



## Article

# Mobility on Demand for Everybody—Investigation of the Current Challenges in Establishing Ride-Pooling Services for Persons with Mobility Impairments in Germany

Martin Dorynek <sup>1,\*</sup>, Analena Aumüller <sup>1</sup>, Jessica Ma <sup>2</sup>, Björn Rathsack <sup>1</sup>, Julian Weidmann <sup>1</sup> and Klaus Bengler <sup>1</sup>

<sup>1</sup> Chair of Ergonomics, TUM School of Engineering and Design, Technical University of Munich, Boltzmannstraße 15, 85748 Garching, Germany; ga58xev@tum.de (A.A.); bjoern.rathsack@tum.de (B.R.); ga63vid@mytum.de (J.W.); bengler@tum.de (K.B.)

<sup>2</sup> Media Informatics, Ludwig Maximilians University, Frauenlobstraße 7a, 80337 München, Germany; j.ma@campus.lmu.de

\* Correspondence: martin.dorynek@tum.de

**Abstract:** The ongoing transformation of mobility, including new services such as on-demand mobility, raises the question of how services need to be designed so that everyone can use them. The number of persons with mobility impairments is increasing as a result of demographic change, and with the current amendment of the law, it will be mandatory in Germany to take these person's needs into due consideration. After all, a transport provider's success relies on sufficient demand in society (including persons with and without disabilities). Due to changing mobility routines, increased comfort, and other individual personal requirements, vehicles smaller than conventional buses are necessary for passenger transportation. The following investigation is a research study, which is based on an intensive literature review and expert interview study. The goal of this work is to evaluate the current status quo of the German public transport system with respect to inclusive on-demand services and their satisfaction with user requirements. Therefore, guideline-oriented interviews with experts from the mobility sector were consulted and analyzed. For this purpose, the procedure of the qualitative analysis was used. Furthermore, user analysis and methodological processes were conducted in order to strategically establish necessary measures. On the one hand, the current initial situation is addressed and initial experience with these new services is reported. The current focus is on the automation and electrification of these vehicles. In order to make them accessible to all potential customers, ergonomic requirements should be considered from the beginning. The previous experiences with other vehicle classes as well as the legal framework conditions are to serve as a benchmark. On the other hand, existing challenges will be discussed, and necessary steps will be worked out. A result of this situational analysis shows that the currently available vehicle concepts do not fulfill all requirements. It is important to consider the vehicle and the barrier-free mobility chain (booking and paying for the journey or vehicle, as well as boarding, traveling, and alighting). Overall, the design of barrier-free mobility systems requires a process of both political and social rethinking in order to succeed.

**Keywords:** mobility on demand; social inclusion; barrier-free ingress; purpose-built vehicle



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## 1. Introduction

Section 8(1) of Germany's Passenger Transport Act defines local public passenger transport (ÖPNV) as follows: "For this Act, local public passenger transport is the generally accessible transportation of passengers by streetcars, trolleybuses and motor vehicles in regular service, which predominantly serves to satisfy transport demand in urban, suburban or regional transport. The criteria are that the total distance of the majority of journeys by one means of transport does not exceed 50 km, or the total travel time does not exceed one hour." (§ 8 paragraph 1 Passenger Transport Act (PBefG)). Around 10.4 billion

passengers used local public transport (ÖPNV) in Germany in 2019. Buses and trains thus replace around 20 million car journeys on German roads every day [1]. The modal split varies greatly depending on the region. In rural areas, up to 70 percent of all trips are made by car. The larger the cities, the higher the proportion of trips made by public transport and the lower the proportion made by private motorized transport [2]. While people from metropolitan areas make almost two-thirds of their trips on foot, by public transport or bicycle, and a good third by car, the reverse is true for people from small towns. Demographic change is one of the many drivers of change in our mobility. In Germany, the share of the over-65s is very high, with percentages of 21.7% in 2020, 26.2% in 2030, and 30% in 2050. With increasing age, the health restrictions that can affect mobility increase sharply. Up to the age of 50, a health restriction occurs in less than one in ten people. Between the ages of 60 and 70, one in five is affected, and among those over 80, about half are affected by health restrictions [2]. The research of [3] also indicates that in the coming decades, with an aging society in many industrialized countries, the proportion of the population with some form of mobility impairment will grow. However, 7 percent of the total population is mobility-impaired and has special mobility requirements [2]. In addition, some of them do not own a car, which is why they rely on other mobility services. In summary, the term includes all passengers for whom overcoming steps and edges can become an effort or an obstacle. It should be noted that in this context, general accessibility will be a legal requirement as of the year 2022. There are still no mandatory requirements in the case of ride-pooling or other mobility-on-demand services. As the PBefG states: “Local public passenger transport is also transport with taxis or rental cars that replaces, supplements or condenses one of the modes of transport mentioned in paragraph 1” (§ 8 paragraph 2 PBefG). According to the German Disability Council, on-demand transport services are also means of public transportation. Mandatory accessibility should therefore also apply to these services from 2022 onwards, according to that group [4].

Accessible environment design is based on international, European, and national resolutions, action programs, standards, guidelines, legislation, regulations, etc. Access to mobility has been a focus of research for a long time, as it enables people to participate in everyday life. The regulations in [5–8] are essential for the accessibility and safety of persons with disabilities in road transport vehicles in Germany and Europe. There is also a large community of associations and boards to strengthen the participation and mobility of persons with disabilities as well as international standards, in which the following may be mentioned [9–12].

The focus of the study is on Germany because of the rapidly increasing number of on-demand mobility services. The initiation of new funding opportunities aims to support the transformation of the transport system and help climate protection. Therefore, we can expect ride-pooling to become even more widespread. The political framework and the development of barrier-free mobility are at different stages of progress so a comparison or an extension to more countries would make less sense. The insights gained can be transferred to other regions in the ideal scenario.

