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Exploring the determinants of autonomous minibus adoption: empirical findings from a demand-based service in Germany

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Abstract

Autonomous on-demand services as part of public transport are discussed to improve public transport substantially. A household survey in Karlsruhe, Germany, was conducted among inhabitants of a residential area where a combined autonomous and on-demand minibus service with automation level 4 was offered. The study investigates the residents' appraisal of this service and reasons for using and not using it. Results indicate that people generally have a positive attitude towards it and are willing to use it in the future. Difficulties are found in travel speed, availability, and complexity of using such a new service. Favorable factors in the intention to use the service are having a mobility impairment, being open to other forms of new mobility, and not having a car in the household. In the future, to be successful, such services should improve travel times and reliability and address issues of their primary target group, such as the high complexity of accessing these services.

Keywords Autonomous minibus, User acceptance, Household survey, On-demand, Demand responsive transport

1 Introduction

To protect the climate and the environment, national governments worldwide have set themselves the goal of strengthening public transport [45]. However, traditional public transport reaches its limits in many applications. For example, sufficient services cannot be provided at reasonable costs in areas with spatially dispersed demand, at off-peak times, or generally in areas with a lower population density, resulting in low shares of modal split for public transport [17, 30]. Moreover, providing attractive access and egress to and from existing public transport infrastructure is still challenging for transportation planning. With the technological progress in recent years toward vehicle automation with the goal of self-driving, these difficulties could be overcome [44]. According to its application in the public transport system, one promising technology is the establishment of autonomous minibuses. These are much smaller than conventional busses, engineered to efficiently transport a small number of people, and aim to drive fully autonomously, making it a cost-efficient and flexible transport mode [31, 32]. However, automation and, consequently, abolishing a bus driver could also place burdens on possible users as these are not only drivers but also service providers for passengers [4, 15]. Nevertheless, the technology and, hence, the adoption of the mobility service itself is still in the early stage of its development.

While research on the acceptance of autonomous mobility concepts, in general, has already begun several years ago [1, 37], its focus in public transport just started in the past few years [6]. In Germany, for example, the first implementation of an autonomous minibus took place in Bad Birnbach only in 2017, the first minibus operating on public roads. Since then, projects such as 'Seemeile' (Berlin), 'TaBuLa' (Lauenburg), 'EMMA' (Mainz), and the A01 minibus line operating in

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'Monheim am Rhein' have initiated further projects with such vehicles in many other places in Germany [47]. Outside Germany, the first projects started only a few years earlier. One of the first initiatives took place within the CITYMOBIL research project in the European Union, whereby a minibus operation was tested in Trikala, Greece, at the end of 2015 and the beginning of 2016 [35]. Similar projects followed worldwide.

However, past and current projects differ in the mode of operation of the minibuses. According to Klinkhardt and Kagerbauer [22], the services offered by autonomous minibuses can be divided into three dimensions: temporal, spatial, and functional. This classification distinguishes the operation of a minibus, e.g., whether it runs according to a fixed timetable or on-demand (temporal), in which area the bus is used (spatial), and which form of operation is chosen, i.e., a designated line operation or demand-driven routes (functional). Each combination may result in a different mode of operation and, hence, other implications for the willingness to use those buses. Consequently, researchers must continue their work and investigate minibus operations in various operational modes. Moreover, the term "autonomous" is only used for simplification. The vehicles in the mentioned projects typically move along previously set "virtual tracks". In the five levels of autonomous driving according to the Society of Automotive Engineers' (SAE) J3016 [38], they, therefore, only meet level 2 or 3, depending on the interpretation, as they are not able to react to traffic situations other than with braking and acceleration processes. In the event of obstacles on the route, they stop, and driving personnel must intervene. Consequently, research also must focus on minibus operations with a greater level of automatization, which is still scarce in practice. This conclusion is also supported by the work of Pigeon et al. [34], who found that the level of automation is less considered in current research on the acceptance of autonomous minibuses.

In Karlsruhe, Germany, an autonomous minibus service test operation was carried out in 2021 called "EVA Shuttle", which differs significantly from many other autonomous minibus services. The project was one of the first on-demand minibus services operating autonomously in a designated area. In contrast, previous projects have been either an on-demand service or have been run autonomously, but not at the same time. Hence, the vehicle did not travel on a virtual track but reacted to the traffic situation independently. It avoided obstacles on its own; intervention by the driving personnel was only necessary for exceptional situations. According to the project initiators, it was the first time with such a mobility service in the minibus domain in Germany that automation level 4 was achieved [18, 43]. The higher level of automation was achieved by the project partner 'FZI Research Centre for Information Technology' upgrading technologically advanced EasyMile buses ('EZ10 Gen2') with additional sensors and software.

Hence, at the example of the EVA Shuttle, this study extends existing research on the use and non-use of autonomous minibuses, considering the new level of automation and its innovative operating mode, i.e., the on-demand service operated autonomously. Extending other studies, not only are passengers asked, but a household survey is conducted addressing all residents within the district where the service was offered to investigate their willingness to use and not to use such a new service. After presenting existing literature on the use of on-demand services, i.e., demand responsive transport (DRT), as well as autonomous mobility services, the survey's methodology and results are presented in this paper, and conclusions for further adoption of autonomous minibus operations are drawn.

2 Literature

Due to the novelty of an autonomous minibus service that runs in an on-demand operation, the study presents literature on both research streams in the following paragraphs. Hereby, acceptance studies from both study areas are focused, and results obtained in other empirical studies in Germany, Europe, and worldwide are presented.

2.1 Autonomous minibus services

Research on the adoption of autonomous minibus services shows that people who have already used autonomous minibuses and those who have not used them have a fundamentally positive attitude toward them [8]. People who have already used them show even slightly more positive approval ratings [3, 6, 25]. Even if most people have only few safety concerns about autonomous minibuses, it is considered an essential factor for the acceptance of the service [6]. Past and ongoing research revealed that minibuses are often used out of curiosity or technical interest. In Bad Birnbach (Germany), for example, it was shown that only 13% used the service because the bus route was suitable for their destination [36]. However, in Trikala, Greece, where an autonomous minibus was implemented as a timetable-based bus operation, people also started integrating the new service into their everyday mobility [35]. Nevertheless, in that case, the newly installed minibus service was used for trips previously done by bicycle or foot.

Studies also emphasize that users of autonomous minibuses are more likely to be male and younger than non-users [9, 20, 35]. This finding is supported by studies of new on-demand mobility services where young males are often the largest proportion of the so-called "early adaptors" of such a new service [21]. In contrast, females, elderly, and mobility-impaired people are regarded to use autonomous minibuses less likely [20]. However, several studies present considerable advantages in such a service, especially for vulnerable groups such as mobility-impaired people, if adequate access to the services is considered [26]. A recent study on Germany's first automated minibus fleet in a regular service could support the latter empirically. The busses were implemented as a timetable-based operation enabling low-level access and, hence, attracting primarily elderly, female, and mobility-impaired passengers [4, 15].

