Accompanying Research on Automated Minibusses in Monheim am Rhein

Report on Results

Institute for Transport Studies
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Short summary

The shift towards sustainable transportation has led to the expansion of public transit as a central objective. An innovative step in this direction is the introduction of automated minibusses, which have been deployed in Monheim am Rhein since February 2020 as Germany's first automated minibus fleet in regular service. The aim of the city and Bahnen Monheim as the operator of the small bus fleet is to make public transit more attractive through the automated minibus service, increase traffic safety, and familiarize the population with automated driving and, thus, digitization.

The Institute for Transport Studies at the Karlsruhe Institute of Technology (KIT) accompanied the introduction and operation of the automated minibus fleet in Monheim am Rhein over a period of two years with empirical studies to explore the acceptance and impacts on the mobility behavior of the Monheim population. By conducting repeated passenger interviews, usage patterns and behavioral changes over time since the introduction of the service are identified. Interviews with the accompanying personnel of the automated minibusses provide additional insights into the acceptance of the novel service. Based on a household survey among all residents of Monheim am Rhein, representative insights into the attitudes of users, especially non-users, are obtained.

The results show that primarily women, older people, and individuals with mobility impairment use the existing service. For the latter two groups, in particular, the automated minibus serves as a facilitator of mobility. The integration of automated minibusses into the existing bus network has increased the accessibility of public transit and further promoted its use. Overall, high satisfaction levels among users of the automated minibusses and a clear willingness to use them among non-users are observed. Safety concerns regarding the automation technology of the automated minibusses

cannot be identified among the residents, partly due to the presence of accompanying personnel. Of greater importance is the service function perceived by the accompanying personnel themselves, as well as by the passengers, such as assistance with boarding and exiting. Despite the generally positive perception, the accompanying research identifies expansion potential of the automated minibus service to reach a larger user group. This includes measures, such as increasing travel speeds and improving driving behavior, as well as expanding the service area, such as intermodal use as a feeder to the nearest train station. The study suggests considering further information campaigns to promote a unified understanding of automated driving and the automated minibus service. This can create additional acceptance for the current weaknesses of the service.

Table of contents

List of figures

List of tables

List of abbreviations

CAPI	Computer-Assisted Personal Interview
CAWI	Computer-Assisted Web Interview
IfV	Institute for Transport Studies
IU	Infrequent users of the automated minibus
KIT	Karlsruhe Institute of Technology
km/h	kilometers per hour
m	meters
NUP	Non-users of the automated minibus with usage potential
NUWP	Non-users of the automated minibus without usage potential
RP	Revealed preference
RU	Regular users of the automated minibus
SP	Stated preference
UF	Usage frequency

1 Introduction

The German government, along with many other countries worldwide, is making efforts to expand its public transportation system to promote sustainable transportation. This is being done in various ways to encourage people to use eco-friendly modes of transportation. One such method is the use of automated minibusses, which are smaller than conventional busses and designed for efficient and flexible passenger transport. They are also expected to increase the reliability and environmental friendliness of public transport. Automated minibusses allow for more flexible routing at potentially lower costs and better consideration of individual needs compared to traditional bus routes. Additionally, this transportation option aims to reduce the drawbacks of current public transport compared to private cars.

While research on mobility concepts related to automated driving began several years ago, automated public transport offerings are still in their early stages. One of the first projects was an automated minibus trial operation in Trikala, Greece, as part of the European Union's CITYMOBIL project in 2016. In Germany, the first deployment of such a service began in Bad Birnbach a year later. Further initiatives followed in cities such as Hamburg (HEAT), Berlin (Seemeile), and Karlsruhe (EVA-Shuttle).

Since February 2020, Monheim am Rhein in North Rhine-Westphalia, located between Cologne and Düsseldorf, has been running an automated minibus service. What sets this service apart from others is that it was designed as a permanent offering from the beginning. The automated minibusses in Monheim am Rhein are fully integrated into the existing network of local bus lines operated by the public transit agency ‘Bahnen Monheim’, making them Germany's first autonomous minibus fleet in regular line operation. With five

vehicles from the manufacturer EasyMile, six stops between the bus station and the traffic-calmed old town are served in a 15-minute interval from 7 a.m. to 11 p.m (as of 2022). These automated minibusses can currently travel at a speed of about 10 km/h, but the goal is to increase this to 18 km/h in the medium term. Each bus can carry up to 11 passengers, of which six can be seated, for a distance of approximately 2 kilometers. The route of the automated minibus line A01 includes a complex traffic situation that involves interactions with all modes of transport. An operator accompanies each journey to oversee technical operations, grant permission for specific driving situations, and intervene in emergencies. Operators also serve as points of contact for passengers during the trip.

Figure 1-1: Route of automated minibus line A01 (main route); Source: Bahnen Monheim (left), Tim Kögler (right)

In addition to the goals associated with the introduction of automated minibus operations, the city of Monheim am Rhein aims to increase the connectivity and accessibility of public transport with Line A01. Until the introduction of the automated minibusses, especially the historic old town of Monheim was not connected to public transport, as the narrow streets were inaccessible to conventional buses. Additionally, the city seeks to enhance road safety by introducing automated minibus services, as a significant portion of traffic accidents are still caused by human error. Furthermore, the presence of automated mobility services aims to familiarize residents with new technology, make digitization tangible, and contribute to increasing

acceptance of automated driving in general. Monheim am Rhein sets a precedent for public transportation by fully integrating an autonomously operating automated minibus fleet as a permanent offering. Both the technology and the research on the acceptance of such mobility services are still in the early stages of development and require further exploration. It remains unclear how the population of Monheim am Rhein and visitors to the city will react to this offering, what impact the automated minibus operation will have on other road users, and how everyday mobility behavior in Monheim am Rhein will be influenced. Understanding these backgrounds and motives is essential to align such offerings with the needs of the population and thereby increase acceptance of automated minibusses. Only then can the long-term goal of enhancing attractiveness in public transport be achieved.

To gain insights into these and other questions, the Institute for Transport Studies at the Karlsruhe Institute of Technology (KIT) has accompanied the introduction of the automated minibus fleet in Monheim am Rhein. Starting in autumn 2021, empirical surveys were conducted over a period of two years to investigate the acceptance of the new service and its effects on residents' mobility behavior. The focus of the research was on determining the motives for usage through repeated passenger surveys. Interviews with the accompanying personnel of the automated minibusses provided additional insights into the operation of the automated minibusses. A household survey among all residents of Monheim am Rhein additionally provided representative insights into the attitudes of users as well as non-users, such as reasons for non-use.

This report presents the results of the accompanying research. Chapter 2 introduces the overall research project on a methodological level. Subsequently, Chapters 3, 4, and 5 present the results of the three empirical investigations. Chapter 6 summarizes, discusses, and contextualizes the results within existing literature. The study serves as a basis for identifying potential adjustments needed for the operation of the automated minibus line. The report concludes with a summary in Chapter 7.

2 Overall project

The accompanying research aims to explore the acceptance of the automated minibus service in Monheim am Rhein and examine its effects on the mobility behavior of the local population. Non-users are also part of the research along with users. Over a two-year project period, behavioral changes, including learning and adaption effects, were recorded, and various influences on the usage behavior of automated minibusses were analyzed. Based on this foundation, recommendations for adjusting the operation of the automated minibusses can be derived, and usage potentials quantified. Acceptance is assessed through three different coordinated survey concepts, as shown in the following figure.

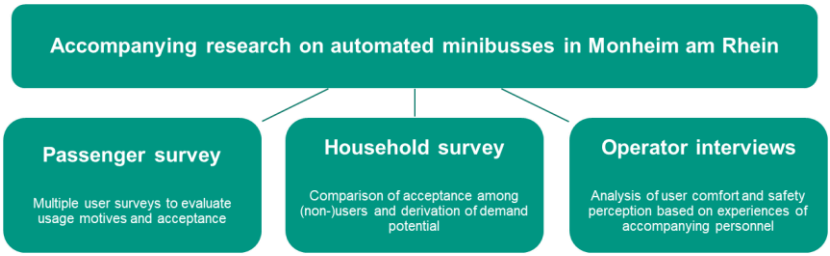

Figure 2-1: Structure and description of the overall project

The passenger survey aims to gain insights into the motives for usage and satisfaction of passengers, as well as to understand the influence of automated minibus usage on their daily mobility behavior. The research concept includes multiple rounds of passenger surveys with the aim of exploring dynamics in perception and usage over time. Circumstances related to the COVID-19 pandemic and associated restrictions, including a maximum of three persons in the vehicle at times, led to the implementation of only two survey rounds within the project duration. Conducted as Computer-

Assisted Personal Interviews (CAPI), where responses are recorded by the interviewing person unlike Computer-Assisted Web Interviews (CAWI), CAPI offers stronger control over the quality of the collected data despite the same level of question standardization. Due to the lower effort required for plausibility checking compared to CAWI, CAPI is recommended, especially when expecting lower participant numbers. Additionally, CAPI surveys allow for higher success rates in asking open-ended questions since text entry is done by the interviewer. This question type is suitable for exploratively discussing a topic and developing standardized answer options (Collins and Mitchell 2014). In this case, selected questions or standardized answer options were integrated into the subsequent household survey.

An expansion of the surveyed content of the passenger survey consists of interviews with operators or accompanying personnel. The accumulated experience and practical knowledge of these individuals enable the analysis of passenger reactions to specific traffic situations, particularly allowing conclusions to be drawn about the comfort and safety perception of users. To this end, structured interviews were conducted with operators from Bahnen Monheim". The guide provided a reference to cover specific topics across all interviews while ensuring flexibility for new insights.