Since the availability of local public transportation in rural areas is limited and often not barrier-free, new mobility services could significantly increase mobility—especially for persons with disabilities and their participation in public life. Rurality—as the opposite of urbanity—is associated with various characteristics and the understanding of rurality has continuously changed in the scientific discussion. In view of the diversity of rural areas in terms of their socioeconomic strength, the lifestyles pursued there, the intensity of land use, and the infrastructure provided, the question arises as to what remains as a common feature of this type of space and what distinguishes it from other spaces [13]. For this study, only the need for a good transport connection is of interest, which according to IOKI is lower for 55 million German citizens who live in the suburbs and rural areas. Less than half of the stops in rural areas are served more than twice an hour [14]. Adequate alternatives are necessary for the transportation turnaround and the accompanying renunciation of one’s privately owned car, as otherwise, no one will voluntarily change their behavior. At the

same time, public transport in rural areas should be offered more cost-effectively. Finally, when these services are redesigned, ergonomics must be considered from the beginning so that the system sounds promising in theory and proves its usefulness in everyday life. This work starts here and evaluates the new mobility offerings from the (different) user's perspective. In the context of on-demand mobility, passengers are also able to travel to virtual stops, which are not necessarily designed to be barrier-free. It is more important to ensure barrier-free access through specific vehicle designs. What does it mean, however, for a vehicle to be truly accessible?

New mobility services need to consider multiple aspects that even go beyond the vehicle itself to meet user requirements. They include booking and paying for the journey, locating and accessing the vehicle, and providing suitable restraint systems.

For persons whose disabilities affect their mobility, each aspect plays a considerable part in enabling accessibility. The booking process must be accessible because it has to enable people to book their journey intuitively and easily and choose among different booking modes. It must be easily understandable, use simple language, and include voice information to serve persons with vision impairments. This paper aims to identify the status quo, highlight the main challenges, and present possible recommendations for action to take the needs of persons with disabilities into account when establishing new mobility services from the beginning. Whenever possible, steps to be prioritized will be identified and recommendations will be derived. Finally, the transfer of existing experience and knowledge should help to establish the services. There is already a great amount of expertise that needs to be combined in a meaningful way so that the available forces can be used to solve the remaining challenges.

## 2. Literature Review

### 2.1. To Be Mobile

The findings of the Mobility in Germany (MiD) study [15] for the Federal Ministry of Transport and Digital Infrastructure in 2019 provide some key data regarding the previous mobility behavior of the German populace. They show that 85% of all people leave their homes to pursue various activities on an average day, with young men making up the largest group. The reasons for travel are evenly divided among education and work (34%), shopping, personal travel (30%), and leisure (28%). The average journey length is 12 km, and a typical individual travels 39 km per day. People in urban areas travel for a total average time of 1 h and 20 min per day, about 15 min more than those in rural areas.

### 2.2. Different Users' Requirements

Accurate determination of the expected user groups is essential in designing a new transportation concept. To maximize the strengths of any new mobility service, it needs to be integrated into the existing transportation system. To do this, it is necessary to understand the users' requirements and their reasons for desiring mobility. Therefore, this study starts by presenting the different user groups and their mobility patterns. The new mobility offerings are aimed at the following four target groups [16]:

- School and college students: This group's most common travel time is in the morning rush hours between 6 and 9 a.m. The most crucial factor in their mobility choice is the ability to plan, as they must reach their destination by a certain time (8 a.m. in the case of school pupils). Security services are also required for children. Additionally, the service must be cost-effective and remain affordable to students in the long term.
- People in employment: This group constitutes the bulk of travelers during the morning and evening peak hours. Nearly 27% of overall daily traffic is in the rush hour [2]. Morning traffic is more congested than in the evening, as many people work only part-time and leave work earlier in the afternoon. Due to workplace time constraints, people need to be able to plan their journeys. Thus, flexibility and cost are major factors in this group's choice of mobility service.

- Temporarily mobility-impaired persons: This group includes various categories, such as pregnant women, people with heavy luggage, and tourists. The main consideration for this group is to have a short walking distance to a virtual stop combined with a reliably calculable walking time. For pregnant women or a person with a broken leg, for example, a short walking distance is a major consideration.
- Long-term mobility-impaired persons: This group covers persons with long-term health impairments or age-related impediments. They require a mobility service that they can use without assistance or accompaniment. Besides offering barrier-free services, the vehicle must be easy to find. As nearly 6% of the population in Germany has no access to the internet [17], it must be possible to book the service via a variety of platforms.

The main focus here is on the mobility-impaired, as their needs have not so far been sufficiently considered in the context of ride-pooling. The proportion of persons with long-term personal mobility impairments and who are thus restricted in their choice of transport is around 7% [2]. Adding to this, for those who are temporarily mobility-impaired, these concerns affect about one-third of the total population [18]. Unfortunately, there are no reliable figures on exactly how many people are restricted in their mobility. Only specific disabilities are recorded in statistics, but these are not openly accessible due to strict German data protection laws. However, it can be assumed that the number of unreported cases is high. After all, anyone can be caught unintentionally.

### *2.3. Current Requirements of Barrier-Free Mobility in Public Transport*

There is a lot of research on the needs of mobility-impaired users. The SAE standard work [9] sets out the minimum requirements for securing wheelchair users. The aim is to offer wheelchair users a similarly high level of passive safety during transport as non-disabled passengers in conventional vehicles through the use of a belt-type occupant-restraint system.