People with an affinity for public transport have a strong interest in the service; the potential of usage is shown by the fact that access to public transport is eased by autonomous minibuses [23]. In general, studies emphasize the presence of a positive attitude towards automation technology as a necessary prerequisite to using autonomous minibuses [50]. Moreover, the environmental friendliness of the minibuses plays a vital role in the acceptance of the service [6]. In addition, people request flexibility and reliability of such services as crucial determinants for adopting autonomous minibuses [13]. In some cases, however, the projects would raise high technological expectations, which the vehicles do not yet meet at the current stage of development [28, 51]. For example, people often complain about the low speed of the minibuses, which typically cannot drive faster than 20 km/h and usually do not even reach this speed in practice [10].

2.2 Demand Responsive Transport (DRT) services

Services offering rides on-demand as part of public transport exist in many places. They need to be differentiated from bus services that run only by request but with a fixed schedule and line. As described by Schasché et al. [39], DRT services "react to actual user demand only, thus, need to be booked in advance. […] DRT services are not bound to a set course or timetable and mostly utilize small floor buses." Vansteenwegen et al. [46] further differentiate a DRT service by three degrees of responsiveness. They have existed for several decades – see, e.g., Ambrosino et al. [2] for the description of a service in Firenze (Italy) since 1996 – however, they have emerged much more in recent years. Nowadays, they often use online booking instead of booking by telephone (see Schasche et al. [39]).

Schasché et al. [39] conducted an extensive literature review on studies of demand-responsive transport services, analyzing 44 research papers with socio-scientific methods, many based on case studies from actual DRT services. Many articles highlight the potential of DRT for specific target groups, primarily commuters, elderly people, and impaired people. While most studies take place in urban areas, it is in rural areas where the social performance dimension (e.g., geographical coverage of public transport) seems most central [39]. For example, some studies discuss elderly people as a potential target group, especially when telephone booking and short walking distances are apparent [19, 48]. However, there are also studies stating the opposite, explaining this with unfamiliarity with modern technologies as a particular obstacle to acceptance in this group [19, 40].

Wang et al. [48] show that DRT services are used more in less populated areas and that women use them more before retirement age. After retirement age, no gender differences are seen. Dotterud and Skollerud [27] find – based on three services in rural Norway – that DRT services help elderly people do grocery shopping by reducing the distance required to walk and thus helping them maintain an independent life. Gkavra et al. [14] support this finding. Furthermore, they show – based on two services in rural Austria – that a DRT service can, to a large extent, attract trips that otherwise would have been done by car.

One of the earliest and large-scale modern services was 'Kutsuplus' in Helsinki (Finland) from 2012 to 2015. As analyzed by Weckström et al. [49] for this service, public awareness can be a major issue for DRT services. They conclude that "the lack of marketing was seen by many as one of the main failures" because "the respondents who had not tried the service would, in many cases, have liked to be informed about this option". This shows that it can be challenging, but informing people about such services is essential. Similar observations were already mentioned by Enoch et al. [12] for earlier services.

Another literature review on DRT services, focusing on the European region, was conducted by Campisi et al. [7]. In addition to the previous studies, the authors elaborate on the systematic and regulatory requirements for implementing a DRT service and its position within the overall public transport system. They conclude that the adaptability of a DRT service to its context is a crucial barrier to overcome. A more detailed overview, focusing on DRT services in Italian rural areas, is provided by Pavanini [33]. A further focus on DRT services in rural and interurban areas, in general, is discussed in Martí et al. [29]. They stress that in a rural context, the flexibility of a service should only be increased when it matches the demand, achieving an economically sustainable service. Moreover, potential is seen to install a DRT service in a multimodal transportation system.

3 Study background

In the EVA Shuttle project, an autonomous minibus was developed and operated in passenger service in Karlsruhe, Germany. In the first phase, the EVA Shuttle operated daily from 21 April 2021 to 30 June 2021. In the second phase, from 1 July 2021 to 1 August 2021, the service only ran on weekends. In both phases, the operating hours were between 8 am and 6 pm. The service area comprised a large portion of the district Weiherfeld-Dammerstock in Karlsruhe, Germany. It had an extension of about 1 km in west–east direction and between 200 and 700 m in north–south direction. The area is predominantly built with detached, semi-detached, and multi-family houses. Thus, it is a typical, relatively densely populated, suburban residential area. There is mixed traffic on the streets, with motor vehicles, bicycle traffic, and pedestrians. A suburban rail stop is located at the edge of the service area (see Fig. 1). In addition, a bus line runs on the central axis every 20 min.

As described in the introduction, minibuses constructed by EasyMile have been used, which were technologically upgraded to allow a SAE level 4 operation. In total, three vehicles were retrofitted and were active in the operating area. These vehicles offer 6 seating places. Since the vehicles did not run according to a timetable but on-demand, trips had to be requested by booking in an app. For this purpose, the technical platform of another project participant (ioki) was used. Although the minibuses drove autonomously, an accompanying person was present during each ride, reducing the number of maximum passengers possible to 5. However, due to the COVID-19 pandemic, the maximum number of passengers was restricted to 3. To get a better impression of the vehicles' interior, exterior, and booking process, see Fig. 2.

The service could be used for trips within the district. Furthermore, it connected to the Dammerstock suburban rail stop. The maximum speed of the vehicles was 12 to 20 km/h. The EVA Shuttle service in the spatial dimension is an area service; in the temporal dimension, it is an on-demand service. In the functional dimension, it predominantly fulfills the requirements of a last-mile service and approximately a door-to-door service. The service was offered in ride-pooling mode. A major road (Belchenstraße, west–east link) was not permitted for transit by the minibus, which prolonged travel times for many relations as detours were necessary.

4 Study design and methodology

A Computer Assisted Web Interview (CAWI) was conducted from the end of October to the beginning of December 2021 to investigate the potential transport-related effects of the EVA Shuttle service. The survey's target group were all residents in the catchment area inside the district of Weiherfeld-Dammerstock in Karlsruhe, Germany, as the service was only available in this area. Various channels were used to recruit participants. First, all the households in the catchment area were invited to participate in the online survey by direct postal mailing. Due to legal restrictions (rejection of direct postal mail), only about half of the households could be reached through this channel, i.e., about 1,400 households were invited by this way. The survey was also advertised in busy places and shops