The household survey, as the third component of the study, forms the representative basis of the results. Through a combined revealed- and stated preference approach, the effects of automated minibusses on travel behavior and especially on the mode choice of the Monheim population are determined. By involving non-users of the service, reasons for non-usage can also be evaluated, and future potentials analyzed. The empirical database also enables the development of quantitative models of travel behavior, from which conclusions about the demand potential of automated minibusses in the population can be drawn. By linking the survey components, a holistic overview of the effects and acceptance of the new mobility offering in Monheim am Rhein is obtained.

3 Passenger survey: Insights into automated minibus usage

3.1 Design and methodological approach

The passenger survey aims to explore the reasons for using the automated minibus line A01 in Monheim am Rhein and its integration into the daily mobility of users. The content structure of the survey is depicted in Figure 3-1. At the beginning of the survey, the characteristics of the individuals are captured, including sociodemographic questions such as the age and gender of the respondent. This block also includes questions about a person's daily mobility behavior. Another part of the passenger survey captures usage motives and perceptions of the mobility service. These include characteristics of the route taken with the automated minibus, such as origin and destination, and which other modes of transport were used. Furthermore, questions are asked about the perception of the vehicle, especially its comfort and driving behavior, as well as the new service in general. This includes, for example, the feeling of safety in the automated minibus.

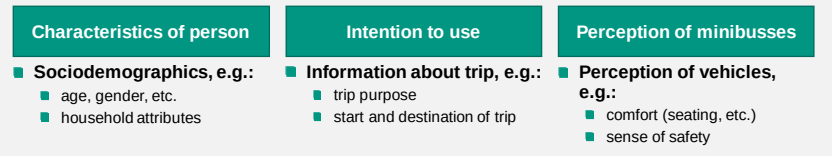

Figure 3-1: Structure of the passenger survey

A compact questionnaire design was ensured since the passenger survey was conducted during the journey. Therefore, the answering time is just under 5 minutes. Two different channels were offered to recruit participants. Due to the design of the CAPI interview (see Chapter 2), the primary recruitment was the direct approach of the automated minibus passengers before or during

the trip by the interviewing person. In addition, the passenger survey was promoted with posters inside the automated minibusses. Interested parties could access the survey via QR codes, allowing individuals to participate independently.

The passenger survey aims to capture usage motives and changes over time. For this reason, it was repeated at intervals of approximately one year. The questions remained identical to maintain comparability between the survey rounds. It should be noted that the route of automated minibus line A01 was changed between both survey rounds. Only during the second survey round did the automated minibus drive along the initially planned route through the old town of Monheim am Rhein, as shown in Figure 1-1.

The methodological approach and implementation in both survey rounds are depicted in Figure 3-2.

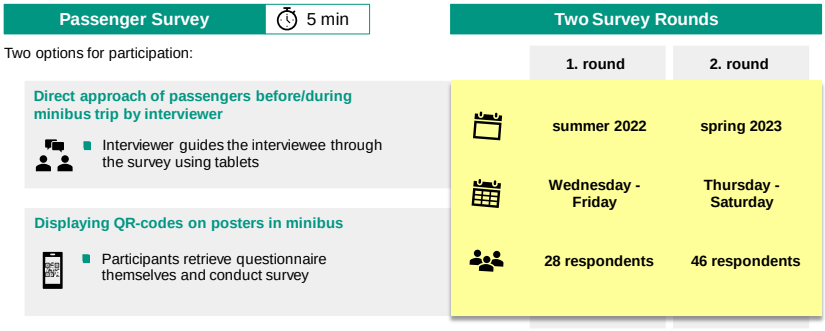

Figure 3-2: Methodology of the passenger survey

The first survey round was conducted in summer 2022. Nine months later, in spring 2023, the second survey round took place. The survey period lasted for three weekdays, starting in the middle of the week, as according to the utilization trends of Bahnen Monheim, more frequent use of the automated minibusses was observed from this point onwards. A total of 74 passengers were reached over both survey rounds. Of these, 28 participated in the first

round and 46 participants in the second survey round. Two interviewing persons conducted the survey between 8 a.m. and 8 p.m. The lower response rate in the first survey round is due to operational reasons for the minibus operation. Due to bad weather and a tense personnel situation, some automated minibus trips were canceled during the survey period, thus disrupting the passengers' survey.

3.2 Results

Characteristics of surveyed passengers

First, Table 1 presents the socio-demographics of all survey participants and compares these with statistical data from the federal state of North Rhine-Westphalia (NRW) (GENESIS 2024). The analysis of personal characteristics shows two tendencies compared to the population in NRW, which can also be confirmed in the later household survey: automated minibus users are predominantly female and tend to be older. Among the surveyed passengers, nearly 60% are female, and two-thirds are 45 years and older. The proportion of those over 64 years old accounts for more than 40% of all passengers. Young passengers also used the automated minibus during the survey, as one in five participants was 24 years old or younger. Regarding household size, most respondents, accounting for 40%, live in a 2-person household. With slight deviations, this proportion corresponds to the average of 2-person households in the federal state of NRW. However, surveyed passengers of Monheim’s automated minibus line A01, compared to the NRW average, less frequently live in 1-person households but more regularly in multi-person households (3 persons and more). This is an indicator of increased automated minibus usage by families. Although most surveyed passengers live in Monheim am Rhein, a quarter reside outside Monheim. One in five surveyed individuals stated that they were visiting Monheim am Rhein.

Table 1: Sociodemographic characteristics of survey participants compared to statistical data from the federal state of North Rhine-Westphalia (NRW) (GENESIS 2024)

	share	statistic NRW
gender		
female	58,6 %	50,8 %
male	41,9 %	49,2 %
age		
< 18 years	11,4 %	24,7 %
18–24 years	10,0 %	
25–44 years	14,3 %	24,8 %
45–64 years	22,9 %	30,2 %
> 64 years	41,4 %	20,3 %
household size		
1 person	24,3 %	41,0 %
2 persons	38,5 %	33,7 %
3–4 persons	28,6 %	25,3 %
5+ persons	8,6 %	
relation to Monheim am Rhein		
residents of Monheim	75,0 %	
visitors in Monheim	20,6 %	
workplace in Monheim	4,4 %	

N = 74

In addition to sociodemographic variables, passengers were asked about their mobility behavior. On a scale from 1 (almost daily use) to 6 (never used), respondents indicated how frequently they use a specific mode of transportation in their daily mobility. The results are presented in Figure 3-3. Additionally, Table 2 presents the mean usage frequencies of selected transport modes across all survey participants and differentiates them by both survey rounds.

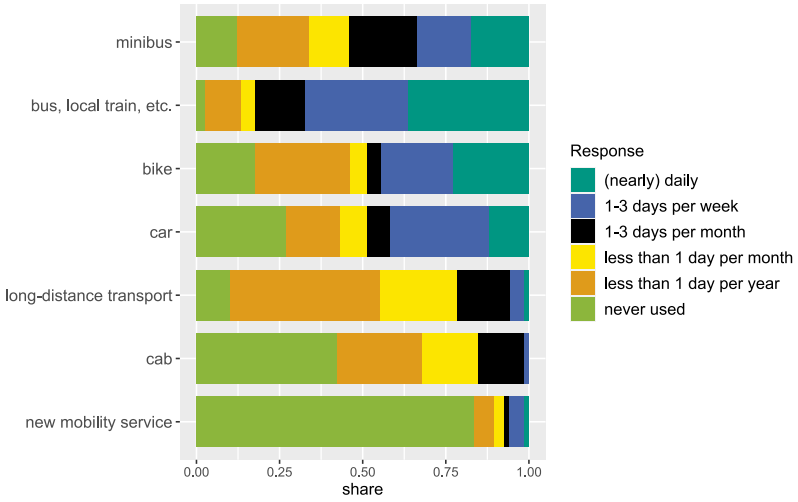

Figure 3-3: Usage frequency of selected transport modes; N = 74

Passengers use the automated minibus line A01 predominantly regularly, i.e., at least 1 to 3 times monthly. Nearly 10% of the respondents indicated that they had never used the automated minibus before the survey. It is noteworthy that, on average, surveyed passengers use the automated minibus as frequently as they use bikes or cars. The most used mode among respondents is public transportation (PT), which includes buses and local trains. In comparison, according to the results of the national travel household survey 'Mobility in Germany (MiD) 2017,' the car still dominates the use of other modes of transportation on average in Germany (Nobis and Kuhnimhof 2018). Thus, surveyed automated minibus passengers demonstrate a strong affinity for PT. Additionally, almost a quarter of respondents reported using PT more frequently since introducing the automated minibus line A01. All others stated that introducing the automated minibus line A01 did not change their use of PT.

Passengers rarely take long-distance trips. These are mostly not part of one's everyday mobility but rather special occasions, which is why less frequent

usage is expected. Even less frequently, surveyed passengers use cabs. Nearly half of the respondents have never used a cab before. New mobility services such as bike or car sharing play a minor role. Four out of five respondents have not used these forms of mobility up to the time of the survey. This can be attributed, on the one hand, to the limited availability of such services in Monheim am Rhein. Carsharing has only been offered since 2019, and bike sharing has only been offered since 2022, so passengers had hardly any opportunity to use these services until the survey. On the other hand, the age structure of the surveyed passengers also plays a role, as new forms of mobility are more commonly used by young men, the so-called "early adopters," who are less likely to be part of the automated minibus passengers (Kawgan-Kagan 2015).