Looking at Europe shows very different efforts and approaches. At the beginning of the new millennium, the correlation of serious injuries in public transport was investigated [19]. Two-thirds of all injuries did not occur because of accidents but during regular operations. The main reason is inadequate interior design, which is highlighted by several examples, such as handholds or sharp edges. The user group of older women especially is particularly often and severely injured. New regulations and rules ensure that new generations of vehicles will be better equipped. Nevertheless, existing vehicles will remain in use for a long time, so a solution must also be found here.

Analysis of accident data shows that wheelchair users more often suffer serious injuries and have to seek medical help [20]. For wheelchair users, getting into and out of a vehicle is extremely dangerous, and actually securing the wheelchair is also an unsatisfactory cause of injury. While boarding, accidents with and/or on-ramps are particularly common. However, the authors do not mention any indicators or particular reasons for this.

A study [21] also evaluated personal injuries after accidents in public transport in Sweden. When interviewed, passengers expressed very different perceptions of their experiences and reported some major grievances. Based on this, the researchers made suggestions for improvements in vehicle design but also recommended driver training, optimizations in timetable design, and pavement management.

In the early 2000s, the cornerstone was laid for the safe fixation of wheelchair and mobility-impaired passengers [22]. Previous systems had major weaknesses and could not provide any real protection. Objective measurements during everyday traffic situations showed horrendous forces. The paper recommends rearward-facing installation on a holding plate, which is standard in city buses today.

What a travel facility on ships for older people and persons with disabilities should look like has been defined [23]. This document describes what the access to the cabin, the location, and also the layout of the cabin should look like. It also covers the training of the

staff involved, as well as the necessary equipment and services. It includes all eventualities of a voyage.

The research and subsequent debates led to a rethinking and a new standard for transporting and securing persons with long-term mobility impairment in passenger transportation vehicles. ISO [10–12,24] standards were developed for standardization. They cover the entire travel time from boarding/alighting to securing in place.

Weidmann [25] has noted that each type of vehicle used in local and long-distance public transport has its own accessibility requirements in Germany. In the case of train transport, this is also regulated by an enactment of the European Commission known as the PRM TSI, while other requirements to be observed include [26] (pp. 128–130, 134–135).

- Priority seats: At least 10% of the seating in each carriage must be prioritized for disabled travelers or those with reduced mobility. An accompanying person is allowed to sit next to them. These seats are marked as such and located close to the exit.
- Wheelchair spaces: One to four wheelchair spaces must be provided, depending on the length of the train. There must be enough space to accommodate a wheelchair facing either in or opposite the direction of travel plus sufficient space beside the wheelchair to enable wheelchair users to move their hands freely. In addition, there must be a travel companion seat for each wheelchair space.
- Floor level changes: Obstacles or steps between the vehicle and the entry, inner space, and the universal toilet should be avoided. Otherwise, a hoist will be needed, although ramps may be an alternative. Depending on the length of the ramp (above or below 840 mm) and the carriage type (single or double deck), the maximum slope must be between 6.25% and 15%.

According to Directive 2001/85/E.C., there are three classes of busses that can carry more than 23 persons, including the driver. Class I is a regular city bus, defined as a vehicle for passenger transport, including standing room, operating on routes with a large number of stops. Class II vehicles are designed to carry mainly seated passengers but may also carry standing passengers. Standing passengers are accommodated in the gangway and areas smaller than the space occupied by two benches. A typical example is an intercity bus. Examples of Class III vehicles include coaches and long-distance buses in which only seated passengers may be carried [27,28].

- Seats for disabled passengers: These must be located near a service door suitable for both entry and exit and must be oriented in or opposite the direction of travel. Sufficient space for a disabled person's dog must be provided under or adjacent to this seat.
- Wheelchair spaces: The space for a wheelchair must be at least 750 mm wide and 1300 mm long and designed for the wheelchair to face in or opposite the direction of travel. The floor in this space may have a maximum slope of 5% and must be designed to be slip-resistant. An exception applies to parking spaces in buses where no occupant restraint systems are prescribed. In this case, the longitudinal slope may be up to 8% if the wheelchair user is facing the direction opposite to the direction of travel and the edge of the parking space in the front direction of travel is lower than the edge in the rear direction of travel.
- Path to the wheelchair space: Between the disabled seat or wheelchair space and at least one entrance/exit, the slope of the floor must not exceed 8%. Furthermore, the sloping areas must be provided with a non-slip surface. The path must be sufficiently spacious so that a defined reference wheelchair can be maneuvered alone and there are no obstacles that might hinder the wheelchair user.
- Safety: If a passenger restraint system is required, the wheelchair space must be designed to face in the direction of travel and must be equipped with a wheelchair and passenger restraint system.

The requirements for accessibility in trams are comparable to the requirements mentioned above for buses [29].

#### 2.4. New Mobility Services

For a century, public and private transport have served different needs within the urban mobility landscape. Public transportation was designed to carry as many people as possible at the lowest cost, while private vehicles offered flexibility and freedom. For various reasons, this dichotomy no longer applies.

Ultimately, all this has consequences for the design of transport services. The familiar and proven forms of service cannot be provided at an economically realistic cost in many areas. Due to various influences and the resulting changes in society, scheduled services no longer fit the needs of the individual. For example, many employees have rethought the way they work due to technological advances and now increasingly use home offices or only commute to the office when necessary. Corona has also contributed to a decline in the willingness to use public transport. The dilemma of scheduled transport with fixed routes and fixed intervals can be summed up easily. High-frequency service with many different routes would affect the capacity utilization of the vehicles at certain times. There is also the unattractive alternative of offering low-frequency transport with only a few routes. Nevertheless, German citizens must be ensured mobility since its provision is part of the state's primary service. People in rural areas are mainly dependent on secure and future-proof mobility. This challenge will additionally require an on-demand service that enables great time flexibility.