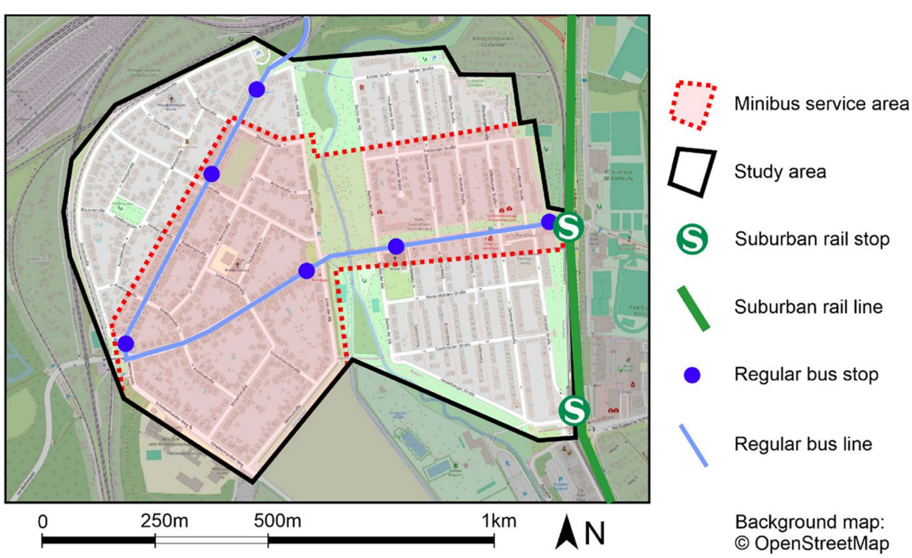

Fig. 1 Service area of the autonomous minibus and study area

Fig. 2 Interior, exterior, and booking process of EVA shuttle, Source: Paul Gärtner, Uli Deck, KVV

in the district, on the neighborhood website 'nebenan.de', and in a monthly district magazine. Another channel used was the newsletter of the citizens' association of Weiherfeld-Dammerstock. Even though the questionnaire was designed as an online survey, the invitations offered the possibility of a telephone interview. This ensured that people who are not online-savvy, especially the elderly, could also participate in the survey. To increase the response rate, participation in the survey was incentivized with the help of a raffle of gift vouchers.

The questionnaire was designed for both users and non-users of the EVA Shuttle. The survey design primarily drew upon two existing surveys from literature. Kostorz et al. [23, 25] conducted a general survey on the acceptance of minibuses in 2018. With over 1,000 participants, the deployed questions were sufficiently tested. Additionally, to capture the aspects of DRT in this study, the survey by Kostorz et al. [24] was also incorporated. They conducted an acceptance study of one of the first DRT systems in Germany, MOIA, in a large-scale study with over 12,000 participants. Both surveys served as the basis for the survey conducted in the study at hand but were expanded with components based on the literature review presented in the previous section. In summary, the survey covered the following topics:

- Availability or possession of mobility tools (car, public transit pass, memberships at mobility service providers, etc.)
- Usage frequencies of transport modes
- Attitudes towards different modes of transport
- Patterns of using EVA Shuttle in terms of a trip diary or reasons for non-use
- Evaluation of the possible applications of autonomous minibuses in general and their advantages and disadvantages

Furthermore, sociodemographic characteristics of the respondents were solicited (age, gender, household properties, etc.). The latter, the availability or possession of mobility tools, as well as the usage frequency of transport modes, were adopted from Kostorz et al. [23, 25] and Kostorz et al. [24] but are based on standardized questions from national travel household surveys in Germany. These questions are intended to contextualize the respondents' use or non-use of minibuses within their everyday mobility behavior.

Studies also showed that attitudes play an essential role in understanding the adoption of autonomous vehicles in general. Hence, and in line with the reference studies of Kostorz et al. [23–25] questions about the attitudes towards different modes of transport were added, referring to the well-tested and established item set of Hunecke et al. [16] and Steg [42], where certain items are rated on a 5-point Likert scale. To identify the further potential of such an autonomous on-demand minibus service, the evaluation of possible applications of this service in general, as well as their advantages and disadvantages, were adapted from Kostorz et al. [25]. Getting an understanding of how people used the MOIA service, Kostorz et al. [24] used, among others, a revealed preference section, where respondents were asked about their last trip and when they used the service. This technique was adapted, and participants were asked about the last trip(s) where the EVA Shuttle was used. In terms of a traditional travel diary, specific trip-related questions were asked. From the literature, it became clear that, e.g., the waiting time in DRT systems plays an important role, so this section was extended for such questions. Moreover, non-users of the service were asked why they did not use the bus. Again, these reasons were based on Kostorz et al. [23–25] as well as further reasons based on the literature review.

A total of 207 people took part in the survey. All participants completed the survey online except for six people who wished to use the telephone interview option. 165 people were recruited by direct household mailing, resulting in a response rate of this recruitment channel of 11.8%. The local recruitment measures resulted in almost 95% of the participants being residents of Weiherfeld-Dammerstock. The remaining participants also have a connection to Weiherfeld-Dammerstock – whether it is their workplace, the residence of relatives or acquaintances, or they live in the neighboring district. After conducting a plausibility check of the data for contradictory or incomplete information, the data from 202 people could be used for further analyses.

5 Survey results

5.1 Characteristics of users and non-users

Among all participants, 38 people stated that they used the EVA Shuttle service. Almost 81% of the survey participants did not use the service. Table 1 compares the sociodemographic characteristics of the survey participants, distinguishing between users and non-users of the service. Regarding the gender distribution, the non-user group matches the district's official population statistics. Thus, the survey is not biased in this factor. The group of users, however, consists of two-thirds males and thus deviates significantly from the overall residents' gender distribution. Regarding the age distribution, it can be noted that the survey respondents are older than the average residents; in other words, the young population is underrepresented in the survey. Only two survey participants were younger than 18 years. The share of people between 18 and 30 years is lower than the average of the residents within the study area. The comparison of the age distribution between the users and non-users shows

Table 1 Sociodemographic characteristics of users, non-users, and all respondents

	Users ($n=38$)	Non-users ($n=164$)	All respondents ($n=202$)	Population study area[a]
Gender				
Female	13 (34.2%)	86 (52.4%)	99 (49.0%)	51.3%
Male	25 (65.8%)	77 (47.0%)	102 (50.5%)	48.7%
Diverse	0 (0%)	1 (0.6%)	1 (0.5%)	n/a
Age[b]				
18–29 years	3 (7.9%)	14 (8.5%)	17 (8.4%)	11.9%
30–44 years	11 (29.0%)	35 (21.3%)	46 (22.8%)	19.2%
45–64 years	16 (42.1%)	80 (48.8%)	96 (47.5%)	30.4%
> 64 years	7 (18.4%)	34 (20.7%)	41 (20.3%)	22.3%
Occupation				
Full-time	17 (44.7%)	73 (44.5%)	90 (44.6%)	
Part-time	7 (18.4%)	40 (24.4%)	47 (23.3%)	
In training	3 (7.6%)	5 (3.1%)	8 (4.0%)	
Pensioner	11 (29.0%)	35 (21.3%)	46 (22.8%)	
Housewife/husband	0 (0.0%)	8 (4.9%)	8 (4.0%)	
Parental leave	0 (0.0%)	3 (1.8%)	3 (1.5%)	
Household size				
1 person	7 (18.4%)	33 (20.1%)	40 (19.8%)	49.5%
2 persons	13 (34.2%)	77 (47.0%)	90 (44.6%)	
3–4 persons	17 (44.7%)	44 (26.8%)	61 (30.2%)	50.5%
5–6 persons	1 (2.6%)	10 (6.1%)	11 (5.4%)	
Children in HH				
Yes	15 (39.5%)	43 (26.2%)	58 (28.7%)	18.4%
No	23 (60.5%)	121 (73.8%)	144 (71.3%)	81.6%

[a] Inhabitants in the area where EVA Shuttle was provided. Source: Stadt Karlsruhe [41]

[b] People younger than 18 years are not displayed, and hence, sums may not add up to 100%

that the non-users of the EVA Shuttle tend to be older than the users.