As Table 2 shows, except for bikes, the reported usage frequency of various transportation modes only slightly fluctuated between the two survey rounds, indicating stability in usage. Bicycle usage only decreased between the first and second survey rounds. Seasonal effects may play a role here, as the first survey round was conducted in midsummer, while the second survey round took place at the end of winter, during which bike usage tends to be lower than in summer.

Table 2: Mean usage frequencies of selected transportation modes

	overall	round 1	round 2
Automated minibus	3.41	3.61	3.28
bus, local train, etc.	2.30	2.36	2.26
bike	3.47	2.96	3.78
car	3.68	3.43	3.83
long-distance transport	4.36	4.44	4.31
cab	4.93	5.07	4.84
new mobility service	5.58	5.57	5.59

1 - (almost) daily use; 6 - never used; smaller values indicate more frequent usage ***N = 74***

Usage patterns of automated minibus line A01

Passengers were asked when and where they started their journey with the automated minibus and where it should end. An approximately even distribution throughout the day is observed regarding the temporal usage patterns, with increased usage from 11 am to 2 pm during the midday hours. During this time, over a third of all automated minibus trips took place. In the mornings (8 am - 11 am) and afternoons (2 pm - 5 pm), a quarter of the trips each occurred, with a decrease in the evening hours. After 7 pm, no usage was observed in both survey periods so that no further passenger interviews could be conducted.

The spatial characterization of automated minibus trips is based on the route layout during the second survey round. The distribution of start and destination stops on all reported automated minibus trips is shown in Figure 3-4. It becomes clear that the central bus station (‘Busbahnhof’) is the most frequently accessed stop on all automated minibus trips, whether as a starting or ending point. The high attractiveness of the station can be attributed to two reasons. Firstly, the central bus station offers numerous transfer options to other bus lines. Secondly, the bus station is located directly at the beginning of the commercial center of Monheim am Rhein, with multiple shopping and dining options, making the bus station attractive as a starting point for journeys. The stops ‘Gesundheitscampus’, ‘Schelmenturm’, and ‘Alter Markt’ are approximately equally likely to be a trip's start or destination stop with the automated minibus. Still, they play a minor role, accounting for just under a quarter of all trips. In contrast, it is striking that the automated minibus is more frequently used for trips to the Altstadt, but passengers choose other options to leave the Altstadt.

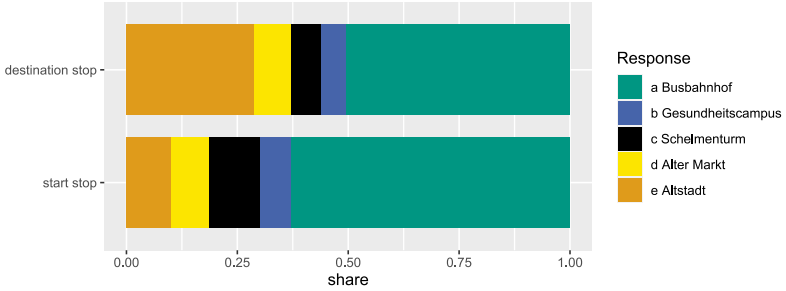

Figure 3-4: Distribution of start and destination stops of automated minibus trips; N = 74

The inquiry about the purpose of the trips, as shown in Figure 3-5, reveals that passengers mostly use automated minibus line A01 for leisure trips. One-third of all reported trips were undertaken for this purpose. The second most common purpose, accounting for 23% of all trips, was using the automated minibus line to travel home. Similarly, at a rate of 12% each, the automated minibus line was used for trips to shopping destinations or to test the new service. The automated minibus was rarely used for commuting purposes. Overall, trip purposes that commonly do not require time commitments dominate, as would be the case with trips to work or business trips.

On the right side of Figure 3-5, it can be observed how the purposes of the trips have changed between the two survey rounds. Notably, "testing the service" decreased significantly in the second survey round, indicating the establishment of the service. Passengers are using the automated minibus less often for leisure purposes. In the second survey round, every tenth trip with the automated minibus was made for a doctor's visit, a purpose not mentioned in the first survey round. This is due to the changed route of the automated minibus line, as in the second survey round, the ‘Gesundheitscampus’ stop with numerous healthcare facilities was added to the route. Notably, the use of the automated minibus for trips home increased in the second survey round, while the proportion of usage for leisure trips decreased to the same extent. This could mean a further shift

towards purposes with fewer time commitments. Additionally, different survey times could also play a role. The first survey round took place during the North Rhine-Westphalian summer holidays, during which the proportion of leisure trips tends to be larger due to vacation times than outside holiday periods.

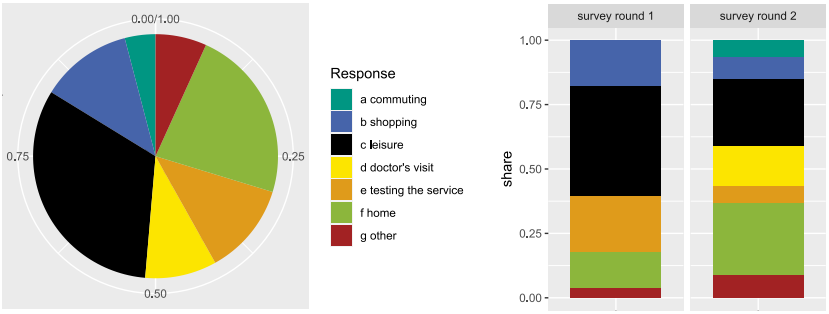

Figure 3-5: Distribution of trip purposes; left: overall; right: differentiated by survey round; N = 74

Furthermore, passengers were asked how they would have done their current trip if the automated minibus line A01 service had not been available. The results are shown in a Sankey diagram in Figure 3-6. On the left, the combinations of modes of transportation used on the current journey with the automated minibus are shown. On the right, it can be seen how the journey would have been undertaken without the availability of automated minibus line A01.

Initially, it is noticeable that the automated minibus is mainly combined with walking or other modes of public transportation. Although combinations with cars or bikes were reported, they play a negligible role. Without automated minibus line A01, Figure 3-6 shows that most automated minibus trips would otherwise be made by foot. Passengers who combine the automated minibus with walking would, therefore, walk the entire way if the automated minibus did not exist. A quarter of these trips would not have been realized without the automated minibus line A01. Passengers who combine the automated

minibus with other public transportation would also predominantly replace the automated minibus journey with a walk and leave the other public transportation segment unchanged.

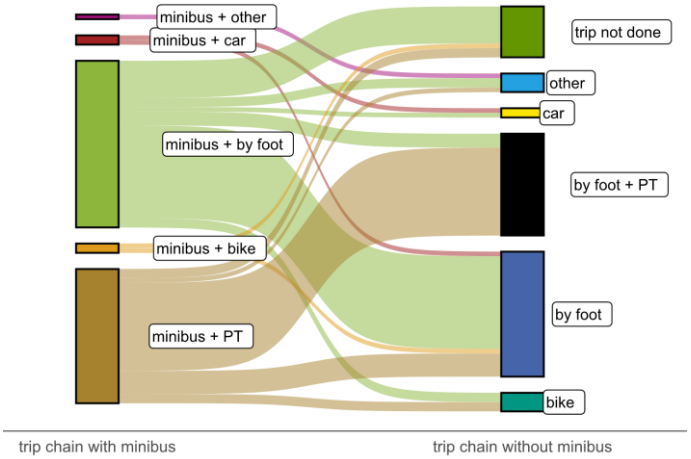

Figure 3-6: Sankey diagram with/without automated minibus, N = 74

Figure 3-6 illustrates that the new offering of the automated minibus line currently mainly contributes to substituting pedestrian trips or even inducing trips due to the availability of the service. From a transportation perspective, this result would typically be negatively assessed under the planning premise of traffic avoidance. However, an analysis of the reasons for using the automated minibus shows that a significant portion of passengers utilize the service because the trip would otherwise be too long or strenuous. Considering the socio-demographic profile of passengers, who tend to be older and may have difficulties with walking, the automated minibus service facilitates or enables mobility for these individuals in their daily lives. Given that more than half of the respondents indicate making a regular trip in their daily lives with the automated minibus, this argument gains further significance.

Additional reasons for using the automated minibus line A01 are listed in Table 3 .The most frequently cited reason for using the automated minibus is to try out the service. A comparison between the two survey rounds shows that as the service becomes more established, the number of trips to try out the service has decreased. The proportion of this reason decreased by 25% between the two survey rounds. Instead, other motives come to the fore. As described in the preceding paragraph, simplifying the automated minibus service for passengers on their desired route is noteworthy here. This reason was cited by almost one-third of passengers as the primary motive in the second survey round.

Table 3: Reasons for using the automated minibus line A01 in descending order of frequency of mention

	overall	round 1	round 2
testing the service	34,3 %	40,0 %	31,1 %
trip too long/strenuous	25,7 %	16,0 %	31,1 %
weather	15,7 %	8,0 %	20,0 %
fun	8,5 %	12,0 %	6,7 %
shortest route with PT	5,7 %	8,0 %	4,4 %
convenience	4,3 %	4,0 %	4,4 %
other	5,7 %	12,0 %	2,2 %

N = 70

However, weather also influences the choice of the automated minibus. While in the first survey round, only 8% of respondents chose the automated minibus due to prevailing weather conditions, this proportion increased to 20% in the second survey round. The different survey periods play a role here. In contrast to the first survey round, the second round took place at non-summer temperatures, leading passengers to mention the comfort of the heated bus more frequently in the interviews. Other reasons, such as using the automated minibus for fun or due to a route shortcut in public transport, were also mentioned but played a minor role in the overall picture.

