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Potential Analysis for a New Vehicle Class in the Use Case of Ride-Pooling: How New Model Developments Could Satisfy Customers and Mobility Makers

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Abstract: Due to changes in mobility and the emergence of new services, it is becoming necessary to establish new vehicle classes between conventional buses and privately owned vehicles. New mobility scenarios need concrete specifications to develop the most user-centered shuttle buses. As a result, we are looking for the requirements and needs of operators and customers. Initially, we want to determine the status quo, as there is no preliminary work in this regard. During the course of extensive literature research, expert interviews, and follow-up workshops, the respective solution space was highlighted and narrowed down. Services such as ride-pooling require adapted vehicle concepts to ensure optimal implementation of their offer. Due to its optimized processes, the automotive industry depends on producing vehicles in a certain quantity and manner. Faster changes and extensive experiments are not possible with the current production approach. Purpose-built vehicle concepts can make mobility services more attractive to customers while facilitating business operations. For instance, potential improvements can be identified in the seating concept.

Keywords: purpose-built vehicle; new mobility; ride-pooling; Mobility-as-a-Service (MaaS)

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1. Introduction

Mobility is an integral part of life. It "is a basic human need" [1] and a decisive factor for the economy [2]. Without it, many people would not be able to get to work. It makes social encounters possible in the first place. Mobility determines where we live because, for many, it is essential to live close to the nearest railway line or motorway. Most people in Germany attach particular importance to their mobility, including being flexible, independent, reliable, plannable, and safe [3].

There are a variety of influential factors that affect and change our mobility habits. Mobility is part of social change and, therefore, closely linked to it. Most trips are made in one's car, which has been the center of mobility for most people over the years. Since the Fridays for Future protests, the impact of our current mobility behavior on the climate has become a hot topic of social and political discourse. In 2018, more than 19% of Germany's climate-damaging greenhouse gas emissions (GHG) were attributable to the transportation sector [4]. The European Green Deal calls for a 90% reduction of GHG in the transportation sector by 2050 to help the EU become the first climate-neutral continent. [5].

To satisfy individual and diverse mobility needs, a variety of new offers have begun, from which the user chooses the optimal means of transportation. Users do not necessarily see optimal as optimal in terms of protecting the climate. Convincing people to give up their personally-owned cars could be one of the main obstacles to the necessary measures [6]. Public transportation needs to be more attractive to users, and new mobility concepts need to be developed.

Mobility-as-a-Service (MaaS) is a holistic system that allows users to book and pay for various means of transportation via online platforms [7]. Thus, mobility is provided as a service and is independent of vehicle ownership [8]. The service consists of having different means of transportation available from the starting point to the destination and managing them as a single source. A promising approach to an embodiment of MaaS is on-demand mobility.

On-demand mobility implies that passengers get their mobility requests fulfilled when they need it. Customers' travel requests are fulfilled flexibly and in real-time [7]. The service is enabled by an online platform that processes customer requests in real-time and notifies the driver in an available vehicle, eliminating the need for planning [9]. The term on-demand mobility covers ride-sharing (e.g., BlaBlaCar), car-sharing (e.g., ShareNow), ride-pooling (e.g., CleverShuttle), and ride-hailing (e.g., Uber) services [10]. Here, on-demand mobility can be seen as the primary means of transportation and as a feeder to the following public transportation connection point, thus covering the "first and last mile" [11]. In addition, relevant reference literature argues that on-demand mobility is the cornerstone for implementing autonomous shuttles as a complement to public transportation [10,11].

The increasing popularity is reflected in the rapid spread of the service in Germany. For example, ride-pooling is starting in more and more federal states of Germany. The following map shown in Figure 1 provides an overview of the current situation in 2021. It is particularly noticeable that services are initiated mainly in the western federal states of Germany.

User acceptance is significantly influenced by the willingness to share a mode of transportation with strangers [12]. Hall [13] specified the discomfort associated with the violation of personal privacy, which is hardly avoidable in public transportation. The perceived violation of privacy results in stress and inconvenience [14]. For this reason, it is important to adapt the seat configuration and design to privacy requirements. The switch from driver to passenger can also lead to an increased incidence of kinetosis [15]. Kinetosis describes symptoms such as nausea, headaches, and discomfort that can occur during a car trip. These symptoms occur especially during a secondary activity, such as reading or working.

On the one hand, the current concepts do not meet future customer needs and ensure increased use. On the other hand, providers could save costs with smaller and more targeted modes of conveyance. The need for conventional bus drivers with the appropriate qualifications, who are currently a scarce resource, would be minor. In theory, all parties would bene-fit.