Full-time workers make up the largest share, with just under 45% each in the group of users and non-users. It is striking that the proportion of pensioners among the EVA Shuttle users is almost seven percentage points higher than in the group of non-users. This difference cannot be explained easily. It can be assumed that pensioners can generally organize their everyday lives more flexibly in terms of time since they no longer have professional obligations and are, therefore, more inclined to use such a new service. Furthermore, there are differences between users and non-users concerning household size and composition. In the group of users, people have more household members and have more often children in their households.

Furthermore, the availability or ownership of mobility tools is analyzed, such as the number of cars in the household or membership at a carsharing provider, differentiated by users and non-users of the service, depicted in Fig. 3. First, it is noticeable that the users of the EVA Shuttle own or have more mobility tools at their disposal and thus tend to be more multimodal than non-users. While both groups show a similar high ownership rate of a driving license of over 95%, the group of non-users has a car ownership rate that is eight percentage points higher (84% against 76%). The proportion of participants owning a conventional bicycle is similar in both groups and in line with the German national average [11]. Furthermore, it is noticeable that the EVA Shuttle users have a ten percentage points higher ownership rate of both a public transit pass and a discount card for national railways (BahnCard). EVA Shuttle users thus show a stronger affinity for public transport than non-users. Moreover, users and non-users also differ regarding their memberships at providers of new mobility forms such as bikesharing or carsharing. Users of the autonomous minibus are more often registered at bikesharing, carsharing, and e-scooter providers. While the differences are slight for bikesharing providers, they are pronounced for carsharing and e-scooter providers with more than 10 percentage points. Thus, users of the autonomous minibus seem more open-minded towards other new forms of mobility.

Next, the usage frequency of different transport modes is investigated. In the survey, participants were asked to indicate on a 6-point scale how often they usually use different transport modes in their everyday life. Non-available transport modes, such as carsharing for people who are not members of a carsharing provider, were not presented for the individual participants. Table 2 shows the mean values of the categorical frequency data. A smaller value means more frequent usage. These results confirm the findings from the analysis of the mobility tools. Users of the autonomous minibus own a car less often and use it less frequently in everyday life than non-users. In contrast, they use public transport more often than non-users and thus show a relative affinity for public transport in their mobility behavior. The differences can be observed mainly for the public transport modes relevant to Karlsruhe's city transport, such as bus and

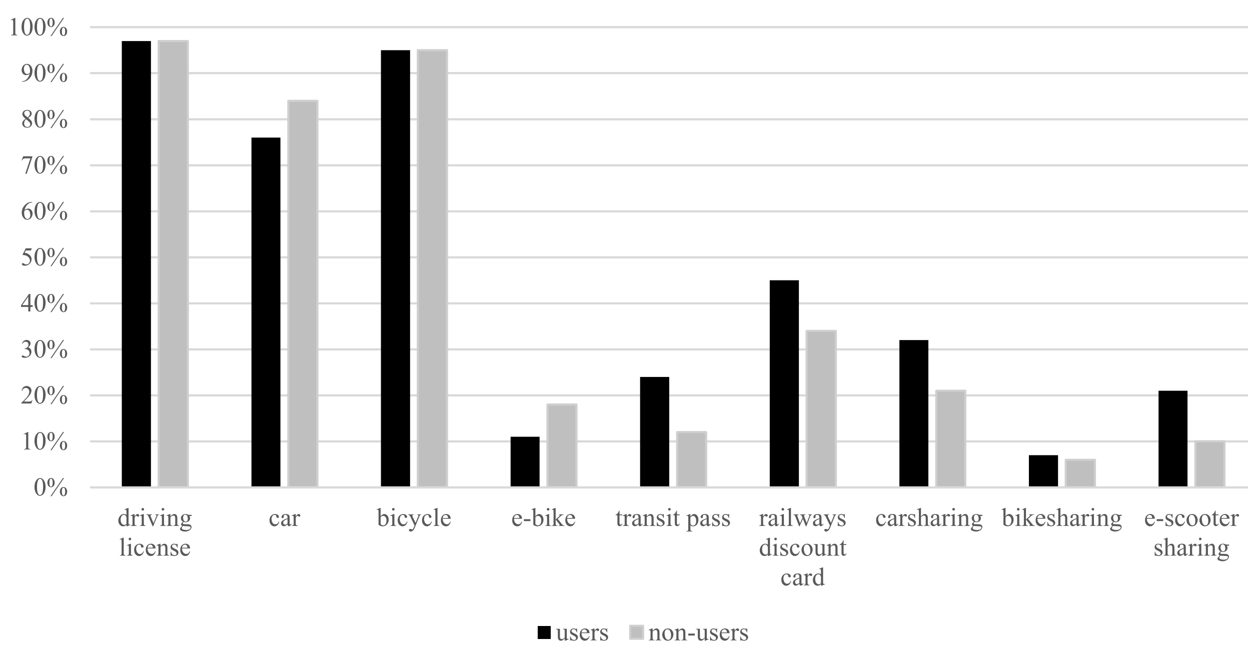

Fig. 3 Availability or ownership of mobility tools

Table 2 Mean values of usage frequency of different transport modes (larger values mean less frequent use)

	Users	Non-users	Difference
Car	2.34	2.00	-0.34
Bicycle	1.69	1.75	0.06
E-bike	1.75	1.73	-0.02
Bus	3.76	4.45	0.69
Suburban rail/tram	3.52	3.95	0.43
Regional train	4.13	4.25	0.12
Long-distance rail	4.16	4.29	0.13
Carsharing	3.83	3.73	-0.10
Bikesharing	4.00	4.30	0.30
E-scooter	4.25	3.76	-0.49
Taxi	5.08	5.09	0.01

Scale: 1 = (almost) daily, 2 = on 1–3 days per week, 3 = on 1–3 days per month, 4 = less frequently than 1 day per month, 5 = less frequently than 1 day per year, 6 = never used

urban/suburban rail, but also apply to regional and long-distance public transport. A more frequent use correlates with a higher proportion of public transit pass and BahnCard holders. Nevertheless, on average, both groups use the car more often than public transport. Concerning bicycle (including e-bike) and taxi use, users and non-users of the minibus use the modes similarly. For sharing modes, there are slight differences in diverse directions: while users use e-scooters more often, non-users travel by bikesharing more frequently.

5.2 Appraisal of advantages and disadvantages

How do users and non-users envision using an autonomous minibus in the future, and what advantages and disadvantages do they see in a minibus? The respondents stated they consider the operation of autonomous minibuses to make more sense in urban than rural areas. However, the endorsement for an operation on the urban outskirts (suburban) was higher than in the urban cores. Regarding the form of operation, the respondents could imagine using an autonomous minibus operation primarily as a feeder to stops of other local public transport or as a shuttle in clearly defined application areas such as company premises. Respondents gave the potential use of minibuses as a substitute for conventional bus services less importance.