Perception of the new mobility service

Furthermore, automated minibus passengers were asked to evaluate selected characteristics of the automated minibus service in general and the vehicles specifically. The assessment was based on a 5-star rating system, with one star indicating very poor and five indicating very good. The mean ratings of all evaluation criteria, differentiated by both survey rounds, are presented in Figure 3-7.

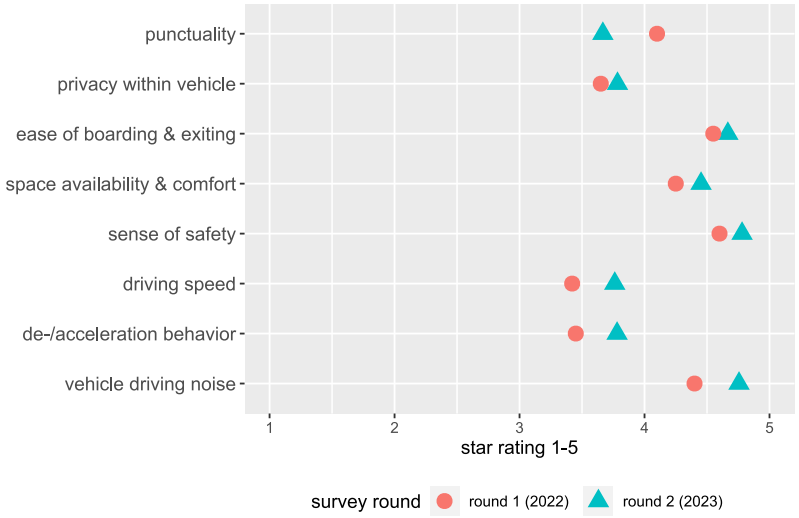

Figure 3-7: Evaluation of automated minibus line A01; N = 70

First of all, it is noticeable that the automated minibus line A01 is generally positively evaluated across all criteria. All of the evaluation criteria received at least 3.4 stars on average. The speed of the automated minibusses and their braking and acceleration behavior are rated the most negatively by passengers. However, privacy in the vehicle is also rated lower compared to other criteria, with around 3.7 stars. In personal conversations, the seating arrangement in the vehicle was cited as a reason for the lack of privacy. Unlike

conventional buses, passengers in the automated minibus face each other instead of sitting in rows. Also, the presence of staff in the middle of the bus contributes to a reduction in privacy. The simplicity of boarding and exiting, the space availability, comfort, and the feeling of safety in the automated minibus are rated very positively, with over 4 stars. With over 4.5 stars, the sense of safety is the best-rated category, indicating passengers' trust in the technology. The noise level during the trip is also positively rated and minimally bothers passengers.

The comparison between both survey rounds shows that the evaluation has improved in almost all categories over time. The most remarkable improvements concern the vehicle's driving characteristics – speed, braking and acceleration behavior, and noise levels. With the duration of operation, passengers are presumed to become accustomed to the reduced speeds and other driving behaviors, perceiving them less negatively. Furthermore, technical improvements to the vehicles between the two survey rounds may also have positively impacted the improved evaluation.

Further improvements in the evaluation by passengers were also observed regarding perceived safety. An exception is the punctuality of the automated minibus line A01, which decreased from 4.1 to 3.6 stars. However, while passengers' subjective perception strongly influences other evaluation criteria and are therefore more difficult to influence, punctuality can be objectively measured and improved through operational and planning measures by the automated minibus line operator. This is particularly important for increasing confidence in the reliability of the automated minibus line A01 and ultimately making the use of the automated minibus line more attractive for routes with time dependencies, such as appointments or connections with other public transport.

In open-ended questions, passengers were asked at the end of the interviews to mention the advantages and disadvantages of the new automated minibus line A01. Two aspects stand out among the advantages. Firstly, passengers find the automated minibus line particularly useful for older people.

According to the sociodemographic analysis in Table 1, these are the people who currently use the automated minibus line A01 the most. Passengers also see the connection to smaller neighborhoods as particularly advantageous. Both aspects support the role of the automated minibus line A01 in enabling mobility, whether for otherwise mobility-impaired individuals or in areas where other mobility options are limited. One passenger summarized the role: "A great offer for seniors and the less mobile. When we become older, we will also move to Monheim".

Furthermore, the comfort of the bus and the convenience compared to walking were mentioned equally frequently as advantages. One passenger sees these advantages, especially when accessing smaller neighborhoods like the old town: "The bus is good if you've had a drink in the old town. Monheim is dynamic and stands out". Five of the surveyed passengers consider the automated minibus advantageous because it is driverless and thus represents a future-oriented service: "The automated minibus line A01 is part of progress. Development only happens through small steps. In the future, public transport can be designed more individually in this way".

Passengers' positive perception of the automated minibus line A01 is also evident when querying the disadvantages. The most frequently mentioned option is that the automated minibus has no disadvantages. Besides that, passengers report the greatest disadvantages as the automated minibus disturbs other traffic and drives at a reduced speed. One passenger associates the disruption of other traffic with adverse environmental and safety effects: "The bus is a traffic hindrance and unnecessarily holds up traffic. This increases emissions and the risk of accidents." However, the negative perception of speed affects the disruption of other traffic and increases travel times with the automated minibus: "The use does not save time and is therefore not yet suitable for distances of more than 2 kilometers."

Less frequently mentioned, but still the fourth most common was the behavior of other road users. Some passengers observe that the automated minibus is sometimes deliberately disrupted in its operation, for example, by

aggressive lane changes of others, forcing the automated minibus to make emergency stops. Equally often, negative comments were made about the fact that the automated minibus only operates in the old town. Instead, there is a desire to expand the service to the places where the leading target group of the automated minibus line A01 lives: "The route should be changed. The bus should travel where older people live." Other disadvantages, which were rarely mentioned, relate to the technology of the automated minibusses, e.g., the abrupt braking of the buses.

4 Operator interviews: Perspectives of the accompanying personnel

4.1 Design and methodological approach

Each automated minibus trip is accompanied by operators who, among other tasks, oversee the technical aspects of the ride, must approve certain driving situations, and can intervene in emergencies. The accompanying personnel are exposed to various driving situations and the passengers' perceptions or feelings, which are of interest for evaluating the acceptance of the automated minibus line A01 by passengers. Their observations and experiences provide additional insights into the automated minibus line's passenger evaluation, the service's integration into the existing transportation system, and the interaction of the automated minibusses with other road users. Furthermore, the operator's role differs from the traditional position of bus drivers. To ensure a comprehensive examination of automated minibus operations, the perception and assessment of the operator activity compared to bus driver activities offer additional perspectives for evaluating such an automated service. For these reasons, semi-structured interviews with the operators of ‘Bahnen Monheim’ were conducted as part of the study.

The interviews aimed to supplement the examination of passengers' comfort and safety perceptions and discuss the perception of the new role as an operator during the automated minibus operation. To achieve this goal, the interviews were divided into five thematic blocks, as shown in Figure 4-1. The first two parts of the interviews address the operators' perceptions of passengers. This includes, on the one hand, the behavior of passengers during the ride and to what extent their behavior differs from a conventional bus ride. On the other hand, this includes the operators' perception of passengers' comfort and safety. The third block addresses all interaction

points between passengers and operators before, during, and after the ride. The focus is mainly on services provided by the operators for the passengers but also on typical conversation topics between passengers and operators.

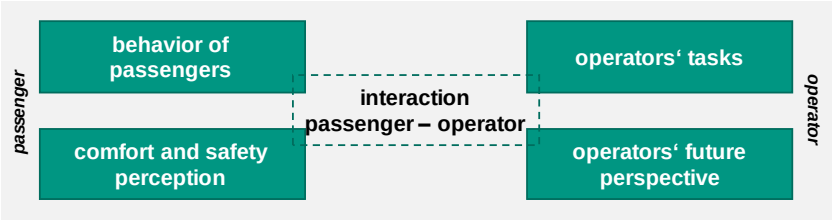

Figure 4-1: Sankey diagram with/without automated minibus, N = 74

The last blocks explore the operators' perception of their role and the evaluation of their position. This includes, on the one hand, the perception and reflection of an operator’s tasks. On the other hand, the future perspective of the operators is examined. With increasing automation in public transportation, it can be assumed that future demand for bus drivers will decrease, and concerns about the future rather than job security may arise among current personnel. In the interviews, therefore, the operators were asked how they assess this development and what personal perspectives they see for themselves.

A semi-standardized, semi-structured questionnaire was developed to conduct the interviews, as described by Meier Kruker and Rauh (2005). The questions are divided along the previously presented thematic blocks. Due to the semi-standardization, no answer options were provided, allowing the operators to communicate their views and perceptions freely.

The interviews were conducted in two rounds: November 2022 and March 2023. The division into two rounds was purely operationally motivated to increase the potential number of interviews conducted. Twelve interviews were conducted with operators of ‘Bahnen Monheim’. Each interview took an average of 45 minutes. No audio recordings were made; instead, the

interviewers noted the contents in bullet points. The interviews were therefore conducted using qualitative content analysis, which does not rely on the linguistic structures of what was said but focuses on the substance of the corresponding statements. The evaluation was structured based on the structure of the interview guide and, thus, the selected thematic blocks.