The debate about new mobility offers is also fueled by new possibilities in providing information. Due to digitalization, much more data is available, which can be very helpful in designing an offer. Simulation models show the existing mobility flows and could provide tailor-made solutions. This could ensure that we no longer rigidly align our mobility behavior but decide dynamically or spontaneously. At the moment, the possibilities are being exploited rather hesitantly. On the one hand, it is up to politicians and regulators to create a framework to implement this. On the other hand, there is uncertainty about who owns the data and whether it has to be shared at all (privacy and security concerns).

This is where many start-ups that have recognized the market potential come in. More and more companies are specializing in data collection and evaluation. With ride-pooling, for example, requests for transport are booked via an app and grouped by an algorithm. This makes it possible to combine several ride requests in the same direction with a single vehicle. Ride-pooling satisfies customer demands for an individual and flexible mobility service that can be offered at a low price due to the high vehicle utilization. As personnel costs make up a large share of operating costs, significant cost savings are not expected until autonomous on-demand shuttles are deployed [27].

#### 2.5. Automobile Manufacturers in Transition

The automotive industry is in a state of considerable upheaval. The combustion engine is losing ground in the industry to counter climate change, focusing increasingly on the electric motor and the fuel cell. However, other technological advances, such as vehicle automation, are also taking place. The automotive industry plans to incorporate driverless vehicles into its portfolios over the next ten years [30]. As automobile automation increases, the demands of occupants are also changing. Once the actual task of driving has been rendered obsolete, the understanding of what is meant by mobility will change.

The automotive industry is facing enormous economic pressures. A solution is no longer based on implementing the best engineering but is a compromise among several required fields. Consequently, vehicles or vehicle concepts rely on the forecast quality provided by market research before work can even begin.

### 3. Method

With a situational analysis, previous experiences in the mobility of mobility impaired persons are to be compiled. This is necessary in order to be able to develop new mobility offers in a targeted manner. For the practical evaluation of the status quo of the German transportation market, especially with regard to barrier-free design, guided interviews

were conducted with experts from the fields of mobility and inclusion. In the following, the underlying processes in the selection and acquisition of the interview participants, the execution of the interviews as well as the subsequent transcription are explained in more detail.

### *3.1. Participants Contributing to Situational Analysis*

In order to gain seamless insights into the different aspects required for accessible on-demand mobility for all, interviews are necessary to gather the knowledge of different experts. The aim was to compile a comprehensive list of requirements for special, purpose-built vehicles and explore additional obstacles for barrier-free mobility. A total of 18 expert interviews were conducted. In the course of the last interview, two experts took part to ensure complete insight into the field of mobility and inclusion.

Expertise from three different areas of mobility development was crucial for the further analysis and evaluation of the interviews: service providers/projects, public authorities, and users. The selection and acquisition of potential interview partners were initially based on the definition of an expert given by Bähring et al. [31]. The activity and experience profile of potentially interesting interview partners presented on the websites or company pages was also taken into account for the final selection and contact. In particular, the relevant connections and knowledge base with regard to the research interest were also taken into account. Furthermore, care was taken to select and contact only one person per institution or company. The underlying motivation is to avoid the impression of arbitrariness in the selection of subjects. It is not possible to provide explicit information about the employment relationship or the institutions and companies due to the anonymization of the data.

This investigation is not a subject study, but an analysis of the as-is state. Ethical approval was not sought, as all interviews were conducted with informed experts. Expert interviews, in contrast to other survey techniques such as the narrative interview, do not focus on the person as such in terms of their underlying analysis, but on their explicit expertise. In addition, this type of research does not involve any risks or harm to the participants. The basic ethical principles were also not violated at any time. All interviews were conducted as web meetings. In addition, every interview was set with a duration of 30 min. If the interviewees gave consent, audio recordings were made to enable subsequent evaluation of the interviews. On the recommendation of Bogner et al. [32], no guide was sent out to interviewees beforehand since the aim of interpretation-based expert interviews was to ascertain the subjective ideas and experiences of the interviewees. In addition, the aim was to encourage the interviewees to respond spontaneously. Many parties involved are very cautious due to the sensitive nature of the issue and the different ways it is treated. Many stakeholders are aware of the impending challenges so that there are partly standardized answers to such inquiries. Nevertheless, this scientific study aims to find out the real circumstances. This procedure made it possible to obtain a broad range of expert insights.

The interviews were conducted with experts from the mobility sector, especially regarding persons with disabilities. The experts can be divided into five main sections:

- Service provider
- Government agencies
- Funding project leaders
- Scientists
- Foundations

Service providers were both purely private entrepreneurs and projects funded by government subsidies. On the one hand, the user perspective was covered by foundations and scientists in the mobility sector who are themselves limited in their mobility by physical restrictions, and on the other hand by institutions and experts who work very closely with persons with disabilities and mobility restrictions. The commitment of experts on the government side proved to be difficult due to the federal election as well as scheduling

commitments. It was possible to interview experts at the municipal level in this context. Accordingly, there is a lack of expert knowledge at the federal level.

This interdisciplinary approach enabled insights to every party involved and affected either by using on-demand services or by providing and influencing the offer.

### 3.2. Approach Evaluation and Classification of the Statements

Every interviewee agreed to the audio recordings, thus no notes needed to be taken. On the one hand, the questions aimed to assess fundamental problems of the mobility sector and on-demand mobility for persons with disabilities in general. On the other hand, the interviewees were asked to specify necessary measures in order to provide accessible on-demand services in Germany on a broad scale.