In addition, Fig. 4 shows the evaluation of the advantages and disadvantages of certain aspects of an autonomous minibus service. The most striking disadvantage of a minibus operation is seen in possible interaction problems that autonomous vehicles might have with other road users. Two out of three respondents considered this likely, although safety concerns were rarely the reason for not using it. The respondents, therefore, seem to have enough confidence in the safety of the buses, knowing that problems can still occur during the journey. This aspect has two dimensions. On the one side, interaction problems can be seen as a disadvantage from a passenger perspective as the minibus might stop suddenly due to other traffic participants. In this sense, the interaction problem might reduce driving comfort for passengers. On the other side, interaction problems can occur from a traffic participant's perspective outside the minibus. Car drivers or pedestrians might be unsure how to behave correctly towards the minibus. More than half of the respondents consider hacking attacks or misusing personal data such as location information unlikely. Again, the perceived safety, especially concerning information technology, is overall high among the survey respondents.

Over 40% of respondents see problems in the fact that using a minibus could be more complicated than using conventional buses. Considering the reported reasons for non-use, this seems primarily due to the necessity and complexity of booking through a mobile phone app. Moreover, the absence of bus stops might affect this perception. In contrast to conventional busses, an on-demand service requires action and obligation from passengers. They must request the service for a specific time at a particular place, which requires commitment and might be perceived as more complex.

Regarding the expected benefits of autonomous minibus operations, enabling mobility for elderly and mobility-impaired people is striking: 90% of the respondents consider this benefit to be likely. The minibuses are wheelchair accessible, which may positively affect this perception. In addition, the lower driving speeds of those buses may be seen less as a problem for elderly people who have fewer time obligations in their everyday lives. Three out of four respondents also expect improved connections to other modes of public transport. This fits well with the assessment that the respondents see great potential in minibus operations as a feeder to other public transport. Presumably, due to the electric drive of the vehicles, almost 70% of the respondents expect lower emissions with autonomous minibuses. Within the study area, conventional buses still have combustion engines. It is of interest how this advantage would be perceived if conventional buses also use electric drives. The expectation of shorter travel times that could result from the use of autonomous minibuses, on the other hand, is relatively low, possibly due to the current low speeds of the minibuses.

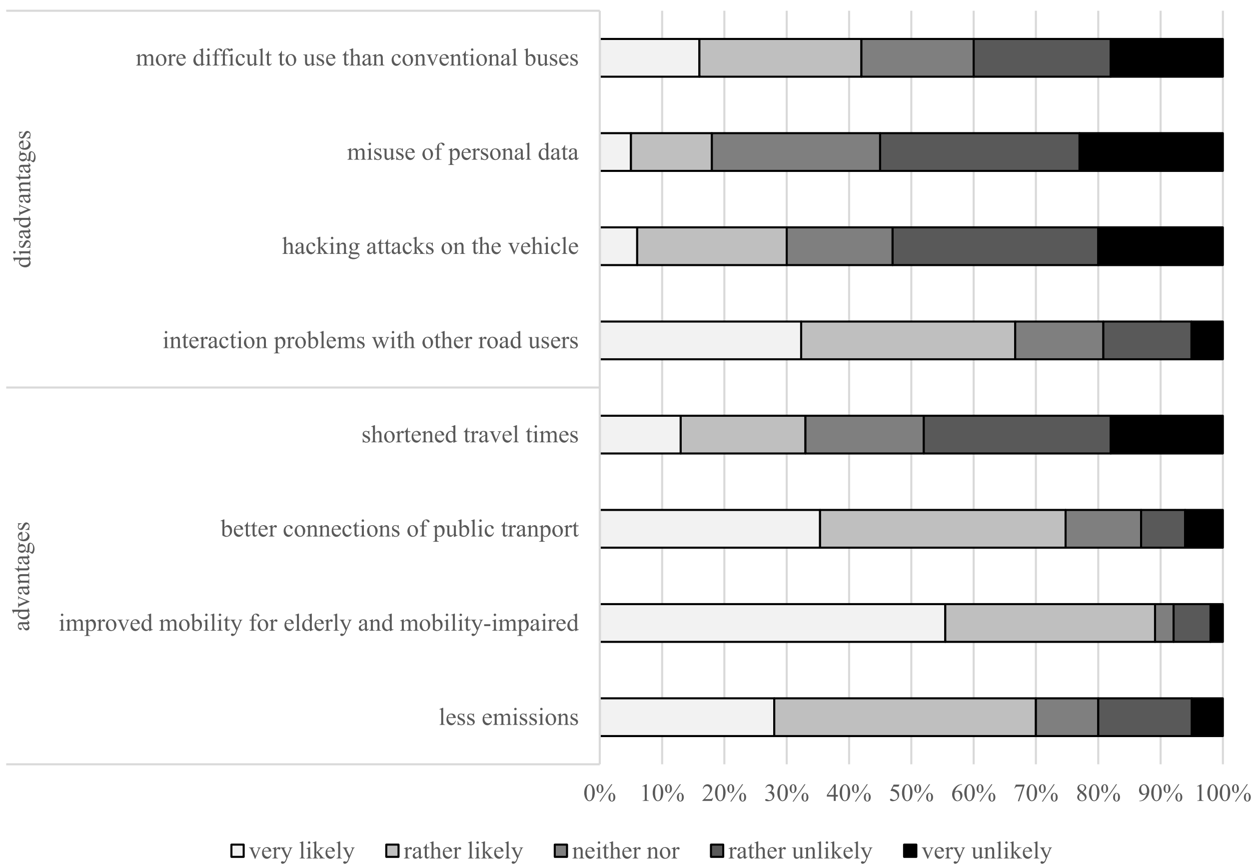

Fig. 4 Advantages and disadvantages of using autonomous minibuses

5.3 Usage of the autonomous minibus

Among the 38 users in the survey, 60% stated that they had used the EVA Shuttle once, and 34% had used the minibus two to three times, while a small proportion of the respondents used the service four to six times. None of the respondents had used the EVA Shuttle more than six times. However, about two-thirds of the users reported wanting to use the EVA Shuttle more often, but their trip request via the app was declined. To understand how the autonomous minibus was used, the users were asked to characterize with more detail a maximum of three trips on which they used the minibus (revealed preference). In this way, insight was gained into 43 reported trips with the EVA Shuttle. Not all participants who made more than one trip with the minibus also reported other trips.

The EVA Shuttle usage times analysis shows that over half of the reported trips (56%) were made between Friday and Sunday, with most trips (25%) reported on a Saturday. As described, the operation was restricted to Saturday and Sunday in the second test phase. Therefore, a clustering of reported trips on weekends was expected. During the typical operation between 8 am and 6 pm, there are noticeable peaks of usage in the morning (10 am to 12 pm) and afternoon (2 pm to 4 pm). During these peaks, about two-thirds of the reported trips took place.

Participants were also asked to indicate the travel time in the EVA Shuttle. The reported average was 13 min. The distribution of the reported travel times is shown in Fig. 5. The trip times are relatively long considering the size of the EVA Shuttle's catchment area and the associated relatively short distances that can be covered by the minibus. In addition to the maximum speed of 12 km/h, this can also be explained by the closure of a main road for this service. In addition, the respondents reported an average occupancy of 2.5 passengers during their journey, mostly travelling without companions. This means that other people were picked up during the rides. This results in a higher number of stops, which negatively impacts travel time in addition to the low driving speed.