4.2 Results

The presentation of the results of the operator interviews is also based on the thematic blocks. The essential statements of all operators are aggregated, and key findings, as well as trends, are synthesized. Regarding passenger behavior during the ride with the automated minibus, operators most frequently mention communication among passengers. While they rarely observe this in conventional buses, it is noticeably familiar in automated minibusses. The topics of conversation mainly revolve around everyday topics such as weather, the new automated minibus service, political issues regarding the future of Monheim, etc. The second most mentioned activity are conversations between operators and passengers. These often involve technical questions about the automated minibusses and schedule inquiries but also frequently include personal topics. Operators support this observation by stating that, compared to conventional bus services, they have developed a personal relationship with regular passengers of the automated minibus service, which is reflected in the interactions and conversations. Additionally, operators observed that passengers use their phones less frequently in the automated minibus compared to conventional buses. This observation is also influenced by the socio-demographic composition of passengers, who tend to be older and thus have a lower average phone usage frequency. In summary, the automated minibus encourages communication between operators and passengers and among passengers, and the contact is significantly closer than in conventional buses. Regardless, operators occasionally observe passengers enjoying the view and looking out the window without engaging in communication.

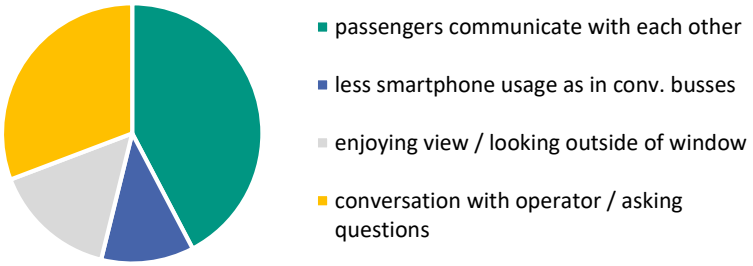

Figure 4-2: Frequency of reported passenger activities during automated minibus ride; N = 12

From the operators' perspective, passengers' comfort and safety perception is also considered very high, as reported by the passengers themselves. Operators were asked to rate both dimensions on a scale of 1 (very poor) to 5 (very good). On average, across all interviews, the comfort perception was rated at 4 out of 5 points, and the safety perception was rated at 4.5 out of 5. Comfort perception is positively influenced by the vehicle's driving behavior, which passengers perceive as very pleasant, according to the accompanying personnel. Additionally, the presence of heating and the low noise emissions of the vehicles are perceived as further comfort aspects. In particular, the heating has already been identified as a comfort driver in the passenger survey, as passengers prefer to use the automated minibus in corresponding weather conditions. According to the operators, the seating arrangement and design of the automated minibus negatively impact passengers' comfort perception. Some passengers perceive the seat width as narrow, especially when the buses are more crowded. Furthermore, the view for seated passengers outside is greatly restricted, which some passengers negatively comment on. The emergency brake is the most frequently mentioned negative aspect by operators. At the same time, operators also note that the emergency brake is one of the main aspects that contribute to passengers' high sense of safety. Although the emergency brake, considered in isolation,

is uncomfortable due to the forces exerted on the body, it shows passengers that the system reacts independently to dangerous situations, thereby increasing safety perceptions. However, the presence of accompanying personnel strongly influences passengers' high sense of safety, as they enable continuous intervention in the automated minibus's driving system. Furthermore, in the current development stage, accompanying personnel must approve certain automated minibus driving maneuvers, enhancing passengers' sense of safety. Operators report a negative influence when passengers have to stand. Passengers perceive this as unsafe, considering potential emergency braking, as secure holding is not guaranteed. However, even when seated, there is fear of emergency braking among passengers, so the seatbelt morale among passengers, especially regular ones, is firm.

This service or assistance role is one of many tasks of the accompanying personnel. According to their statements in the operator interviews, they are also responsible for checking the vehicle before the service begins, including a technical check of all necessary systems. Additionally, they see their role in technical ride monitoring, such as approving certain driving maneuvers or manually taking control of the vehicle in selected situations. Ticket sales were also mentioned by the accompanying personnel as a task, although this activity has decreased significantly with the introduction of the Monheim-Pass. However, the greatest added value perceived by the accompanying personnel is in their service and assistance function, under which the operators primarily understand ensuring safety during operation.

Figure 4-3 provides additional insight into how operators perceive their work in the automated minibus compared to their conventional role as bus drivers. About equally frequently, and by most of the accompanying personnel, it is reported that the work in the automated minibus is both cognitively and physically more demanding. Monitoring the driving systems and observing traffic in parallel requires greater concentration than in a conventional bus. Furthermore, operators do not have a seat on the bus but must stand permanently during their shifts. Firstly, sitting is impossible due to the limited

views outside the automated minibus, making adequate traffic observation impossible while seated. Secondly, the control panels in the bus are positioned at a height that can only be accessed while standing. The prolonged standing places greater physical strain on operators than they are accustomed to in the conventional bus. However, the strain is due to standing and the stronger forces experienced while standing. For instance, an emergency brake while standing is felt much more intensely than while seated. A minority of the interviewed operators perceive this strain as providing more physical activity and thus as a positive effect on health. Additionally, operators perceive more social contact than in conventional buses, which they generally view positively, as highlighted in the previous section.

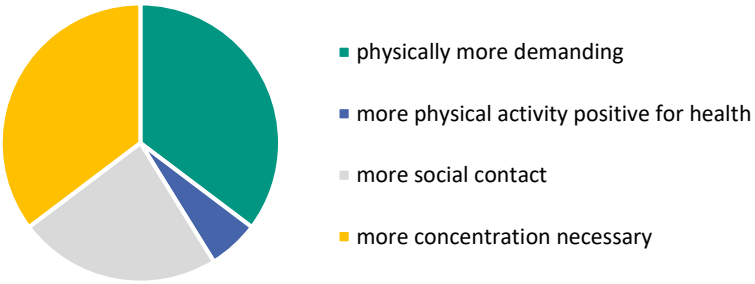

Figure 4-3: Evaluation of operator activity compared to conventional bus operation; N = 12

No clear trends can be derived from the statements of the accompanying personnel regarding whether operators find the work in the automated minibus more or less burdensome. An equal number stated that they find the work in the automated minibus more and less demanding than their usual work as bus drivers. Additionally, some operators reported feeling differently challenged but, overall, similarly as in the conventional bus.

In the final section of the operator interviews, the future perspective of the operators was examined, considering that with the advancement of autonomous driving technology, the roles of bus drivers and operators could eventually be eliminated. The majority of the accompanying personnel are hardly concerned about this development. Four out of the twelve operators expressed a neutral stance on the development of autonomous driving; three out of twelve even see the development positively despite the potential loss of their jobs. According to the operators, the lack of fear of the future can be attributed to two motives. Firstly, they partially perceive the development as needing to be more mature for many years and expect an initial expansion in the private sector. Therefore, they expect to avoid being directly confronted with the consequences during their working lives. Two out of the twelve operators cannot even imagine the development of a fully autonomous public transport system without drivers or other accompanying personnel to be realized. Secondly, most operators indicated they could imagine engaging in different activities besides driving, whether in the control center or another field of work. This flexibility also prevents the operators from developing fear for the future.

However, three out of the twelve operators view the development of autonomous driving negatively. The reasons are not related to the fear of job loss. Rather, they see that with the elimination of driving personnel, passengers are increasingly left to fend for themselves. As a result, no one can fulfill the service and assistance role for passengers anymore. As highlighted in previous sections, this is precisely the function where the operators see the greatest added value in their work.

5 Household survey: Analysis of acceptance by users and non-users

5.1 Design and methodological approach

A proven method in transportation research is household surveys. They enable in-depth analyses of attitudes and behaviors related to modes of transportation, particularly regarding innovative mobility services such as automated minibusses. Through these analyses, both potential for usage and operational measures for adapting existing transportation services can be derived. With the aim of exploring the acceptance of the automated minibus line A01, a household survey was conducted in Monheim am Rhein over a period of six weeks during the summer of 2023. The study targeted the entire population of Monheim, including users of the automated minibus line A01 and individuals with no experience of its use.

Approximately 25,000 Monheim households received postal invitations to participate, with an additional incentive for participation created through the raffle of 20 vouchers worth €20 each for local gastronomy and retail. A total of 1430 completed questionnaires were returned, of which 72 had to be excluded from further analysis due to significantly shortened completion times or apparent ‘straightlining’ behavior during data plausibility checks. To ensure that the survey results were representative of Monheim residents, distortions in the sample, particularly regarding gender and age structure, were corrected through a comparison with the registration office and subsequent weighted analysis. The structural layout of the online questionnaire can be found in the following figure.

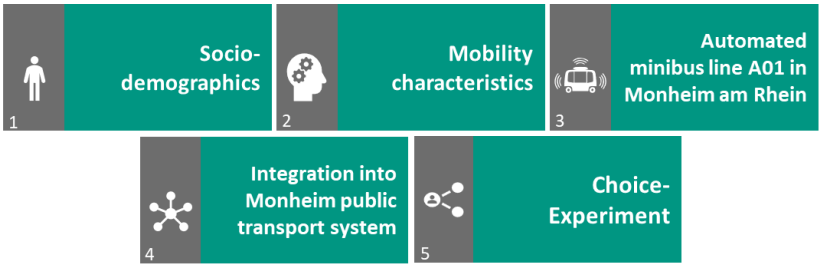

Figure 5-1: Structure of the household survey

The structure comprises five chapters, starting with socio-demographic questions about the participating individual and their household. This is followed by a block of questions on mobility characteristics to capture characteristics of previous modes of transport usage and existing ownership of mobility tools (e.g., car, bike, public transport pass). The survey focuses on questions regarding usage motives and reasons for non-usage, individual attitudes towards automated minibusses, and the concept of automated driving. Subsequently, there are questions to investigate the local impacts of the operation on the rest of the public transport service. The survey is rounded off by a hypothetical mode choice experiment, also known as a "Stated-Choice Experiment". In this experiment, participants choose exactly one mode of transport in various choice situations, which also corresponds to their situation-specific preference. The different conditions in the decision situations arise from slight variations in the attributes of the various modes of transport (e.g., travel time, travel costs). Only in this way the sensitivities of various choice parameters can be analyzed.