Lastly, the interviews were transcribed and qualitatively evaluated. Therefore, the transcription procedure used in this work is based on the semantic-content transcription procedure and was further developed by [33]. The developed procedure consists of a total of three parts: the content-semantic transcription, the extended content-semantic transcription, and notes on uniform spelling [33]. The interviews were manually transcribed. The further evaluation and analysis of the transcripts are based on the qualitative content analysis procedure according to [34]. The individual analysis steps can be divided into paraphrasing, abstraction-level generalization, a first reduction, and a second reduction. In the context of the qualitative analysis of the expert interviews, a total of 233 quotations were extracted and analyzed. Finally, eleven categories emerged, which are listed in the following Table 1.

**Table 1.** Categories formed and their frequencies.

Ranking	Category	Frequency
1	Vehicle concept	55
2	Political requirements	21
3	Accessible transport market and the problems	21
4	The taxi industry	17
5	Social issues	15
6	Profitability and financing	13
7	Influences on the development	13
8	Local public transportation and accessibility	13
9	The travel companion	9
10	Autonomous vehicles	8
11	The technical implementation	5

The selected statements are about experiences and estimations concerning the developments, problems, and requirements of an individual and barrier-free transport market. In the broadest sense, the term “expert” refers to professionals, connoisseurs or specialists, or persons who have a high level of knowledge. Consequently, the expert interview is aimed at a distinguished group of people who have specific knowledge of the topic in question. Nevertheless, a certain degree of uncertainty remains in the statements, as not everything can be fully verified.

## 4. Results

The results focus on the requirements for booking, the requirements for the vehicle concept, and the general implementation of such services.

#### 4.1. Challenges and Pitfalls during the Booking Process up to the Start of the Journey

Finding a vehicle is often difficult for persons with mental and visual disabilities. Drivers need to be trained to guide and support such transport users. Vehicle accessibility must be such that it enables smooth entry and exit. Passengers with and without disabilities need to be aware of their current whereabouts, which means that both visual and auditory information must be provided during the journey. Additionally, the safety of all passengers must be ensured, which requires specialist knowledge on the driver's part, particularly for securing wheelchairs. Contactless payment is necessary as certain disabilities prevent people from distinguishing among different cash denominations. For a mobility service to be accessible, several additional aspects need to be considered in addition to the ride itself. Only by considering all the various steps in this process, a ride-pooling concept can be sustainable in the long run. This was also confirmed by an expert as follows: "So in view of the demographic change, nothing can actually be sustainable today that is not barrier-free."

When a barrier-free service is introduced, particular attention should be paid to the following:

- Booking and paying for the service: "Very important with the new on-demand services is that here the access via apps, the ordering and payment is then also completely accessible and barrier-free." Booking should be offered not only via an app. It must also be possible for passengers to book online and by phone. Visually impaired people need to be able to adjust the font size of their display dynamically. In addition, voice guidance must be available with adjustable tempo and sound volume. Small groups must also be able to make bookings for several vehicles together. In addition, a preset for users with special circumstances such as guide dogs or wheelchairs needs to be offered. Payment options should include PayPal, direct debit, and cash. The possibility of advance booking by purchasing a fare credit on an app should also be offered. Since most people travel daily for education or employment, displaying the arrival time would be a bonus. According to some experts, the legal obligation comes too late: "Barrier-free apps are not mandatory for private providers until 2025. In other words, the on-demand services that are already running now may not even be bookable, orderable, and affordable by severely visually impaired and disabled persons."
- Reaching the stop: One expert described a concrete use case: "For me, one of the biggest sticking points is when there are no more stops. How will the blind person find the vehicle? How will the driver find the blind person? So how do they find each other if one of them can't see?" A route description with voice navigation should be offered to find the virtual stop. Door-to-door service must be offered to passengers with disabilities and the location of the virtual stop must be displayed. The user needs to be able to view and adjust the walking time to the stop. Reducing possible sources of confusion increases the level of recognition and trust. The correct destination must be displayed on the outside of the vehicle; this is particularly important in view of the growing number of vehicles envisaged in the future. Where necessary, the user must also be able to consult the driver.
- Boarding and alighting without assistance: A simple platform with an adjustable angle that extends to the outside of the vehicle is required. Boarding must be carried out from the side of the vehicle so the traffic behind is not obstructed. The ramp must be fully automatic and descend safely onto the pavement. Other experts suggest providing a hoist to assist wheelchair users in steep environments. "In the long term, this will no longer be the case. At some point, there will no longer be an attendant and then the ramp will have to be fully automated," noted an expert from a transport company.

#### 4.2. Obstacles and Requirements for Barrier-free Accessible Passenger Vehicles

There are numerous DIN standards and regulations, some at the federal level, which must be fulfilled. They contain rules and regulations on how to make vehicles, including taxis, barrier-free. However, operators are not obligated to make conversions, which means that the decision is based on the social interest of the individual operators. Many operators

are reluctant to modify their vehicles for fear of violating regulations. The changes could affect a vehicle's approval, leading to further costs and downtime. There are as yet no standards for providing accessibility for different types of users and user groups. One challenge that was noted in the course of this is the strategic decisions of the companies. As commercial enterprises, vehicle manufacturers in particular concentrate on the mass production of their vehicles for a large group of users ("After all, they are commercial enterprises in the final analysis and they want to tap into the masses, i.e., quickly achieve a certain size").