Regarding the trip purposes for which the EVA Shuttle was used, two-thirds of all trips were made to try the new service. The second most frequent use of the EVA Shuttle (14%) was on leisure trips, followed by 7% each on trips to the doctor or shopping trips.

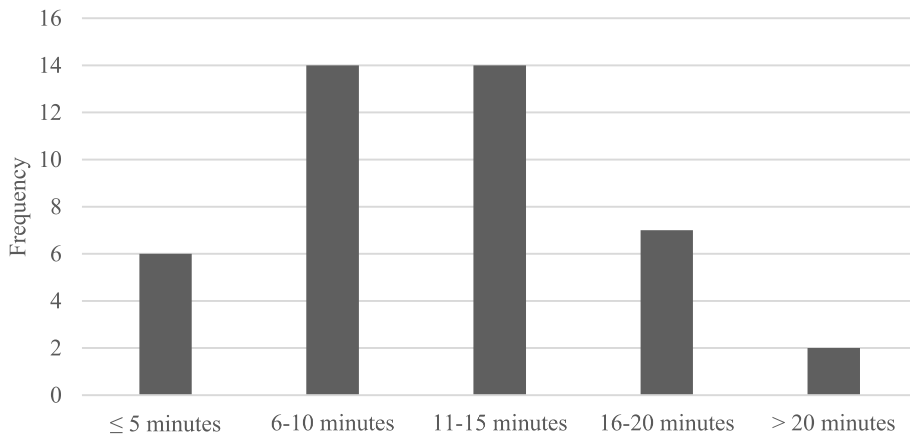

Fig. 5 Distribution of reported trip times in the EVA Shuttle

For over 90% of the reported trips, both the start and the destination were within Weiherfeld-Dammerstock. Therefore, the EVA Shuttle was primarily used to access one's district. Besides few exceptions, the respondents accessed and egressed the EVA Shuttle by foot, showing that the minibus was primarily used to access one's neighborhood.

As the EVA Shuttle operated on-demand, trips had to be requested in an app, which could result in varying waiting times depending on the service's utilization. Therefore, the survey participants were asked to indicate their waiting time for the EVA Shuttle. In addition, they were asked how long they would have been willing to wait at most. The comparison of both times is shown in Fig. 6 as a difference function across all users. It becomes clear that the users in the study's sample mostly had to wait shorter than they would have been willing to.

5.4 Non-usage of the autonomous minibus

Also, non-users' motives for not using the service are of interest. For this purpose, possible reasons for non-use were suggested to the survey participants. In addition, they had the option to report other reasons. The results are shown in Fig. 7. Two out of three respondents stated that they did not see a need for the EVA Shuttle and, therefore, did not use it, which is the most frequently selected reason. The low speed of the minibus was given as the second most frequent reason (by every third non-user). This leads to the assumption that many respondents did not see a need to use the service because they could reach their destination faster by other modes of transport.

One in five people did not use the minibus because of the booking process, which was the third most frequent reason. Respondents also stated in the free text that they generally found the booking process complicated and that the requirement of using a smartphone to book a ride excluded them from using the service. The lack of

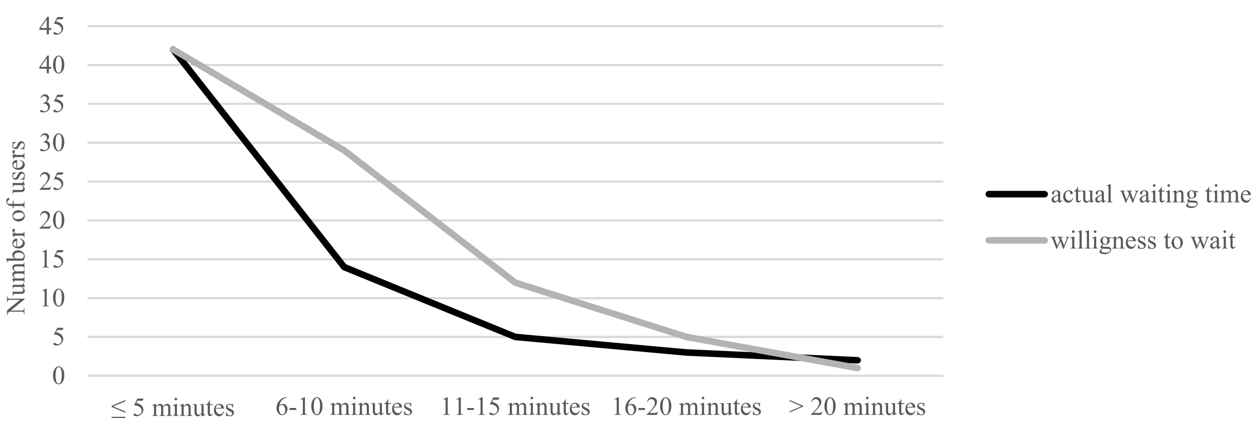

Fig. 6 Comparison of the actual waiting time with the waiting time willingness

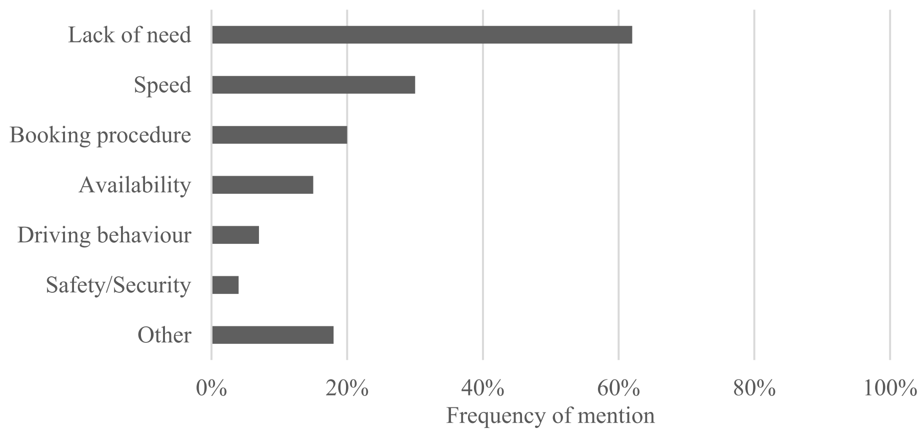

Fig. 7 Reasons for not using the EVA Shuttle

availability of the EVA Shuttle was also mentioned as a barrier to use. In fact, 14% of non-users stated they wanted to use the autonomous minibus, but their ride request could not be served (two-thirds of the users also reported a request could not be fulfilled). Therefore, the number of users could have increased with a higher availability of the EVA Shuttle. Only a small proportion of the reasons for non-use were related to the driving behavior of the vehicle or safety concerns regarding the automation technology. Other reasons for non-use given by the respondents were mainly external. Firstly, the specific situation around the pandemic and the associated avoidance of public transport was cited as an impediment. Respondents also reported that they did not have the time to test the service or were unaware that the minibuses were already allowed to be used – they had understood the test operation to be closed to the public. This shows the high importance of the effective promotion of new mobility services.