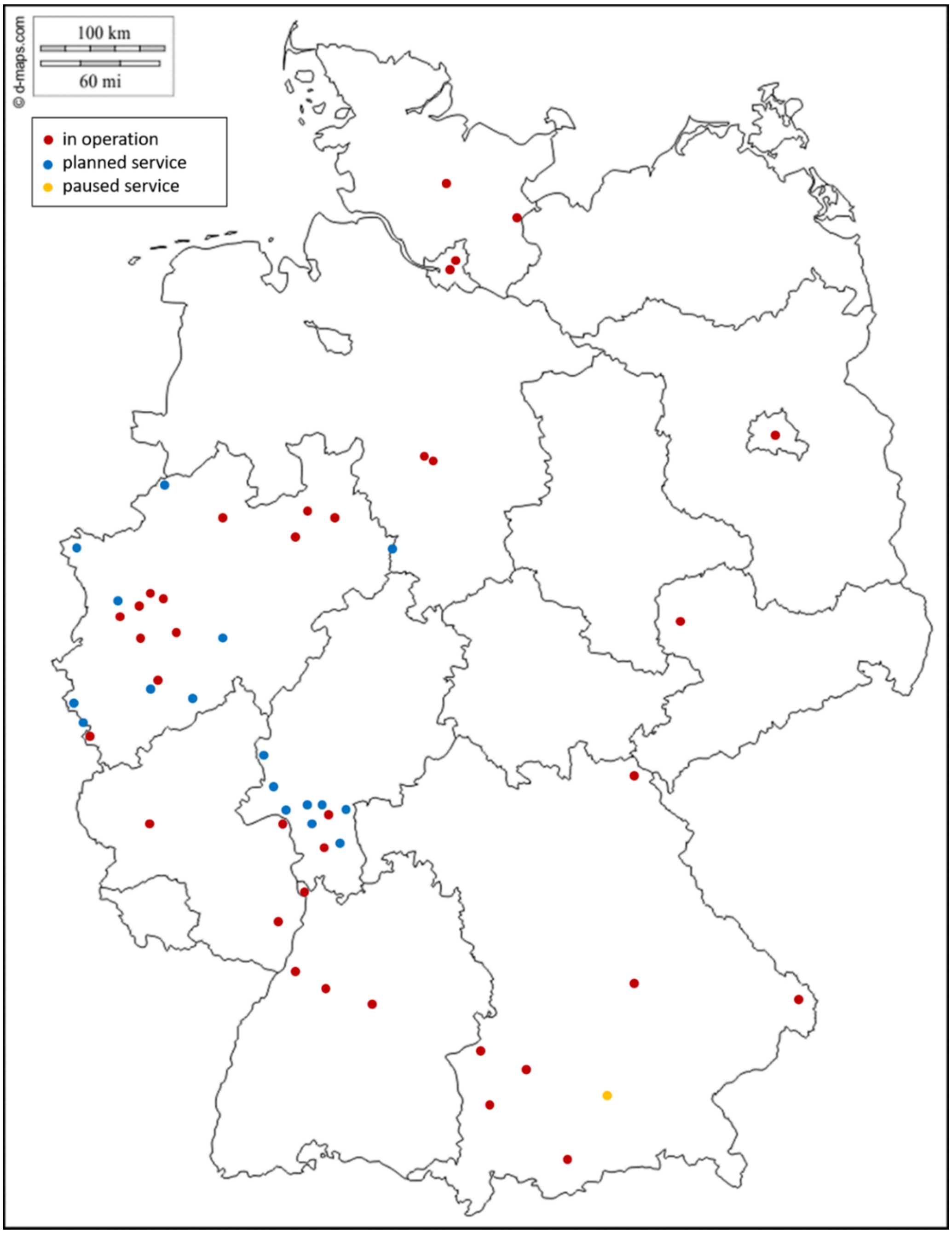

Figure 1. New mobility offers vary significantly from state to state. This map shows Germany with its 16 federal states. The data set was collected in May 2021. The red dots show the current mobility services. The yellow locations are currently suspended, while the areas marked in blue will be starting soon.

2. Theoretical Background

Many people prefer to live in cities or the surrounding suburbs. In 2017, about two-thirds of the German population lived in urban areas [16] (p. 22). More people inevitably create more traffic. This, in turn, leads to adverse effects on people and the climate, whether through traffic congestion or increased emissions [2] (p. 28).

From the user's point of view, the current public transportation system has several disadvantages that prevent it from becoming more widespread to every user group. The reasons are, e.g., [17]:

- Trips take too long compared to by car;

- There are no direct connections or distances to stops are too far;
- Comfort is restricted by overcrowding;
- There are no (convenient) options for transporting purchases;
- Passengers;
- Pollution;
- Lack of flexibility;
- Dependence on timetables;
- Costs;
- Frequency is too low;
- Delays;
- Lack of accessibility;
- An unsafe feeling.

These disadvantages can be particularly significant in certain regions such as rural areas, for specific target groups, such as people with age-related physical limitations, or particular use cases such as when having to do one's weekly shopping. Currently, public transport is struggling to bring back the travelers who stayed at home because of Corona and who will continue to commute less and work from home more often.

2.1. Position of Ride-Pooling/Different Modes of Transportation

Figure 2 compares ride-pooling to different mobility options. Offerings range from private to public transportation and are positioned vertically to show how they rate in terms of comfort and functionality. The mobility options on the side of public transportation are distinguished by reducing traffic by increasing the load factor of single transportation units.

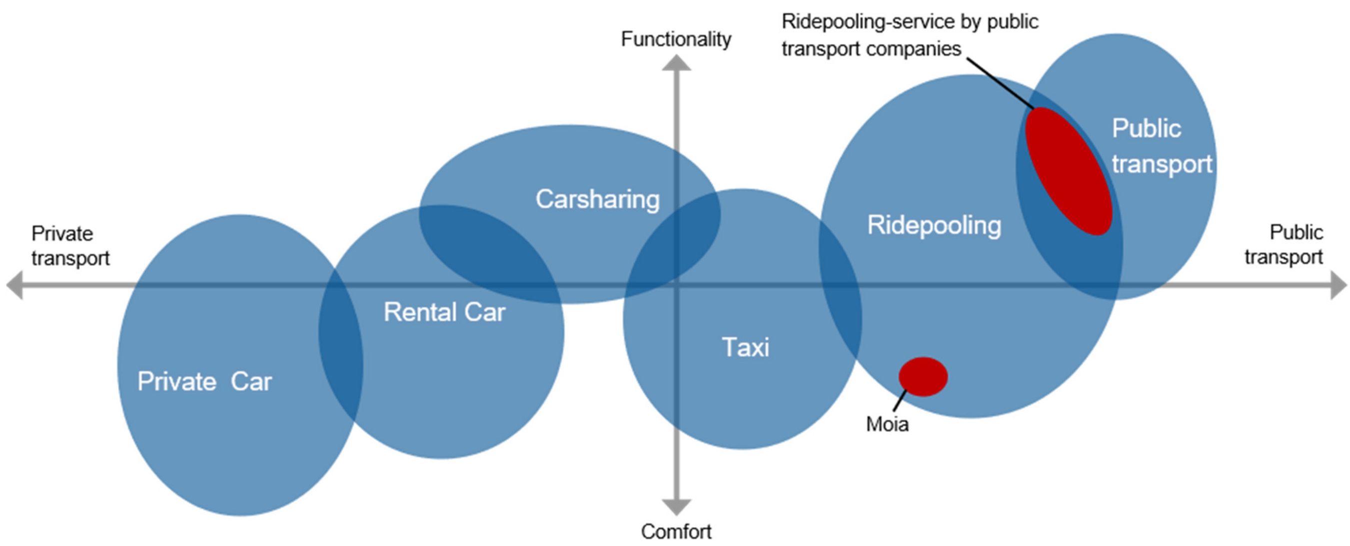

Figure 2. Position of ride-pooling compared to other mobility offerings (i.e., how it measures to the others). The situation presented and the classification made relate to the German market. Offers can differ greatly regionally due to their positioning. (Own diagram based on Gaul [18].)

Personally owned cars can be classified as individual transportation and are characterized by a high degree of driving and everyday comfort. Since rental cars are usually rented for more extended periods or at least longer distances, the aspect of convenience also dominates this concept. Both rental cars and carsharing are individual modes of transportation. While they do not really decrease the amount of traffic on roads, the space required by parked vehicles is reduced thanks to the shared use. This creates a public benefit, especially in urban areas with a high population density. When it comes to vehicle configuration and the design of the service, the focus is primarily on functionality. Trips are usually short, and customers use carsharing according to the situation. The cab is found approximately at the origin of the coordinate system. Since the vehicle is not shared, it is still a form of individual transport, but it is possible to use a cab only as part of a travel chain for which, for example, there is no public transportation alternative.