Another aspect was noted in this context that accessibility is usually only associated with the transport of a wheelchair so numerous user groups are excluded and disregarded: "So when we think of people with disabilities, I say we start with them. Of course, there is always the famous wheelchair user and e-wheelchair user and so on." Specially equipped firms retrofit most vehicles to provide at least wheelchair access. The process takes time and is very expensive, primarily due to the lack of interfaces within the vehicle on which to attach the new systems mentioned above. It does not make economic sense for private services to focus on a business case offering disabled people an on-demand service. The accessible transport market is mainly operated by retrofitters, as the small quantities involved are not of interest to the OEMs. The general lack of interfaces makes the conversion very time-consuming and costly. Accessible vehicles and the corresponding purchase are economically unattractive for companies. Fulfilling multiple user requirements requires both a new mobility concept and a new vehicle. Most service providers concentrate on wheelchair users. Persons with other disabilities affecting their mobility are not considered.

Many German legal formalities have undergone modification since the beginning of 2021. Concepts offering ride-pooling services are now legally permitted. Companies providing mobility services are obligated to provide one taxi with disabled access for a fleet size of 20 vehicles, according to the Law on the Modernization of the Public Transport Act [15]. Moreover, public transport providers are now obliged to provide more accessible mobility by 1 January 2022. Private companies, at the same time, are not obligated to comply. According to the Law on the Modernization of the Public Transport Act, they do not need to fulfill any requirements to provide accessible service vehicles [32]. Any interest in doing so arises from social welfare, but this is rare due to a lack of profitability. In addition, the German government aims to establish a regular mobility service based on autonomous vehicles by 2022 [35]. In general, the German government has undertaken to provide accessible mobility for disabled people, in accordance with the U.N. Convention on the Rights of Persons with Disabilities [36].

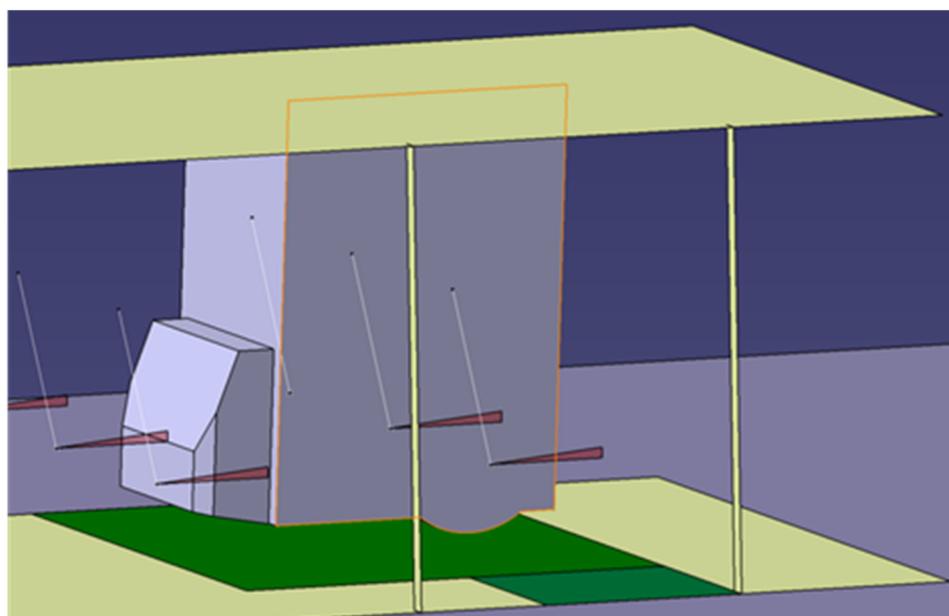
Problems arise when mobility services or companies are not subject to any legal obligations and are not given any further information on making vehicles and services accessible for everyone. The U.K. and Japan are good examples of countries that have made on-demand services accessible. Both London Taxi and JPN Taxi offer a service that enables wheelchair users to enjoy on-demand mobility on a large scale [37–39]. Mobility services in London and the rest of the U.K. are legally obliged to provide accessible mobility. British companies were thus forced to adapt their vehicles [40]. The U.K. and Japan could still improve their offerings by including further user groups, but their services are still superior to German on-demand services. It is clearly unrealistic to provide an on-demand service that includes all user groups and use cases, but it should at least include a large proportion of them. A mobility concept thus needs to satisfy multiple aspects in order to be accessible to most persons with disabilities that affect their mobility. Many services do not fulfill fundamental aspects of mobility and remain inaccessible to many people.

This is also confirmed in interviews conducted with experts in mobility and inclusion. Analysis of these interviews found five distinct user groups that need to be considered in order to provide a generally accessible on-demand service and these include wheelchair users, persons with disabilities affecting their eyesight or hearing, persons affected by microsomia, persons with mental disabilities, and persons without disabilities. It is essential to include persons with no mobility constraints so as to provide a service that can be used

by anyone rather than separating out certain user groups. To make on-demand services more accessible, short-term changes are necessary, such as the following:

- Provide accessible transport for wheelchairs (electric and non-electric)
- Improve information systems (auditory and visual feedback)
- Make vehicles accessible for guide dogs
- Provide adjustable seats for persons with macrosomia
- Provide training sessions for drivers

The transportation of wheelchair users must be ensured. The maneuvering space and footprint required for wheelchairs are shown in a study conducted by the Berchthold architectural office. The study, commissioned by the Federal Office of Transport in Switzerland, examined how a reference wheelchair can be designed that reflects the dimensions required for a 95th percentile male [41]. Figure 1 shows this model and provides a reference for the space requirements. This model also is visualized in a vehicle scale model for a better understanding. The yellow boundary areas represent the heights of the interior and ceiling.



**Figure 1.** To illustrate the space requirements for transporting people with mobility impairments, the following model should be used with the help of the reference wheelchair from [41]. The illustration is self-created and uses only the gathered dimensions.

