastructure can be equipped with sensor and communication systems. Infrastructure assistance systems, like safety monitoring during boarding, can additionally contribute to accessible autonomous shuttle services.

However, the surveyed persons all live in the Greater Munich area, which leads to a set of similar aspects among all questioned individuals. The number of persons surveyed is not representative. Still, it gives good indications on today's challenges with public transportation and the fact that one advantageous factor for a certain user group can be disadvantageous for another.

6. Conclusions and Outlook

This paper describes the perception of passengers with special needs, specifically autists and visually impaired persons using public transport (PT). They stated that they do not feel safe, comfortable, and assisted by the operators of PT. Autists request only little information from their environment both auditory and visually. In contrast, visually impaired people need guidance by speakers or by tactile infrastructure.

When it comes to automated shuttle services where on-demand vehicles pick up and drop off at any boarding zone along a route, it is even more important to assist every individual. One possible method can be an app-based service going along with an on-demand shuttle service

in order to customize in-vehicle elements to meet the passenger's individual needs. Thus, profiles for certain passenger groups can be activated to control lighting, speaker announcements and boarding assistant systems.We recommend to offer an app with predefined settings for certain user groups where every rider can adjust these settings according to their personal use and preferences.

As a next step, this survey will be repeated with people having other impairments, such as wheelchair users or auditory impaired people. Additionally, combinations of needs and impairments such as elderly people, mentally impaired people, and wheelchair users are to be analyzed.

Another aspect to be dealt with in the future is the customization of the PT stop, not only the vehicle interior. Speaker announcements at stops could be transferred to passengers' earphones, allowing them to filter relevant content based on personal preferences or impairments in order to find instruments to equally integrate all people into the future's automated mobility systems.

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