The present experiment is set up on hypothetical trips in and around Monheim am Rhein and serves to evaluate the potential of future operating modes of automated minibusses (e.g., higher speed, on-demand operation). Figure 5-2 illustrates the structure of the experiment.

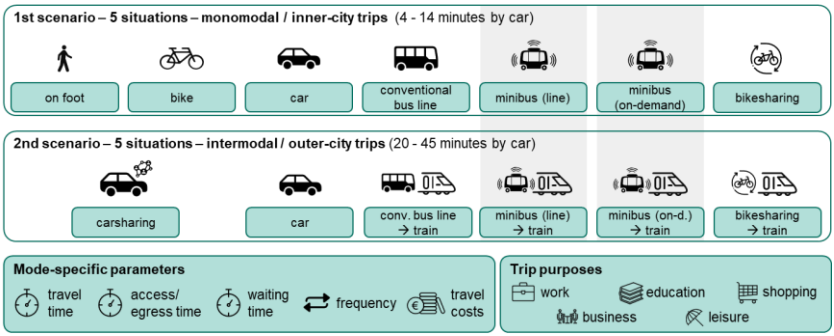

Figure 5-2: Structure of the choice experiment

The choice experiment is fundamentally divided into a monomodal and an intermodal part, with the automated minibusses being used as feeder transport for public transport or the train in the latter case. Concerning Monheim am Rhein, it involves the route between the city center and train station 'Langenfeld'. In accordance with the distances to be traveled, in addition to the options of automated minibusses, other suitable means of transport were also displayed as alternatives. The car was only shown to participants who possessed a driver's license and owned a car, while carsharing was shown only to those with a driver's license. Additionally, based on the individual characteristics of the participants, different routes or purposes of travel (e.g., commuting, educational, shopping) were presented in each decision situation. The following Figure 5-3 illustrates such a decision situation as presented to the participants in the questionnaire.

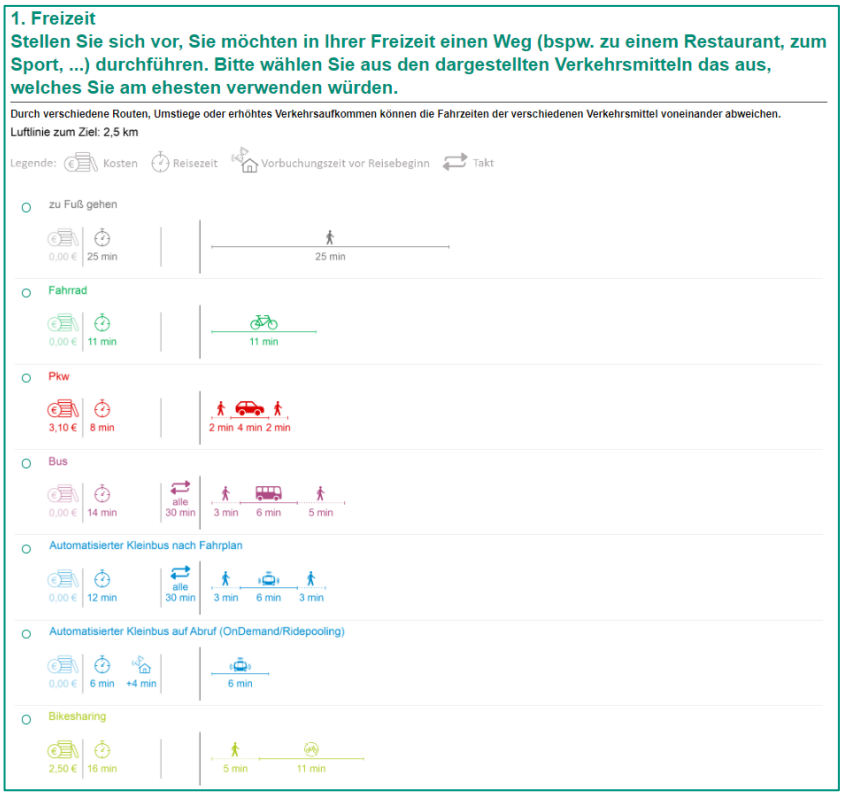

Figure 5-3: Example of a choice scenario

The decisions are analyzed using the principles of discrete choice modeling, which are based on the principle of utility maximization. Based on the decisions made, the relevance of each attribute for mode choice is examined using the Maximum Likelihood Method. One advantage of this method is that it can provoke decisions that occur only rarely. Additionally, complete data on all available alternatives, including their associated attributes, are available. This is not always the case when analyzing travel diaries from traditional RP surveys. The scope of attributes to be examined is arbitrary and includes not only mode-specific factors but also sociodemographic and mobility-related

parameters, as shown in the following table. The specific parameter values can be found in Appendix A.

Table 4: Overview of sociodemographic and mobility-relevant parameters in the choice experiment

sociodemographics	mobility characteristics
age	driver's license ownership
sex	car ownership
occupation	bike ownership
education degree	smartphone ownership
mobility impairment	Monheim-Pass holder
	Deutschland-Ticket holder
	bikesharing membership
	carsharing membership

To illustrate the future potential of the automated minibusses, the desired target speed of the automated minibusses was assumed to be the average speed of a conventional bus. Additionally, the specific situation in Monheim am Rhein regarding the free-of-charge service was considered in the experiment design, so only travel costs for the car, bike, and carsharing services, as well as the on-demand operation of the automated minibusses, were displayed.

5.2 Results

Below, selected results of the household survey are presented following the previously illustrated content and methodological structure. The focus of the analysis is on examining the differences and similarities between users and non-users of the service. Non-users have not used the automated minibus line A01, while users have used it at least once. Additionally, both user groups are differentiated concerning their motives for usage or reasons for non-usage. Among users, a further distinction is made between regular and occasional users, with regular users defined as those who use the service at least once a month. Among non-users, two groups are identified based on

their willingness to potentially use the service in the future: non-users with potential for future use and non-users without potential for future use. The group of (potentially) users includes users and non-users with potential for future use. The following figure illustrates these groups.

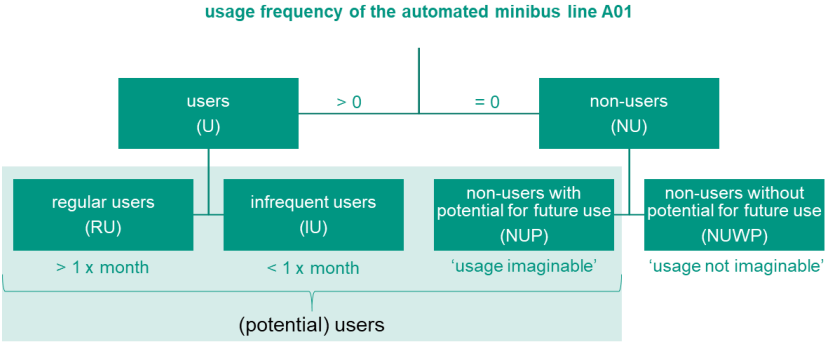

Figure 5-4: Overview of (non-)user groups

Sociodemographics of users and non-users

Initially, weighted two-sample t-tests are conducted to compare various (non-)user groups regarding sociodemographic attributes such as age, gender, occupation, etc. Selected results are presented in the table below and will be further elaborated upon.

Table 5: Results of t-tests between sociodemographic attributes and the (non-)user profile

Attributes	share	U/NU	RU/NU	RU/IU	NUP/NUWP
sex					
female	51.7 %		+++	++	- - -
age					
14 – 20 years	11.0 %		- - -	+	- - -
20 – 29 years	10.8 %	- - -	- - -		
30 – 39 years	14.4 %	+++	+++		++
40 – 49 years	13.3 %	-		-	

50 – 59 years	16.3 %	- - -	- - -	- - -	
over 60 years	34.2 %	+++	++		
occupation					
trainee	3.7 %	- - -	- - -		
homemaker	2.7 %	+			
retiree	26.8 %	+++	+++	+	
pupil	4.1 %		+++	+++	
student	5.8 %	- - -	- - -	- -	
full-time employee	41.4 %		- - -	- - -	+++
highest level of education					
high school diploma	34.5 %				--
vocational qualification	32.7 %	+	++	+	--
academic degree	29.1 %	-	- - -	- -	+++
income					
under €500	6.4 %	+	+++	++	
€500 – €900	16.7 %		++	+++	
€1.500 – €2.000	12.0 %	- -	- - -	---	
€2.000 – €3.000	8.9 %	- -	- - -	- -	+++
€3.000 – €4.000	1.0 %		- -	- -	
€4.000 – €5.000	4.8 %		-		
€6.000 – €7.000	4.0 %	+++			- -
over €7.000	0.9 %	+	+	+	
other					
child(ren) in household	25.8 %	++		- - -	+++
mobility impaired	13.1 %	+++	- - -	++	
- / + = significant; - - / ++ = very significant; - - - / +++ = highly significant					***N = 1,358***

The analyses illustrate that individuals facing challenges in their daily mobility, particularly older people, mobility impaired people, those with lower income, and those from households with children, tend to use the automated minibus more regularly. Furthermore, a significant association is observed between occupation and automated minibus usage. Particularly, unemployed individuals such as retirees and homemakers are more likely to use than other occupational groups. Despite these effects, women also exhibit a higher likelihood of regular usage, with non-using women showing a stronger aversion to future usage compared to men. Conversely, non-using individuals with at least one child in the household see potential for future usage.