An example of this is the way home from the train station. Due to temporary mobility restrictions caused by (a lot of) luggage, the cab is preferred for such a trip. This demonstrates the functionality of cabs. In addition, the fact that passengers are driven and that other actions associated with self-driving (e.g., looking for a parking space) are not necessary also increases convenience. Public transportation is the counterpart to the privately owned car. It is public transportation that bundles different travel requests and thus reduces traffic on the road. A trip by public transportation is functional and is intended to transport customers from A to B at a low cost. The functionality aspect is also visible in the vehicles used, which do not reach the same level of convenience as, e.g., cabs, but are rather optimized for efficient use of space, inclusion, and easy cleaning.

Ride-pooling is positioned between cabs and public transportation. The idea behind pooling is to actively reduce the volume of traffic. The large area that ride-pooling occupies on the diagram illustrates its potential. Ride-pooling occurs in very different stages and forms. Depending on the design of the offer, it is possible to promote both the integration into the public transportation system as well as the convenience of the service. There are a variety of possible combinations. In addition to the design of the app (e.g., the design of the app such as MOIA) and the pricing structure, the selection of the vehicles plays a decisive role, as this is the most significant point of contact that the customers experience during the realization of the service, the transportation to the destination. Looking at the design of today's offerings, it becomes clear how enormous this design scope is.

Services provided by urban transportation companies are integrated into existing public transportation services and thus overlap with them. Vehicle concepts tend to be robust, barrier-free, and functional. The BerlKönig is an exception here. The vehicles used are slightly modified and try to be more comfortable. MOIA has advanced this optimization further with vehicles explicitly developed for the service (MOIA Pluto). With the purpose-built vehicles, the aspect of convenience has shifted more to the fore. This different design of the services makes it possible to address different customer groups (for example, leisure-related users such as students, night-owls, etc.). The mobility options of public transportation benefit from the whole range of all options. Ride-pooling has the potential to be a pull factor and accelerate the shift away from an individually owned vehicle to shared mobility. Ride-pooling adds a mobility option to public transportation that is comparably comfortable to personal transportation and can thus become a real alternative to the privately owned car.

Furthermore, there are reasons for deciding against owning a car. Driving a car is no longer a pleasure in everyday traffic and many young people therefore no longer have a driving license. The rampant lack of parking spaces and the associated search also costs time and energy. Nevertheless, ride-pooling does not reach the same level of convenience as a privately owned vehicle, since the trips are shared and comparable privacy as in individually owned cars cannot be achieved. This is partly due to the vehicle concepts in use today. However, new developments could ensure that the perceived difference at least becomes smaller.

The COVID-19 pandemic has shown that, in exceptional situations, users fall back on tried and tested means of transport, certainly also because the regulations of social distancing can be better implemented in cars and the risk of infection is reduced. However, the current trend shows that users are returning to public transport, and falling restrictions are giving shared mobility services back their former design freedom. In addition, the increasing traffic in urban areas and the challenges posed by the climate crisis do not make a return to pure individual transport possible. What remains is the increased sensitivity to hygiene, which must be taken into account in the future design of vehicles and services.

In addition to the considerable benefits that these ride-pooling PBVs (Purpose Built Vehicles) bring to users, as they are manufactured for specific needs, they offer vehicle manufacturers the opportunity to significantly reduce their vehicle-to-market costs [19]. For example, the average vehicle in the US costs just under $24,000, as it is manufactured on the premise of covering a wide range of users and use cases. In contrast, a PBV that is produced for a specific use case and a limited number of users may have a lower level of complexity, a less powerful engine, a more straightforward assembly process, shorter development times, and lower distribution costs [20]. According to Grosse-Ophoff et al. [20], all this can lead to a PBV costing on average 25% less than a conventional vehicle powered by an internal combustion engine. Bernhart et al. (2018) forecast even speaks of a cost-saving of over 50%.

The cost saving is not necessarily the case for the first generation of PBVs, such as the MOIA Pluto. This is a standard LCV (light commercial vehicle). It has been optimized for its purpose with many expensive modifications. In the future, the total cost of ownership (TCO) will be an important factor, so that even a much more expensive vehicle can be more profitable due to the high utility rate.

Furthermore, decreasing battery prices will lower the production costs of battery electric vehicles (BEVs) compared to combustion engines in the future, making electric vehicles competitive in terms of purchase price as well [21]. In addition, fuel savings allow BEVs to achieve cost parity when considering the total cost of ownership between 2022 and 2026 [22]. At the same time, the required diversity in the product range needs a platform concept, as otherwise the sub-variations would not be feasible.

2.2. Introduction and Comparison of Used Vehicles for MaaS

In a previous study, Dorynek et al. [23] already put the wide variety of different vehicles for the same mobility service to the test. Among other things, it was found that the vehicles are far too small for actual use. In the early days of ride-pooling services, various providers experimented with vehicles, including vehicles such as the VW eGolf. The available space is very limited here, making pooling hardly possible. The vehicles have only a few distinguishing features compared to taxis. With the exception of the provider MOIA, commercially available vehicles are used as in taxi operations. As a result, the vehicles hardly differ for users from those used in taxi service, especially when considering that the opportunity of isolating oneself from fellow passengers is hardly possible. This means that the service cannot be evaluated in a differentiated way. In the meantime, some companies have developed further, and small vehicles have been removed from their fleets. The trend in Germany is increasingly shifting towards minibuses. However, it is also evident that the vehicle plays an important role and must fit in order to be able to offer the service in a user-oriented way.

The vehicles are also difficult to recognize, which is especially relevant at (over-crowded) pick-up points. Although pooling vehicles are usually easy to recognize, it is sometimes difficult to identify the requested vehicle at more heavily-used virtual stops. Significant delays can occur especially in the vicinity of railway stations, as the vehicles do not have displays and do not have dedicated bays where they are supposed to wait. Thus, an obstruction of the traffic flow is possible here.

In the early years of ride-pooling, customer demands were met using diesel-powered vehicles. Mercedes V-Class were the most commonly-used vehicles. Now the focus is often placed on vehicles with an electric drive system and high passenger capacity. Climate change targets are forcing the sector towards electrification. Many operators complain due to the low supply, although the market is moving in that direction quickly.

The most frequently-used vehicles are compared in Table 1.

The left half shows vehicles that are not available worldwide or generally, such as the MOIA Shuttle or the Toyota JPN Taxi. Together with the LEVC TX5, they are all designed for the specific purpose of transporting passengers. The vehicles shown on the right, i.e., the Mercedes-Benz and Nissan minibuses, are not specifically adapted but are designed for the general public. It is obvious that the vehicles vary a lot. They can carry between four and eight passengers and rely on different body types.