5.5 Intention to use autonomous minibuses in general

Besides the actual use of the service provided, survey participants were asked the following question to understand the intention to use minibuses in the future: Would you be willing to use an autonomous minibus in the future?

74% of the users said they would use autonomous minibuses in the future (see Table 3). Among the non-users, 67% intend to use such services. Thus, although many survey participants did not use the EVA Shuttle for various reasons, around two out of three stated they could imagine using such a minibus in the future. Thus, they show a primary intention to use, which could be transformed into the actual usage of an autonomous minibus service by reducing the reasons for non-use mentioned above.

In the following, a deeper analysis of the people willing to use such services in the future is performed. The mean values of positive attitudes towards using the service by different characteristics of the people are depicted in Table 4. Compared to the actual use (cf. subsection "Characteristics of users and non-users"), it can be observed that the difference between people of different genders and age groups is much less pronounced.

Among all sociodemographic groups, the intention to use the service is similarly high. However, it can be observed that while retired people have used the service more often than other groups, the intention to use it in the future is below average. The most considerable difference for people willing to use such services in the future are people with mobility-related impairment: 91%. While the size of this subsample is not very large ($n = 11$), and thus the result must be treated with caution, this high figure of acceptance is striking.

Concerning the ownership of mobility tools and usage of other modes, the subsample with the highest

Table 3 Intention to use autonomous minibuses

		Users of EVA Shuttle ($n = 39$)	Non-users ($n = 163$)	All ($n = 202$)
Intention to use autonomous minibuses	**Yes**	74.4%	66.9%	68.3%
	No	25.6%	33.1%	31.7%

Table 4 Intention of using autonomous minibuses in the future by different categories

	Share of people with an intention to use		Share of people with an intention to use
Gender		**Railway discount card ("BahnCard")**	
Male ($n=100$)	72%	Has rail discount card ($n=70$)	71%
Female ($n=98$)	64%	Has no rail discount card ($n=128$)	66%
Age		**Public transit pass**	
30 years and younger ($n=19$)	63%	Has local transit pass ($n=28$)	75%
Between 31 and 50 years ($n=55$)	73%	Has no local transit pass ($n=170$)	67%
Between 51 and 69 years ($n=97$)	66%	**E-scooter-sharing**[a]	
70 years and older ($n=27$)	70%	Registered customer ($n=24$)	79%
Impairment[b]		No e-scooter-sharing customer	67%
Has a mobility-related impairment ($n=11$)	91%	**Car ownership**[a]	
Has no mobility-related impairment ($n=187$)	67%	At least one car in household ($n=162$)	66%
Occupation		No car in household ($n=36$)	78%
Full-time employed ($n=90$)	72%	**Public transport usage**	
Part-time employed ($n=47$)	70%	At least twice a week ($n=30$)	70%
Retired ($n=45$)	62%	Less frequently ($n=168$)	68%
Other occupation ($n=16$)	56%	**Bicycle usage**[b]	
		Daily ($n=105$)	73%
		Less frequently ($n=93$)	62%
		Car usage	
		Daily ($n=47$)	68%
		Less frequently ($n=151$)	68%

Statistical tests (t-tests) were performed

[a] Indicates that the differences among the groups in this category are significant on a 90% confidence level

[b] Indicates that the differences among the groups in this category are significant on a 95% confidence level

acceptance of such services are people registered at an e-scooter-sharing provider (79%). Furthermore, people who do not have a car in the household present a similarly high share of using such services (78%). Moreover, people who tend to use public transport with a discount card or a transit pass show a higher acceptance, though this difference is not statistically significant. Interestingly, actual public transport usage does not have a visible influence on the usage in the survey. Instead, using a bicycle frequently has a greater positive effect on the intention.

5.6 Attitudes influencing the EVA Shuttle usage

Respondents were asked about their attitudes towards different modes of transport to derive motives behind using different modes. The survey participants rated various transport-related statements on a 5-point Likert scale (1= fully applicable, 5=does not apply at all). A selection of the answers of the survey participants is shown in Fig. 8.

Almost two-thirds of non-users agree at least partially with the statement that they feel safe and protected in the car. In the group of users, the share is lower. At the same time, the statement that strangers sometimes come too close in an unpleasant way in public transport receives higher agreement among non-users than among users of the autonomous minibus. Both motives could be reasons why non-users of the EVA Shuttle use cars more often in their daily lives and, conversely, public transport less frequently. They see a car as a safe space with a high level of privacy, which they value over public transport usage. Furthermore, transfers and waiting times prevent non-users of the minibus from using public transport more than users. This could also be the reason why non-users are more likely to agree that it is difficult for them to make their everyday mobility by public transport. On-demand services such as the EVA shuttle aim to increase the connection to other public transport modes. Due to the on-demand character, waiting times might be reduced with such a service, and the use of public transport might be promoted among today's non-users.

Furthermore, fewer non-users than users state they can organize their everyday lives very well without a car. They seem to be more dependent on their car than the users. Interestingly, both groups attach high importance to climate and environmental protection when choosing

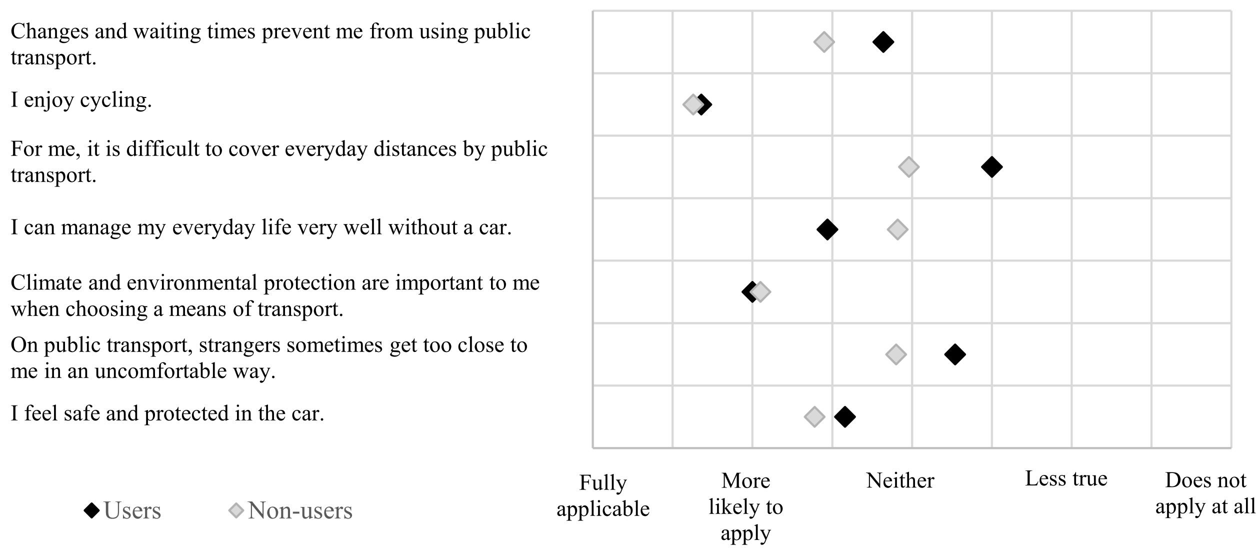

Fig. 8 Attitudes towards modes of transport; differentiated by users and non-users of the EVA Shuttle

a mode of transport. This suggests that non-users would also give up the car for climate and environmental protection if they experienced less dependence on the car in their everyday life and thus had easily accessible alternatives available. The generally high level of climate and environmental awareness in the mode choices of both groups is consistent with the fact that both users and non-users choose cycling as the most common transport mode. Accordingly, at least four out of five survey participants from both groups stated that they enjoy cycling – the agreement is even slightly higher among non-users than users.