While users are typically between 30 – 39 years old or over 60, individuals between 20 – 29 and 40 – 59 years old are particularly disinclined to use the service. The age group of 14 – 20 years old, including students, show ambivalent usage behavior. If they are users, they tend to use the automated minibus more regularly. However, the majority of this group tends to be non-users. This pattern is also observed among men. Additionally, individuals between 30 – 39 years old are open to future usage, while those between 14 – 20 years old are less likely to envision usage in the future.

Despite the current reluctance of full-time employees (approximately 41% of residents) towards the automated minibus service, they are optimistic about future usage. Trainees and students are also among the non-users. Individuals with vocational qualifications are more likely to be users and tend to use the bus more regularly, but if they have no previous usage experience, they may not envision future usage. The opposite is true for individuals with an academic degree. Additionally, individuals whose highest level of education is a high school diploma are less likely to show potential for usage among non-users.

While individuals with an income below €900, as well as those with an income above €7000, show a higher likelihood of usage and ride the automated minibus more frequently, individuals with an income in-between, but up to €6000, have a lower likelihood of usage and use the automated minibus less frequently if they have previous usage experience. Moreover, Individuals with an income between €2,000 – €3,000 who have not yet ridden the automated minibus are more likely to consider future usage. Conversely, individuals with an income between €6,000 – €7,000 are more inclined to abstain from future usage.

Mobility characteristics

The following comparisons of various (non-)user groups regarding their mobility tools and characteristics are conducted again using weighted, two-

sided t-tests. The presentations are made specific to modes of transportation based on ownership patterns among Monheim residents and usage frequency (UF), with the latter reflecting the mobility behavior of users of the automated minibus. The results of the t-tests, as depicted in the table below, will be elaborated upon subsequently.

Table 6: Results of t-tests between mobility characteristics and the (non-)user profile

mobility characteristics	ØUF	share	U/NU	RU/NU	RU/IU	NUP/NUWP
motorized individual transportation						
driver's license ownership		84.7 %	- - -	- - -	- -	
car ownership		89.9 %	- - -	- - -	- - -	- - -
motorcycle ownership		7.7 %		- - -	- - -	
car (as driver)	1.9					
car (as passenger)	3.2					
moped/scooter/motorcycle	3.0			- - -	- - -	
cab	4.8					
public transportation						
Bahncard holder		10.5 %	- -			
Monheim-Pass holder		95.6 %				+++
long-distance bus, IC, ICE	4.6					+
automated minibus	4.6		+++	+++	+++	
conventional bus	3.4		+++	+++	+++	+
tram/subway	3.8		+++	+++	+++	++
regional train	3.9			++	++	+
bike						
E-Bike ownership		20.9 %				
bike ownership		74.2 %	- - -	- - -		
E-Bike	2.1					
bike	2.8			++	++	
new mobility services						
bikesharing membership		3.3 %				+
carsharing membership		10.3 %	+		-	+++
E-scooter-sharing membership		14.8 %		- - -	- - -	
ridepooling membership		1.7 %				+++
bikesharing	4.2		+	+	+	+
carsharing	4.5					
E-scooter-sharing	4.0					

r.pooling/-hailing/-sharing	3.6		- -			++
other						
no mobility tools		1.0 %	++	+		
smartphone ownership		93.6 %	- - -	- -		

1) - / + = significant; - - / ++ = very significant; - - - / +++ = highly significant ***N = 1,358***

2) usage frequency (UF): 1 = (almost) daily, 2 = 1-3 days/week, 3 = 1-3 days/month, 4 = less often than monthly, 5 = (almost) never

A key finding is the highly significant negative correlation between owning a motorized individual transportation vehicle (car/motorcycle/moped/scooter) or a car driver's license and the likelihood of using the automated minibus. Additionally, the majority of car owners who were previously averse to using automated minibusses also cannot envision using them in the future. Nevertheless, users and non-users drive cars with similar frequency if they own one.

Furthermore, there is a public transportation affinity among users, which correlates with more frequent use of inner-city public transportation. Even among non-users, those with an affinity for public transportation are more optimistic about potentially using it in the future. Monheim-Pass holders, however, are equally likely to be users or non-users of the service, although, among non-users, they show a higher potential for future use. Regular users also more frequently use bikes compared to infrequent or non-users.

Regarding new forms of mobility, the proportion of carsharing memberships and the frequency of bikesharing usage are significantly higher among users, while the frequency of ridepooling/-hailing/-sharing services is lower. Among non-users, individuals with an affinity for new mobility services are significantly more likely to consider future use. Additionally, individuals who do not own any mobility tools or a smartphone are more likely to be users of automated minibusses. This result supports the previously described correlation between the likelihood of use and individuals facing difficulties in daily mobility (e.g., advanced age, mobility impairment).

Localization of users and non-users

To better quantify the demand and usage potential of automated minibusses spatially, the respective user groups were analyzed in their spatial distribution. The basis for this was the information provided by the survey participants about their place of residence. For privacy reasons, this was queried in the survey at the level of grid cells measuring 500m x 500m, so it is only known that a person lives within this cell, but not exactly where. This grid division was also adopted for the registration data, and the residents of Monheim were assigned to the corresponding grid cells. To simplify further analyses, the grid cells were divided into five urban areas, as depicted in Figure 5-5 Starting from the downtown area of Monheim, three districts were defined: Monheim South, Monheim East, and Monheim North. The only, in the analyses separately considered residential district is 'Baumberg'.

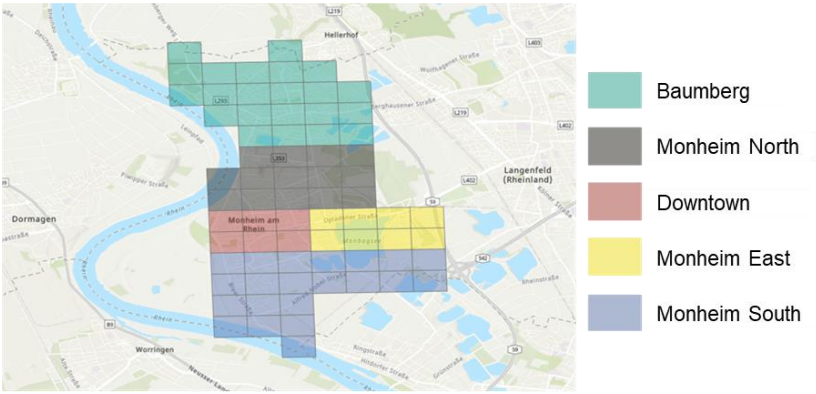

Figure 5-5: Spatial division in districts of Monheim am Rhein

Regarding gender distribution, it is evident that the proportion of women across all districts remains at a similar level. Only in the South area does the deviation from the average for Monheim am Rhein rise to 1%. However, concerning age distribution, significant differences are noticeable. While the city center and the southern part of Monheim are predominantly inhabited

by younger individuals (children or families), the remaining districts (especially northeast of the city center) exhibit a notably higher proportion of seniors (over 60 years old). Particularly, the northern urban area between the city center and Baumberg stands out in this regard. Both distributions can be observed in detail in the following table.

Table 7: Age and gender distribution in Monheim am Rhein according to population registration data; N = 40,343

			age					
districts	**N**	**women**	**< 20**	**20 - 29**	**30 - 39**	**40 - 49**	**50 - 59**	**> 60**
average		*52.0 %*	*8.0 %*	*11.9 %*	*15.5 %*	*13.7 %*	*18.4 %*	*32.5 %*
Baumberg	14.852	+ 0.5 %	- 1.2 %	- 1.9 %	+ 0.4 %	- 0.4 %	+ 0.4 %	+ 2.7 %
North	4.033	- 0.2 %	- 1.7 %	- 1.9 %	- 1.0 %	- 2.1 %	+ 0.5 %	+ 6.3 %
Downtown	10.755	+ 0.1 %	+ 0.2 %	+ 2.8 %	+ 0.0 %	+ 0.4 %	- 1.2 %	- 2.3 %
East	2.124	- 0.5 %	- 0.6 %	- 1.6 %	- 1.2 %	- 0.9 %	+ 0.6 %	+ 3.6 %
South	6.247	- 1.0 %	+ 3.8 %	+ 1.4 %	+ 0.1 %	+ 2.0 %	+ 0.6 %	- 7.9 %

To identify user groups in the registration data, considering the described socio-demographic differences, a discrete decision model was developed using survey data to estimate the frequency of use or, in the case of non-users, the potential for use. The user groups defined in Figure 5-4 were designated as manifestations of the decision variable. Since the registration data only contain information about a person's place of residence, age, and gender, only these two independent variables of the surveyed individuals could be used in the model creation process. The model estimated based on the survey data to classify user groups was then applied to the registration data. As a result, a probability could be calculated for each person in the registration data to belong to a specific user group as depicted in Figure 5-4. Subsequently, through random number generation, taking into account the calculated probability intervals, the actual group membership was determined. The results of the modeling are presented in Table 8.