Table 1. Comparison of currently available and frequently-used vehicles for on-demand mobility services in Germany. In addition, the Toyota JPN Taxi (only available in Japan) was included in the comparison because it is advertised as being particularly user-friendly.

Vehicle Type	**Purpose-Built Vehicle**			**Traditional Vehicle**		
	MOIA	**Toyota JPN Taxi**	**LEVC TX5**	**Nissan E-NV200 Evalia**	**Mercedes eVito/EQV Large/Extra-Large**	**MB Sprinter Mobility 23**
Length	5.99 m	4.40 m	4.86 m	4.56 m	5.14 m/5.37 m	5.93 m
Width	2.03 m	1.70 m	2.04 m	1.76 m	1.93 m	2.02 m
Height	2.59 m	1.75 m	1.89 m	1.85 m	1.91 m	2.65 m
Wheelbase	3.64 m	2.75 m	2.99 m	2.73 m	3.20 m/3.43 m	3.67 m
Boarding height	0.50 m	-	0.37 m	0.52 m	-	0.25–0.27 m
Seats	6	4	3 full + 3 tip-up	Max 7	Max 8	Max 4 wheelchairs or 8 seats
Standing passengers	0	0	0	0	0	0
Autonomous	No	No	No	No	No	No
Propulsion technology	Electric	LPG-Hybrid	Electric + range extender	Electric	Electric	Combustion engine
Range (WLTP)	300 km	≈450 km	101 km (RE 510 km)	200 km	418 km	-
Top speed	90 km/h	-	130 km/h	123 km/h	Standard 140 km/h (Max. 160 km/h)	-
Wheelchair access	No	Yes	Yes	No	No	Yes
Door opening concept	Sliding door	Conventional / opposed	Conventional / opposed	Sliding door	Sliding door	Sliding door
Seat concept	Conventional	Conventional	Face-to-face	Conventional	Conventional	Conventional

2.3. Impact of Missing Standards

If the OEMs do not develop and manufacture the right vehicle, the operators must improve the standard class. Figure 3 shows simple modifications made by a provider to its Mercedes-Benz Vito. To facilitate access, a grab rail was installed in the vehicle at the rear sliding door. In addition, a wooden step stool was made, which is carried in the luggage compartment. This is placed next to the vehicle when needed in order to reduce the entry height for passengers by another step. This shows that the providers are not satisfied with the vehicles in operation and that experience has been gained and used for making improvements.

Figure 3. Necessary conversions because conventional series-production vehicles do not fully meet the required specifications (image rights are held by Pikmi (VBZ)). The provider in Zurich carried out the conversion work in 2021 after it had consulted on the suitability for everyday use in an internal workshop.

3. Materials and Methods

3.1. Literature Review

During the evaluation of vehicle concepts in use, it was possible to identify major weaknesses regarding user-centered design and ergonomic vehicle design. The lack of user-centricity explains the failure of anthropometric-friendly vehicle design by (autonomous) shuttle bus manufacturers, which is made clear by the seats and seat configuration of the shuttle buses [24]. The shuttle buses have not yet been adapted to user requirements and the various user groups. This contrasts with the realization that, for in-vehicle automation and shared mobility, the overall focus is on the passenger experience and sensation [25]. To achieve this goal, ergonomics, handling, and design need to be integrated into the technical development process from the outset [26]. Ergonomic design ensures that the final product is usable and comfortable for the user groups [26]. Before adopting or redesigning the vehicle concept, the first step should be to review the relevant literature for specific recommendations. By researching recommendations for dimensions and vehicle concepts in the area of ride-pooling, it can be seen that there is still a large gap in this subject area.

Customers are likely to find that vehicle concepts become obsolete only after a few years, even though their technical components are still in good condition [19]. Market research proves the decreasing interest in vehicles when ownership changes to service. Due to a very high usage rate, the vehicles used will reach their EOL (End of Lifecycle) significantly faster than with previous use. To maintain customer enthusiasm accordingly, it must be possible to react quickly to continuously changing wishes and requirements. For this to happen cost-effectively, a modular design is needed in the development of PBVs.

Conventional vehicles must fulfill different tasks of the users, including not only short trips for shopping and going to work, but also longer trips for excursions or holiday trips. The seat design must therefore cover the entirety of the scenarios. Trips lasting several hours are also considered and must be covered to a certain extent, depending on the vehicle class.

In the case of PBVs for ride-pooling, narrow usage limits are set, and the seats must offer good support, especially on short trips. In contrast to conventional car seats, there is a significantly increased change in use at the same time. The driving profile in the ride-pooling scenario is also very different from that of a traditional passenger car; due to lower cornering speeds, less lateral support is required. Elaborate adjustment options for the seats are not necessarily required. The surfaces must be designed for heavier use compared to conventional passenger cars. Table 2 lists the different set-ups and adjustment travels for conventional seating options. The variance and resulting complexity are immense and should not be underestimated. At the same time, entries and exits are becoming more important and should be supported.

Table 2. The solution space of current and future seating concepts as a morphological box (own table based on Baumgartner [27]). Almost all available vehicles in Europe in 2021 were inspected for the analysis.

Seating concept											
Driver's workplace		Available	Not available								
Number of seats		1	2	3	4	5	6	7	8	9	
Number of rows of seats		1	2	3							
Number of seats first row		1	2	3							
Number of seats second row		1	2	3	Seat row not available						
Number of seats third row		1	2	3	Seat row not available						
Alignment first seat row	**Basic orientation**	In the direction of travel	Against the direction of travel	Parallel to the direction of travel	Variable						
	Turning possibility	Not rotatable	Small angles <15°	180° rotatable							
	Longitudinal adjustability	Adjustability within the classical seat adjustment field	High longitudinal adjustability (approx. 500 mm)	No longitudinal adjustability							
Alignment second seat row	**Basic orientation**	In the direction of travel	Against the direction of travel	Parallel to the direction of travel	Variable	Seat row not available					
	Turning possibility	Not rotatable	Small angles <15°	180° rotatable	Seat row not available						
	Longitudinal adjustability	Adjustability within the classical seat adjustment field	High longitudinal adjustability (approx. 500 mm)	No longitudinal adjustability	Seat row not available						
Alignment third seat row	**Basic orientation**	In the direction of travel	Against the direction of travel	Parallel to the direction of travel	Variable	Seat row not available					
	Turning possibility	Not rotatable	Small angles < 15°	180° rotatable	Seat row not available						
	Longitudinal adjustability	Adjustability within the classical seat adjustment field	High longitudinal adjustability (approx. 500 mm)	No longitudinal adjustability	Seat row not available						
Basic form of all seat rows		Triangle	Rectangle	Rhombus	Circular	Staggered	Asymmetrical				
Type of seat first row		Standing seat	Folding seat	Classic seat	Bench	Rotating seat	Relax seat	Reclining seat	Lounger	Different	
Type of seat second row		Standing seat	Folding seat	Classic seat	Bench	Rotating seat	Relax seat	Reclining seat	Lounger	Different	Not available
Type of seat third row		Standing seat	Folding seat	Classic seat	Bench	Rotating seat	Relax seat	Reclining seat	Lounger	Different	Not available
Armrests	**Position**	At every seat	Only at selected seats	Not available							
	Assembly	Fixed	Foldable	Concealing	Not available						
		To its own seat	To the door	In the centre console	In the seating bench	Not available					
Centre consoles		In each row of seats	In selected rows of seats	Mobile centre console	Not available						
Luggage/ Storage space	**Volume**	<200 L	200–400 L	400–600 L	>600 L						
	Integration	Integrated into the interior	Separate from the interior	Partly integrated in the interior and partly separated from the interior							