Ramp systems are generally preferable due to their simplicity. A rear cut-out is required so as to ensure a feasible and pleasant clearance height. This can quickly become a problem for Mercedes-Benz Series 2 vehicles such as the Vito, eVito, EQV, and V-Class. The dimensions of a Mercedes Sprinter are therefore recommended [42].

Effective securing is required at speeds beyond 50 km/h and up to 80 km/h or more, otherwise, in the event of an accident, there is a risk of serious injury. A restraint system must secure both wheelchair and occupant. In the event of personal injury, the retrofitter will also be subject to investigation by the public prosecutor's office. In particular, the different dimensions of wheelchairs lead to challenges in providing unaccompanied and quick securing.

More and more manufacturers are now providing purpose-made anchorage points or eyelets. The restraint system must be safely stowed away after use so that other passengers do not damage it. For example, safety cables are subject to wear and tear over time from trampling, etc.

A further aim is to automate ride-pooling in the future by implementing a technology change. It is still uncertain how quickly automated vehicles will become an accepted

form of transport, as user acceptance is not the only factor at play: Road traffic legislation must also be adapted accordingly. However, it is sure to impact mobility in the long term significantly. This means that a ride-pooling vehicle could operate around the clock as part of an area-wide through-connected system. However, the absence of a driver would be a problem for those mobility-impaired users who rely on their assistance. Then, the ride-pooling provider would need to optimize other product features to enable them to function as an adequate substitute. Effective internal and external communication with users is one essential aspect.

#### *4.3. Challenges to Be Solved on the Road to Fair Mobility*

The requirements that need to be satisfied before a customer is able to use a ride-pooling service are discussed above. The legal requirements and standards pertaining to vehicle and service accessibility are thus clear. The many DIN standards and German regulations provide clear specifications on how to make vehicles accessible for numerous user groups. When changes are made to vehicles, these standards must continue to be satisfied in order to obtain approval for use on German roads.

The problem is that mobility service providers are unwilling to risk infringing German standards with their complex and vague regulations, which moreover can differ among states. This means that mobility service providers are unlikely to focus on making their vehicles and services accessible, as they wish to avoid the effort as well as any possible penalties. None of the standards take into account other user groups and their disabilities and needs. Current standards mainly focus on providing access for wheelchair users, while disabilities affecting senses or mental states are not considered. States who are party to the U.N. Convention on the Rights of Persons with Disabilities are obligated to provide accessible mobility for everyone. However, how this is achieved and what measures need to be taken are not clarified.

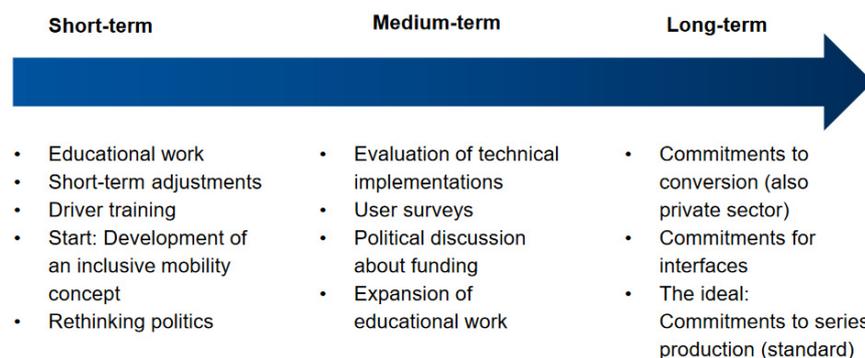
All in all, the development of a vehicle and the measures required to use a service, such as booking a journey, entering the vehicle, and making a contactless payment, still need to be considered. It is not enough to make a vehicle accessible if due attention is not given to the other aforementioned aspects. It is also necessary to develop new accessibility concepts and services rather than just adapting vehicles retrospectively. A renowned expert from the science stated the following: “The real problem is that we do not think inclusively but only in terms of repairing the add-on. This is the repair philosophy that we have, but it cannot succeed”.

This means that current services fail to fulfill even the basic requirements, so persons with disabilities are unable to use them. To render on-demand mobility possible, these basic requirements must therefore be addressed. The long-term success of newly developed services also requires a process of political and social rethinking. People need to be aware of their own vulnerability, which is also a factor of demographic change. Elderly people, in particular, tend to be less mobile and would therefore benefit from such accessible services. It is thus crucial to comprehend this added value.

This awareness will lead to higher consumer demand, as it is not only persons with disabilities who avail themselves of these services. Most companies tend to concentrate on their financial revenue targets, which cannot be met by focusing on persons with disabilities. On the other hand, the user group of persons with disabilities is too small to become economically profitable. Political and social awareness are crucial for long-term success, as is the development of a service that takes into account the whole mobility chain. Figure 2 lists the necessary steps to create barrier-free mobility services in Germany. They can be classified according to how quickly they can be implemented. It will take financial outlays and time to pick up and motivate all stakeholders. When developing vehicle or mobility concepts for shared passenger transportation, all too often the developers take themselves as the benchmark. Assumptions are made and products are designed without knowing the exact requirements and needs of those affected. Very few people involved in the mobility industry have a disability themselves. Reducing individuals on the basis of

their physical or mental disability is a classic case of Ableism. New mobility offers should essentially be comfortable, intuitive, and accessible, and not just for high-revenue target groups, but for everyone. To achieve this, it is necessary to involve an interdisciplinary team in advance for planning, design, and deployment. This does not only mean the relevant developers, such as designers, engineers, traffic planners, and many more, but people with any kind of disabilities. After all, only they can describe their problems and challenges with their mobility in everyday life. This was confirmed by an association spokesperson: “So an inclusion concept that is related to public transport or so on. It starts with the fact that the people with their various disabilities are involved from the beginning in the concept development and that they can also say from their point of view, from their needs, what does such a means of transport look like?”