6 Discussion and conclusions

The findings from the household survey on the EVA Shuttle are primarily in line with the results of other studies, although the service differed in the level of automation and its operating mode compared to most other services. Users are more likely male and younger than non-users, e.g., as Dong et al. [9] already stated. However, in addition to other studies, this study could highlight that while the usage of this trial service was influenced by gender and age, the intention of future usage is not dependent on these factors to a significant degree. In principle, people show a positive attitude towards using an autonomous minibus service, which was also identified in many other studies, such as Christie et al. [8]. However, despite the rare presence of that positive attitude, the study at hand could give insights into the indicators that form that positivity. People value the low emissions, the provision of mobility for elderly and mobility-impaired people, and the increased connectivity to public transport. At the same time, potentially occurring hazards are rated as improbable, making an autonomous minibus a mobility service that has many benefits but does not affect one negatively even if they do not use it.

Users of the minibus were generally more open-minded to new forms of mobility. They indicated a stronger affinity for public transport and a lower dependence on private cars than non-users of the service. Even for the non-users of the EVA Shuttle, the survey revealed a general open-mindedness towards the future use of an autonomous minibus. In contrast to the minibus service in Trikala (see Portouli et al. [35]), but in line with most other studies, such as Rauh et al. [36], the main reason for using the EVA Shuttle was to test the service. That the service was not integrated into one's everyday mobility may be related to its considerably low reliability, which was identified as an essential factor for the acceptance of such services by Etminani-Ghasrodashti et al. [13]. Although the survey revealed a potential for using such a service in everyday life, a non-negligible proportion of actual trip requests could not be fulfilled due to the unavailability of busses. Moreover, 14% of non-users specifically wanted to use the EVA Shuttle, but their request could not be fulfilled. Hence, with an increase in the reliability of the service in the future, the number of users could be increased. Hereby, a sufficiently large fleet of vehicles could increase the availability of the service and thus the willingness and possibility to use it.

In contrast to the study by Kassens-Noor et al. [20], this study's survey indicates that mobility-impaired people especially expect to use such a service in the future. This may be related to the on-demand characteristic of the EVA Shuttle, which is inherently beneficial for mobility-impaired people as a door-to-door service is possible. Consequently, the research emphasizes the findings of Lee and Kockelman [26] that a particular focus in developing such services must be put on the appropriate access for this group of people. Access relates not only to the physical requirements of the busses and infrastructure but also to the booking process of an on-demand autonomous minibus. In the study at hand, a complicated booking process of the service could be identified as a barrier to use the shuttle. The exclusive access to an autonomous minibus service via an app that can only be operated via mobile devices prevents people without a smartphone, for example, from using this service. This primarily affects the elderly population. However, enabling mobility precisely for this group was seen as the greatest advantage of a minibus operation in the survey. Therefore, future projects should offer alternative access to the minibus that is as simple as possible, such as is the case with Germany's first automated minibus fleet in a regular operation that attracted, e.g., elderly and mobility-impaired people due to its easy accessibility (cf. Görgülü et al. [15] and Barthelmes et al. [4]). This result is also supported by literature on DRT systems, where usage potential was identified for elderly people when a telephone booking was possible (cf. Wang et al. [48] and Jittrapirom et al. [19]). Furthermore, the survey showed that communication is essential in introducing such a new service. Based on the literature review, this can be mainly related to the on-demand character of the service, which requires more marketing communication than traditional services (cf. Weckström et al. [49] and Enoch et al. [12]. Higher travel speeds of minibuses can further increase demand for a minibus service, as the minibus could then compete more with other transport modes in terms of travel times.

In addition to hurdles that still need to be overcome, the study of the EVA Shuttle showed a high potential for using autonomous minibuses. High potential is seen for elderly and mobility-impaired people. For this group, an on-demand service is particularly suitable due to its increased flexibility. However, a minimum automation level of 4 in the future is a prerequisite for providing that operation mode. Hence, future research should mainly focus on comfortable access to autonomous minibuses for those people. Moreover, autonomous minibuses shall simplify the transfer to other public transport forms and reduce waiting times, e.g., through the on-demand pick-up service, in the future. However, for that purpose, autonomous minibuses need higher travel speeds and more flexibility to encourage non-users to use the minibuses and, thus, public transport.

Even though this study offers interesting insights, some limitations need to be considered. First, the test operation of the EVA shuttle was performed during the COVID-19 pandemic, limiting the number of passengers and, hence, the number of possible users. Second, the test operation was only over three months, making it challenging to integrate the service into one's everyday mobility and caused the service's public availability to be partially unknown. Moreover, probably not all people who wished could use the service, possibly skewing the sample. Third, due to the local character with a restricted catchment area, the overall number of survey participants was limited. Hence, results were less statistically robust, especially for distinct sociodemographic groups such as younger people who are underrepresented in this study. Still, comparing the results obtained in the study at hand with existing literature could support the verification of the results. Also, other studies could show that already small sample sizes are sufficient to obtain reasonable results. As an example, Görgülü et al. [15] did a minibus passenger survey among 74 people and could validate the results with a consecutive representative household survey with approx. 1.400 participants. Barthelmes et al. [5] conducted a campus mobility survey among 53 participants and could also show the plausibility of the results obtained by comparing the results with a national travel household survey. For future research, this study can deliver valuable insights into the research questions to be analyzed. Based on these results, the study could elaborate interesting starting points for consecutive studies on the adoption of autonomous on-demand minibus services that need to be deepened in representative studies. Furthermore, the study gives policy-makers hints on the challenges and potentials of autonomous on-demand minibus services, which they can use in the trade-off where such a system may complement or substitute a conventional bus service.

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Authors' contributions

The authors confirm contribution to the paper as follows: study conception and design: L. Barthelmes, G. Wilkes, M. Kagerbauer, P. Vortisch; data collection: L. Barthelmes, G. Wilkes; analysis and interpretation of results: L. Barthelmes, G. Wilkes; draft manuscript preparation: L. Barthelmes, G. Wilkes. All authors reviewed the results and approved the final version of the manuscript.

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Availability of data and materials
The data used in the study has not yet been shared publicly. The funding body is currently reviewing the data's open-access provision. As soon as the review is approved, the data will be shared.

Declarations

Competing interests
The authors have no competing interests to declare.

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