The seat is of great importance for the comfort of the passenger. A relaxed and stable position must be provided to ensure that passengers can work, read, and sleep. The view should not be restricted, and the view should be directed towards the road to prevent motion sickness. This affects the seating arrangements in the vehicle. The vehicle interior is a living space, especially due to the role switch from driver to passenger.

For this reason, there must be storage space for personal belongings, and the feeling of space must correspond to the intended use of the vehicle. The color scheme of the interior, the design, and the interior headlining influence the overall impression of the vehicle. Especially in the case of passenger transportation shuttle buses, boarding and exiting must be possible for all user groups, including users with limited mobility. Finally, every vehicle must guarantee safety. This includes, for example, seat belts that are comfortable, safe, and easy to use [28]. The ergonomic aspect of the passenger compartment is significantly influenced by the people themselves, their dimensions, freedom of movement, and accessibility limits [28].

Within the framework of the UNICARagil project for the further development of automated vehicles and their architecture, founded by the Federal Ministry of Education and Research, an autonomous taxi concept was developed, among other things. Kipp et al. [29] investigated the interior concept and the requirements for an automated driverless taxi. In a vehicle that is intended to allow the occupants to work as well as rest, the preferred viewing direction should be in the direction of travel. In addition, the seat height H30 (called by developers in packaging [30]) should be around 400 mm and adaptable to different anthropometric sizes. The seats should be equipped with armrests and tables folded into the armrests. The height of the table should also be adjustable to suit the user's needs. In addition to that, the seats should also offer at least two seating positions. Various options for stowing luggage should be considered in the design. In addition to the fixed seats, UNICARagil's auto taxi offers seats that fold in the opposite direction of travel, which can be moved across the vehicle's width. If the seats are not in use, the free space can be used, for example, as an additional luggage rack.

Another recommendation from the relevant literature concerns the vehicle at total capacity. In this case, an area for multifunctional use is required. Barrier-free access must also be guaranteed for every vehicle [31]. Mueller et al. [31] recommend a seating configuration of six seats, standing room for four persons, and additional space for luggage.

In the research conducted by Christopher Wilson et al. [32], the user experience and related interior design in autonomous vehicles were investigated, and explicit design recommendations were developed. These reduce discomfort or increase the comfort experience. Screens should be placed above the passengers so as not to influence their peripheral vision and direct it to the outside world. This reduces susceptibility to kinetosis. It is also recommended to limit the rotation of seats to 10° to avoid injuries and kinetosis. Seat belts should be built directly into the seat in order not to restrict the freedom of movement of occupants. It is recommended to pay special attention to the storage of objects during the ride in the future. Items used while the vehicle is moving also require some form of securing in case of an accident or unplanned braking of the vehicle [32].

3.2. Preparation of Expert Interviews and Workshops

In order to create a vehicle model that is specifically tailored to the needs of shared commercial passenger transportation, it is first necessary to identify those boundary conditions that differ from the development processes of conventional vehicles. To better understand the industry's necessary user demands and requirements, the current situation was investigated with the help of an expert survey. To this end, 15 experts from Germany were interviewed and asked to assess the current situation of ride-pooling in Germany.

The expert survey provided insight, experiences, and expertise from different perspectives. Among others, stakeholders and experts from operators, the public sector, OEMs, and the consulting industry were interviewed. All interviews were conducted in German and semi-structured with a guideline that contained eight questions. The focus of the interview was on the vehicles to be offered, including their equipment features. The OEMs were particularly interested in the topic so that workshops were held afterwards.

Thus, some of the interviewees were rejected to be recorded, and written notes were taken. The conversations started with a short introduction followed by an explanation of the interview procedure. The interview then moved on to general questions regarding current ride-pooling conditions, operations, and more specific questions referring to the demand for ride-pooling from a user and operator perspective.

4. Results

4.1. Expert View—Interviews for Identifying the Gap

We were provided with many interesting aspects and insight, which will be discussed one after the other in the following. Firstly, many problems and challenges were reported that occur due to unsuitable vehicles. Current vehicles are not designed for the application and are developed accordingly. That said, there are also no specifications that precisely specify what is required so that vague concepts are on the road. However, there is no longer any experimentation or new development to a large extent, as cost pressure is immense. Vehicles such as those from MOIA are the upper end of the scale and overshoot the mark. For example, a single shuttle bus costs up to €300,000, which is a lot more than that of competitors. The suppliers' ideas of what should be achieved diverge widely, even though it is the same product. Much capital is needed to turn all the ideas into reality.

Positive practical examples and experiences were also described. Since the first companies have been on the road since 2015, the first lessons learned have been derived, and the best practices were created. The output will be presented below in the five thematic blocks that concern the vehicle.

4.2. Entry and Exit

For the trip to begin at all, the entry must be suitable. The floor height still has to be lowered properly. Hand grips installed at a wide entry are desirable. Entries above the road surface higher than 400 or 500 mm are not suitable for everyday use and cannot be handled by everyone. Clever packaging coupled with technical progress can be the solution. A battery pack height of 135 mm in five years is likely and possibly even lower. The rise of other battery technologies and higher energy densities will allow for change. Another possibility would be to move the batteries from the middle floor onto the axles or under the seats.

With regard to demographic changes, the primary goal must be to guarantee people their independence, even in old age, for as long as possible. Otherwise, the health care system will collapse. This target group also wants to remain active and mobile because the desire to travel never really goes away. In addition, there is a risk of unnecessarily putting some client groups under stress because they feel that they are hindering the whole process. Unique solutions for entry are always costly, and not only for the technical enhancements themselves. It requires significant training and maintenance efforts.