## Outcomes - Strategies



**Figure 2.** Summary of the necessary steps according to the interviewed experts on a timeline.

## 5. Discussion

The opinions expressed in the interviews indicate a clear tendency towards an on-demand ride-pooling service that anyone can use. There was little support for the idea of shuttles designed to be used solely by persons with disabilities, as they would introduce a separation between persons with and those without disabilities. Furthermore, this development has to be executed in such a way that the underlying reputation is considered. Current ambulance transport that focuses on handling patients with illnesses and disabilities does not have a good reputation. This can be attributed to poor design and a shift in focus. As these services especially concentrate on transporting persons with disabilities, aspects considering comfort, entertainment, and well-being are not taken care of.

A renowned expert from the science community also supports these issues: “You could improve these on-demand services a little bit. For us, it is always a transport for persons with disabilities and this is far below, considering the hierarchy of reputation. A means of transportation for persons with disabilities, this is creating pictures you don’t want to have”. Ride-pooling services should be conceived in such a way that anyone, including a person without disabilities, will be excited to make use of the service. The aspiration is to create a concept for all, which means full integration in the German mobility sector without segregating specific user groups.

The free market will not be interested in implementing all the recommendations, as this will cause additional costs. With the revision of the passenger transport law, a minimum number of vehicles in the fleet was defined that one out of 20 vehicles must be barrier-free. Considering that most fleet operators have far fewer vehicles in their inventory, this is an illusory obligation. The potential of accessibility is not recognized, but rather ways out are increasingly sought. The lack of economic efficiency could be changed if certain barriers were removed. The list of priorities and necessary measures is long, but it will not be shortened, let alone disappear. The new German government has set itself

many goals in its legislature to improve this situation further. However, whether these goals will be followed by action must be seen. “The obligation of private operators to provide accessibility is a goal that we must continue to advance. After all, accessibility is not a nanny state, but a sign of quality for a modern country” (Federal Government Commissioner for the Interests of Persons with Disabilities Jürgen Dusel) [43].

The current process of awarding grants for accessible vehicles must be evaluated and reconsidered at the political level. Therefore, the conversion of vehicles should be promoted in an uncomplicated manner and subsidies should be made available before the conversion. There should also be no regional differences in the amount of any subsidies. Current processes and applications, especially in the cab industry, delay the barrier-free conversion of vehicles and lead to a decline in the attractiveness of these subsidies. In addition, new mobility concepts and projects should only receive government funding if their concepts are designed to be barrier-free. In the course of social acceptance, marketing campaigns and more educational work are necessary so that persons with disabilities are seen as a part of society. Therefore barrier-free mobility concepts are also perceived as a matter of course.

In the medium-term, further steps must be taken to develop a barrier-free mobility concept. The additional allocation of subsidies must be evaluated at the political level. The attractiveness of barrier-free vehicles must also be present in the private sector in particular. However, as long as the economic efficiency is not given to a sufficient extent and no obligations apply here, the accessible transportation market will hardly gain economic attractiveness. In particular, this is also related to the success of educational work and campaigns in the area of social acceptance. The higher the demand for accessible transportation on the market, especially among persons without disabilities, the higher the economic attractiveness for companies.

A good intention is mobility education, which tries to take away shared problems and ignorance from people with mobility impairments as well as from all stakeholders. Unfortunately, this training is handled individually, often unsystematically, and is not experienced by all [44]. In addition, new forms of mobility are not yet part of the curriculum. This also needs to be reconsidered/worked on and offered everywhere.

The technical development, implementation, or reconstruction of generally accessible vehicles is not seen as a challenge. In particular, the user-friendly display of information can be easily improved. However, such implementations can already be found among such German service providers as SOfia and international companies like London EV Company or Toyota [37,38,45]. There are no limitations of this kind with newly developed accessible vehicles. The vehicle can be designed precisely for the purpose of providing accessible passenger transport. This means that there is no need to make the inevitable compromises when using a body designed for a different purpose. The vehicle can be tailor-made to satisfy current and future accessibility demands. Technical innovations such as autonomous vehicles need to be considered with caution. Many use cases are not given sufficient consideration, and there are many situations, especially involving persons with disabilities, which can become rather complex in the absence of a driver. How does the vehicle find a blind passenger and vice versa? How can a wheelchair user enter the vehicle autonomously and secure himself once inside?

In summary, many questions and use cases still need to be considered in developing an on-demand ride-pooling service that is accessible for persons with disabilities. It is important to remember that such a service needs to be considered an entity with many facets that affect the vehicle and the entire mobility chain.

## 6. Conclusions

Everyone is talking about inclusive and fair mobility, but is this even possible? What still needs to be done for this vision to become a reality? Research focuses on testing digital on-demand shuttles, gathering experience, and increasing public awareness. The various pilot projects show that common features are already in use in on-demand shuttles, but they

are employed in many different vehicle models and types of equipment. An initial market review has shown that current vehicles are barely suitable. Due attention should also be given to the customer's perspective, as new mobility services can only be successful only if they represent added value from the customer's point of view. Whether ride-pooling will be successful in the future will largely depend on whether it succeeds in its initial phase in meeting customers' demands for convenience. What is lacking is a user-oriented, systemic and holistic approach.

Support programs exist that are trying to initiate a change exist. At the moment, they are of limited success as they are not yet well known and have yet to exploit their full potential. Compared to Germany, other countries do not fail to put legally binding regulations in place to provide a mode of accessible transport for persons with disabilities. Thus, Germany needs to take other countries as an example to change legislation and especially enhance awareness about these issues within its society.

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