4.3. Seating

The most significant point of contact in the vehicle is and remains the seat, but due to the short driving time, the focus of development shifts there as well. As a result, it is necessary to understand the use cases precisely. For example, one could easily remove the armrests and offer very spartan seats, which would be entirely comfortable. Hygiene is also a factor that should not be underestimated in shared mobility. This can lead to a complete rejection of the concept. Looking at the seat, one could also argue about other surfaces, contouring, and upholstery. That said, everything must comply with the applicable laws, which in turn depend on the application. Somebody must safeguard the product's liability. For short trips of less than 30 min, most would not adjust their seat and area precisely. After all, they would then need to be reset after the trip, and the driver certainly will not always (want to) do that.

Positioning in the vehicle is often debated, and recommendations vary widely. In (series) production vehicles, people sit too close to one another. An example is the spatial construction in minivans developed for the Asian market, where elbows easily bump together. As a result, personal space is violated, which not every guest might accept. After all, one's private space is to be maintained; otherwise, the experience resembles that of public transportation.

However, the head restraint, i.e., a wider headrest such as in MOIA vehicles or ICE, is extolled as being very positive. When transporting children or families, seat shells/child seats are essential, since no one wants to bring their own. For many, faux leather is recommended as it is more durable than velour, which is easy to slip on. Some respondents argued for modern fabric technologies that are highly hygienic.

4.4. Loading and Unloading

The perception is quite different when taking luggage with you or transporting objects. On the one hand, one's car is frequently used to transport stuff or run many kinds of errands. Whether shopping at the supermarket, DIY, or furniture store, people need to stow their purchases somewhere. On the other hand, shopping online is also flourishing. More start-ups and traditional market players deliver almost everything in a few minutes. There are also other means of transport, so not everything has to be served by ride-pooling. However, it is necessary to provide enough space for walkers, strollers, and hand luggage as well, since these things are an integral part of everyday life. Ideally, a boot and tailgate can be dispensed with, as this entails additional operating steps. This poses a risk of injury or safety in everyday use. It can be another cause of delay and lateness. After all, one's own luggage should not be that accessible to third parties.

4.5. Complexity Reduction and Scalability

The more diverse the shuttles, the more difficult it becomes. Complex vehicle systems have to be understood and operated by temporary staff. Most drivers are students or senior citizens and mainly work to earn extra money or voluntarily. Vehicle problems are compensated or compounded by the workforce. Sometimes drivers shy away from these additional tasks because they find them annoying and unpleasant. After all, they are only paid for driving.

A good vehicle concept creates acceptance among users (can help win new customer groups) and among driving personnel, as this is scarce. Based on accounts provided by inclusion taxi operators, we know that lifts are more accepted than ramps. That said, one should not underestimate the complexity of the technology in day-to-day operations, as has already been confirmed by the study conducted by Dorynek et al. [33].

What does the application of small, divided, commercial passenger transportation look like? Vehicle body manufacturers can respond to individual wishes and thus offer batch size one. A common industry standard, as it is for (large) city buses, could help, but there is no need for groundbreaking innovations because the individual parts are already mastered. The possible scaling of a purpose-built vehicle is otherwise difficult. Anything can be built. More handles are likely but already exist as well.

4.6. Other

Due to the other use, the driver's seat has now become a workplace. With changing driving personnel, i.e., several people using one vehicle, time is lost due to the need to regularly readjust the seat. Between trips and shifts, drivers want and need to take a break. They cannot always return to the depot. In addition to that, drivers also want to pass the time during loading breaks. For instance, they many want to listen to their own music/radio station without disturbing passengers.

Overall, the appearance must fit into the mobility concept. Further variations with larger fleets can experiment with higher/more variable prices and comfort seats. A catalog of ergonomic requirements alone is of no use if it cannot be fulfilled. The focus is clearly on the benefits of each passenger and their needs.

Vandalism is not a problem since drivers are always present, and users are registered and not anonymous. The feeling of safety has not been negatively noticed so far.

The employees in charge often have no corresponding knowledge or previous experience in the sector. They sometimes come up with inconceivable ideas so that the gap between what is possible and what is not is sometimes huge.

Due to the rapid developments in entertainment and communication electronics, OEMs should not compete. Otherwise, the vehicles will quickly appear outdated or old-fashioned. A good interface with a fast-charging function should be the goal instead. The possibility of playing advertisements for customers during the entire trip and using the free spaces should be further considered.

4.7. Concluding Remark

The London Cab is a good starting point but would have to be modified for the application. The following changes would be necessary first: it should be 1 m longer, 20 cm higher, and offer two more seats. Vehicles such as the Mid-City Buses, which are currently in use, are designed as cargo variations for logistics or pallet transport. For example, the sliding door is 120 cm wide, whereas 80 cm would be sufficient. Other novel door concepts fail either because of crash and safety requirements or sealing problems. There may be problems with liquids entering the vehicle or the seals freezing in cold conditions (or any other issue).

A particular buffer capacity would be ideal for rush-hour. It should not be forgotten that public transportation does not stand for luxury. Functional bells and whistles are unnecessary and only complicate the vehicles or make them more susceptible to repair. Uptime, i.e., the time such cars are on the road, transporting customers and thus generating revenue, must be maximized. The focus must be on robustness, easy cleaning, and repair. After all, these drain financial resources over the long-term and are decisive differentiators vis-à-vis the clientele (no one wants to be on the road in dirty or old-fashioned vehicles; rental companies renew their fleets constantly for good reasons). Since the COVID-19 pandemic, we know that surfaces must also be able to withstand all disinfectants.

Overall, all experts agreed that a new mobility service such as MoD/ride-pooling requires new and different vehicles.

5. Discussion

5.1. Benefits from a Purpose-Built Vehicle

Conventional vehicles intended for private use are developed on the premise that they can be used for various purposes. This means that they are not really optimized, however, for any of these purposes. For example, a privately-owned conventional vehicle is used to do the shopping, commute to work, and go on family trips, among other things. However, the requirements are not optimally met for any of these purposes. With the introduction of PBVs, the focus in development is shifting to conceptualizing vehicles manufactured for a specific purpose. This enables concept optimization, as the developed PBV is specifically tailored to the requirements derived for the particular purpose. Thus, the precise definition of the purpose is the fundamental prerequisite in the development of PBVs.

5.1.1. Shifting from a Driver-Centered to a Passenger-Centered Experience

The future mobility shift from private vehicle ownership to shared mobility concepts requires a rethinking in the development of PBV concepts. As a result, the focal point of vehicle design is shifting from the driver to the passenger. Formal requirements relating to the driver's cab are moving to the background and will eventually disappear with the future introduction of autonomous systems. This, in turn, will lead to a greater need to address the requirements of the passenger. Accordingly, the development of PBVs in the future requires a passenger-centered (user-centered) approach. This is the most important constraint in development, as the main objective should be to ensure maximum fulfillment of requirements. However, the exact definition is still pending or has not yet been made.

5.1.2. Focusing on Functionality

Conventional vehicle concepts focus primarily on drivers, as they are in most cases the prospective buyers or customers. In contrast, the focus of PBVs for shared mobility is on the functions offered to the passenger and for fulfilling the operator requirements. This includes functionalities regarding the use of space, especially for passengers with limited mobility and more effortless operation in the overall context of the service. The added value is thus no longer defined by driving characteristics but by new passenger-oriented functions [34]. Characteristic features and key figures such as top speed and acceleration, on the other hand, only play a subordinate role.

5.1.3. Development Focus on Interior Conceptualization

Compared to the development process for conventional vehicles for private ownership, the development of PBVs for shared mobility should shift the focus more to interior design. The exterior design becomes less critical as fleet operators or service providers own the vehicles. Thus, in contrast to the conventional development process, where the interior is determined independent of the exterior design, the interior is designed first, and the exterior is adapted to it. This leads to the development process being reversed to a certain extent and running from the inside to the outside.

5.1.4. Modular Design

As purpose-built vehicles will be part of a digital mobility service, they will have to evolve at a similar pace similar to consumer electronics compared to traditional vehicles. Customers are likely to find that vehicle concepts are obsolete after only a few years, even though their technical components are still in good condition [19]. To maintain customer enthusiasm accordingly, it must be possible to react quickly to continuously changing wishes and requirements. To do this cost-effectively, PBVs require a modular design. This means that the individual assemblies, such as seats or displays, can be quickly and easily replaced with modified versions. This can be ensured at various levels, such as the entire vehicle through the platform strategy, in which the whole vehicle consists of two modules. On the one hand, there is the driving platform, which includes all drive modules, and on the other hand, there is the vehicle cabin. So, the interior can be easily replaced for a new vehicle model, but the driveline can be taken over from the old model. This ensures significant cost savings.

5.1.5. Increasing System Attractiveness and Leveraging Synergies

With the many changes in our daily lives, existing mobility services need to be better connected and timed in users′ interest. The COVID-19 crisis accelerated the shift to teleworking, and during the period of mobility restrictions, companies and employees had to perform their work online wherever possible. It is predicted that employees will pursue a hybrid form of work in the future, i.e., work partly from the home office and partly in the office. Thus, the individual mobility requirement for trips to work is likely to decrease slightly. The same applies to business trips. For example, the pandemic has shown that various business trips can be avoided and are more efficient and less expensive online. In summary, it can be said that one or the other route will be eliminated as a result of new possibilities offered by digitization, which will further reduce the occupancy rate of existing public transport vehicles. By introducing new vehicle concepts, an increase in interest in such mobility services is to be expected, since previous disadvantages will be eliminated. In times of MaaS, an on-demand shuttle is considered a guarantor for multimodality. To enable the mobility of people in Germany, there is a dense network of different options and offers from which people can choose. This offer structure differs in detail locally very much. For example, new mobility services in particular are generally found in metropolitan areas and are not available in rural areas. Thus, residents of these areas cannot include such an option in their choice. This kind of new vessel would be quickly ready for use and could be scaled to the respective place of application accordingly. In this regard, there are already many considerations. For example, a flexible shuttle could replace weak scheduled services or connect new development areas with existing public transportation. Even the fine distribution from the station on the first and last mile would be solvable herewith.

5.2. Possible Adaptations in the Seating Environment

A comparison will be made between conventional seats and the possible seating concept of an on-demand service. Considering the large number of different vehicle seats, many comparisons would be conceivable. Since this is an investigation during the concept phase, we restricted the solution space to a more abstract level. During the course of gathering information, experts in seat development were asked about the possibilities and boundary conditions of such a development.

Based on these findings, the possibilities were outlined and sorted into categories. This resulted in the framework in Table 3. It compares the various requirements in four main categories and divides them into requirement (R), desire (D), or not required (NR). Due to indispensability, the categories with requirements are highlighted in red. The possible savings potential is shown in the next column with up to three € signs. In addition, further comments can be found on the far right. Finally, the central technical properties are indicated in the lower section. However, no details were given here for a purpose-built vehicle.

Table 3. Potential analysis in seat development for PBVs compared to existing seat concepts. For comparison, a conventional vehicle seat is used, as it is installed in most vehicles in Europe today. The potentials are estimated based on five main categories previously addressed by the experts.

Category		**Requirement**	**Passenger Car (Passenger Seat) Requirement [R]/Desire [D]/ Not Required [NR]**	**PBV (Passenger Seat) Requirement [R]/Desire [D]/ Not Required [NR]**	**Savings Potential [€] with Elimination**	**Remarks**
The requirements for adjusters and comfort functions differ considerably between passenger cars and PBVs. Only a few points are congruent.						
Seat adjusters and Comfort	1	Electric seat adjustment	D	NR	€€€	Nice to have
	2	Seat belt height adjustment	D	D	€	Useful for comfort & safety when passengers do not conform to the norm.
	3	Longitudinal adjustment	R	NR	€	Necessary for passenger cars, also to be able to adjust the legroom in the second row. Rather not desired for PBVs.
	4	Height adjustment	D	NR	€€	Nice to have for co-drivers in cars, not absolutely necessary in PBVs due to short distances and transport times.
	5	Backrest angle adjustment	R	D	€€	

Table 3. *Cont.*

Category		Requirement	Passenger Car (Passenger Seat) Requirement [R]/Desire [D]/ Not Required [NR]	PBV (Passenger Seat) Requirement [R]/Desire [D]/ Not Required [NR]	Savings Potential [€] with Elimination	Remarks
	6	Headrest: Minimum in 2 ways adjustable (if not integrated)	R	D	€	Important safety feature in passenger cars, similarly important in PBVs but tends to be impractical because passengers may not take the time to adjust the headrest to themselves.
	7	Seat cushion tilt adjustment	D	NR	€€	Not needed for PBV. In some cases considerable savings potential in terms of costs and development time. If necessary, seat heating can be considered, as it is easy to implement and low cost - in addition, it is already almost part of the standard equipment in most vehicles.
	8	Seat cushion extension	D	NR	€€	
	9	Side bolster adjustment	D	NR	€€€	
	10	Lordosis support (min. 2-way)	D	NR	€€	
	11	Memoryfunction	D	NR	€€	
	12	Massage function	D	NR	€€€	
	13	Seat heating	D	NR	€	
	14	Seat ventilation	D	NR	€€	
	15	Angle adjuster in y/ rotating seat rail	NR	D	€€	For PBVs, possibly interesting to increase privacy.
	16	Relax/recline function	D	NR	€€€	An absolute luxury feature in modern passenger cars. Not necessary or not desired in PBVs.
Environment	17	USB port	D	D	€	Nice to have
	18	Grab handle	NR	R	€	Necessary in the PBVs to facilitate access for all passengers.
	19	Armrest	D	D	€€€	Can have a significant impact on comfort, but can also be a cost generator - depending on the solution & effort involved
	20	Storage area	R	R	€	Suitable for both vehicle types
	21	Storage compartment	D	NR	€€€	Storage compartment for PBV not necessary: Danger of things being forgotten in it
	22	Cupholder	D	D	€	Practical and can be implemented relatively inexpensively

Table 3. *Cont.*

Category		Requirement	Passenger Car (Passenger Seat) Requirement [R]/Desire [D]/ Not Required [NR]	PBV (Passenger Seat) Requirement [R]/Desire [D]/ Not Required [NR]	Savings Potential [€] with Elimination	Remarks
Ergonomics	23	Seat height: Even small people equipped with good all-round visibility	R	NR	-	In the PBV, privacy may take priority over good all-round visibility.
	24	Headroom: Tall people should be able to sit upright	R	R		Absolute necessity
	25	Good entry & exit	D	R		Much more important due to frequent entries & exits in PBV.
	26	Good to very good lateral support	R	D		With PBV good entry & exit > Side support (height of side bolsters)
Material	27	Easy to clean / washable	D	R		Today's hygiene standards require a maximum of cleanliness and, if necessary, the possibility of disinfection, especially for ridesharing and ridepooling concepts.
	28	Seat cover with high coefficient of friction	D	D		Can significantly support the lateral support. Especially for seats of PBVs where the side bolsters should not be so pronounced to ensure good entry and exit.
	29	High abrasion resistance	R	NR		Significantly lower number of entrances & exits in the passenger car, therefore lower requirements than in the PBV
	30	Very high abrasion resistance	D	R		
Technical data	31	Seat cushion hardness	6 ± 0.5 KPA *	?		
	32	Backrest hardness	6 ± 0.5 KPA *	?		
	33	Height side bolsters seat cushion	20.8 mm (For Reference) *	?		
	34	Height side bolsters backrest	40.4 mm (For Reference) *	?		
	35	H point height	421.5 mm *	?		

* values of the Mercedes-Benz V-Class/e-Vito in the second and third row of seats.

In the context of seat development, it is unrealistic to initiate entirely new trends rapidly. The number of pieces and tools are designed and optimized for other processes. Otherwise, it becomes costly. As soon as a significant or critical change is made, the entire seat must be cleared again. The requirements for homologation and other approvals should not be underestimated. High crash requirements must also be met, which cannot be circumvented. All extras, such as lumbar support or electric adjustment, show higher equipment costs.

Simple seat concepts still predominate, or the take-rate is considerably high in the lower-priced segment. A viable option: based on an existing seat, one could be tempted to adopt it. If the carrier and basic frame are not changed, no new extensive testing needs to be carried out. Foams and covers can still be changed. Seats in airplanes or train seats have much lower complexity. The focus here was elsewhere, namely maximum lightweight construction vs. suitability for everyday use or traveling comfort. Both are significantly more resistant and easier to care for. However, the application in the vehicle must be explicitly examined, as the boundary conditions are entirely different and, for example, vibrations play a role again, which was not taken into account before. With new kits, extra equipment can be considered early so that it is easy to react to later adaptations and costs remain low. Some solutions are already pre-developed. The focus for innovations and new developments is on Generation Z.

Reference is made to the incredible complexity of seat development. There are many people involved and lengthy processes that cannot be easily changed. Through iterations, development and production are now highly optimized. Therefore, this use case should instead be located in the commercial vehicle industry. There, small quantities and particular adaptations are easier to implement. This was also the case with Volkswagen's MOIA Pluto. With the many expected passenger changes, the seat concept should support easy and fast boarding and exiting.

On the one hand, this can be taken into account in the package through a higher arrangement. On the other hand, active systems would be conceivable and easy to implement but are more expensive. Of course, this can be expanded further and can lead to changes in the entire vehicle concept. Many user-friendly attributes known from family vans or residential properties are not necessarily allowed. For example, the seats may not be rotated while driving, and folding tables may only be used when stationary. Anything else is invalid according to the operating permit. There is a lot of company-internal and -specific knowledge that is not easily shared or published. Thus, superficial knowledge can be found in a few standard works. New technologies are already being used on a global scale, such as dirt-resistant and antibacterial covers. Conventional car seats will not stand up to the strain over time and will need rehashing. However, they are not designed for this, i.e., you cannot simply change the cover, foams, etc. They are assembled in the factory once in their lifetime. Replacement is theoretically possible but not common in practice and cannot be done by one person alone. Standards and specifications are completely different depending on vehicle class. A simple example is that seats in trains must be inflammable, but in buses, everything is allowed. A new vehicle class or registration category could create clarity here and simplify many things.

6. Conclusions

On-demand mobility services should support different customers in their everyday mobility and make public transportation more attractive. To achieve this, vehicle concepts must be analyzed, optimized, and tested from the passengers' point of view. The increasing shift from privately owned motorized transportation towards shared mobility is creating entirely new market segments. OEMs and other participants from the mobility industry must position themselves at an early stage. One such market segment is the so-called "purpose-built vehicle" for ride-pooling services. Companies may manage to establish themselves early in this emerging market segment, win customers, and gain valuable early experience. In that case, they will already be well prepared for the next step towards autonomous driving services.

Overall, PBVs could significantly reduce their vehicle-to-market costs and further customize and fully integrate the user experiences. Our work revealed weak spots in currently used ride-pooling vehicles, and possible improvements for future (autonomous) shuttle buses were identified. For this purpose, an expert survey and workshops were conducted to determine user-specific requirements for ride-pooling vehicles. Based on the work undertaken, it can be clearly stated that new needs and requirements are placed for this vehicle type.

Since every provider will have special requests, this can hardly be taken into account in vehicle production. Automobile production lives on other quantities. Everything else is a unique construction and/or the subject of body manufacturers/converters. As a result, prices automatically go up.

So far, the ride-pooling fleet in Germany is still very small, which is why both the level of awareness and the share of the modal split are low. Larger fleets could increase public awareness and make the development of PBVs economically attractive. This would subsequently lead to an improvement in the quality of service.

The design of ride-pooling vehicles offers much room for further research. Comfort is, therefore, a subjective interpretation of an interplay of different sensations based on experiences, expectations, and preferences [35]. New mobility is a very young field and thus enables ergonomics to be integrated into the vehicle development process from the beginning.

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