Table 8: Geographic distribution of various user groups

districts	users	RU*	NUP**
average	**23.1 %**	**35.4 %**	**50.5 %**
Baumberg	+ 0.3 %	+ 0.5 %	+ 0.3 %
Monheim North	+ 0.4 %	+ 2.3 %	+ 0.4 %
Downtown	- 0.2 %	- 1.2 %	+ 0.3 %
Monheim East	+ 0.5 %	+ 1.1 %	- 0.5 %
Monheim South	- 0.9 %	- 1.0 %	- 1.4 %

* among users ** among non-users

Based on the modeled results, it is evident that overall, more than one in five individuals living in Monheim utilizes the automated minibus. Among them, approximately one-third are regular users of the minibus, with the remaining two-thirds being occasional users. Approximately four out of five residents of Monheim am Rhein currently do not use the automated minibus. However, about half of this group shows potential for future use and can envision utilizing the minibus service. The spatial distribution of user groups provides additional insights. Districts such as Baumberg or Monheim Nord, where older individuals tend to reside, are expected to have a higher proportion of users, according to model estimates. The age effect is even more pronounced among regular users in these areas. Additionally, non-users from these districts often show potential for future use. Although the automated minibus service is available in Monheim's city center, the model predicts below-average numbers of regular users there. However, non-users residing in the city center are more inclined to consider using the automated minibus in the future. Conversely, in Monheim Ost, the opposite effect is expected. As a district with an older population, the expected proportion of regular users is high according to the model, despite the proportion of women being below the Monheim average. However, the potential for use among non-users in this group is less pronounced. The lowest willingness to use the automated minibus is expected in the southern part of Monheim am Rhein. Due to the

younger and predominantly male population in this district, both the proportion of users and non-users with potential for use are significantly below the Monheim average.

Since no further mobility-relevant socio-demographic information could be considered besides age and gender, the presented results should only serve as a guide. For more in-depth, location-specific statements, the integration of additional significant explanatory variables across the corresponding (non-) user groups, as shown in Figure 5-4, would be necessary.

User attitudes toward automated driving and operation

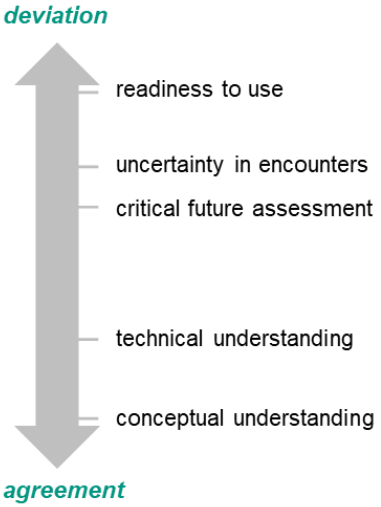

Figure 5-6: Comparison of attitudes towards the concept of automated driving between users and non-users; N = 1,358

In comparing the general attitudes toward automated driving between users and non-users, Figure 5-6 illustrates that almost all residents of Monheim am Rhein feel sufficiently informed about the concept (over 95%) and the technology (over 90%) behind automated driving. However, non-users tend to view the development of automated driving more critically. Additionally, they feel significantly less safe when encountering automated vehicles on the road.

Users and non-users generally assess the advantages and disadvantages of automated minibusses similarly, with users being slightly more positive and optimistic overall. Both groups primarily view potential interaction issues of automated minibusses with other road users

as a disadvantage. Concerning the reduction of pollutant emissions, enabling mobility for older and mobility impaired individuals, as well as improving public transportation connectivity as a consequence of integrating automated minibusses, residents of Monheim am Rhein generally express strong approval (see

Figure 5-7).

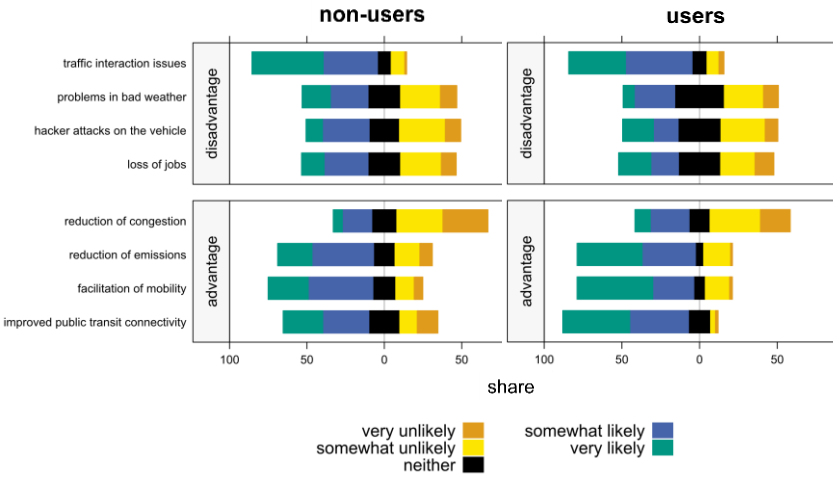

Figure 5-7: Evaluation of the advantages and disadvantages of automated minibusses; N = 1,358

Further insights are illustrated in Figure 5-8. Strong differences between users and non-users in the popularity of the automated minibus and its impact on the attractiveness of the entire public transportation system in Monheim am Rhein are apparent. The present findings suggest that with the use of the automated minibus, there is also a predominantly positive perception of the service. This is supported by the fact that the majority of users enjoy using the automated minibus. Thus, users, as well as about a third of non-users, feel pride regarding the automated minibus line A01 and wish for its deployment on other lines as well. This positive identification and feeling of pride may

indicate a successful implementation and integration of the automated minibus into the public transportation system in Monheim am Rhein.

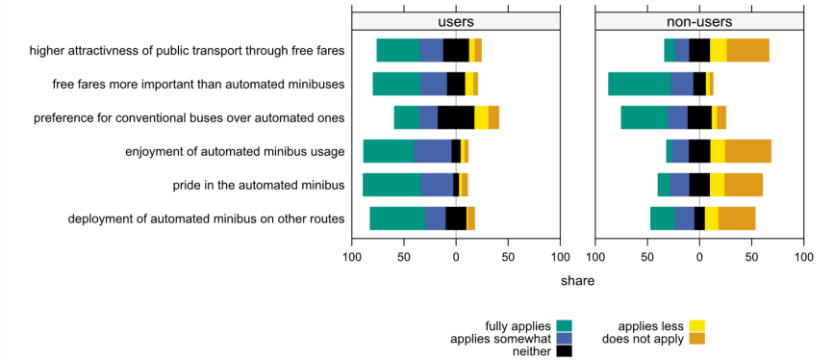

Figure 5-8: Perceived attractiveness of operation and impact on Monheim public transportation

User experience

Regarding the evaluation of the driving experience, a generally high overall satisfaction level can be observed, similar to the results of the passenger survey. However, there are identified areas for improvement concerning driving speed, seating availability, and driving behavior. The lack of privacy is emphasized more strongly in the present household survey results than in the passenger survey analysis (see Figure 5-9).

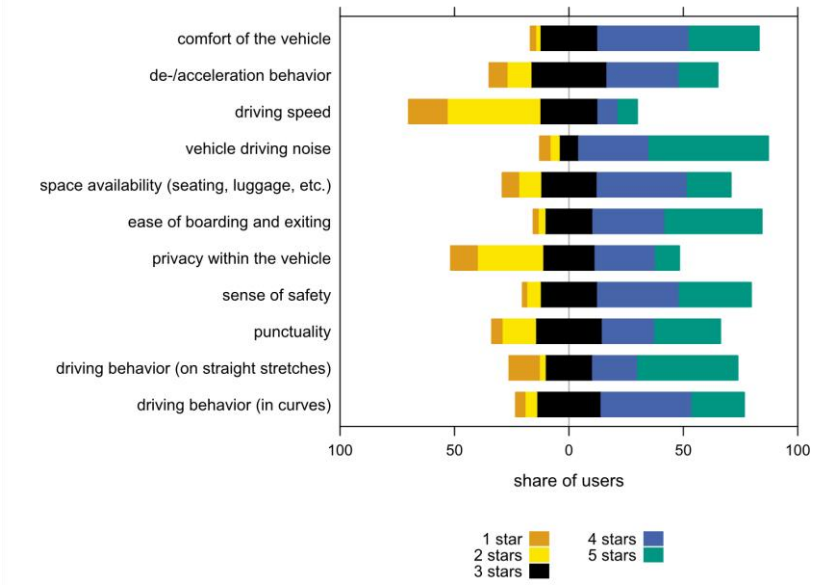

Figure 5-9: Evaluation of the ride by users; N = 347

Additionally, in the assessment of driving behavior, about half of the users reported experiencing an abrupt stop, which was simultaneously perceived as uncomfortable by the majority. The results also show that approximately 8 out of 10 individuals actively observe the operation of the automated minibusses, such as the authorization of specific driving maneuvers by the operator, making them more actively involved in the journey compared to conventional bus services.

A significant portion of users sees the presence of operators as essential for ensuring driving safety, particularly in complex situations, and for preventing crime within the automated minibus. While purchasing paper tickets through operators plays a relatively minor role, approximately every second user values route information and personal interaction with the operator (see Figure 5-10). Furthermore, 9 out of 10 users can envision a trip on the automated minibus line A01 without accompanying staff. More than half of

these individuals would do so "with full confidence," while others might feel "a bit tense or uncertain" during a fully autonomous journey.

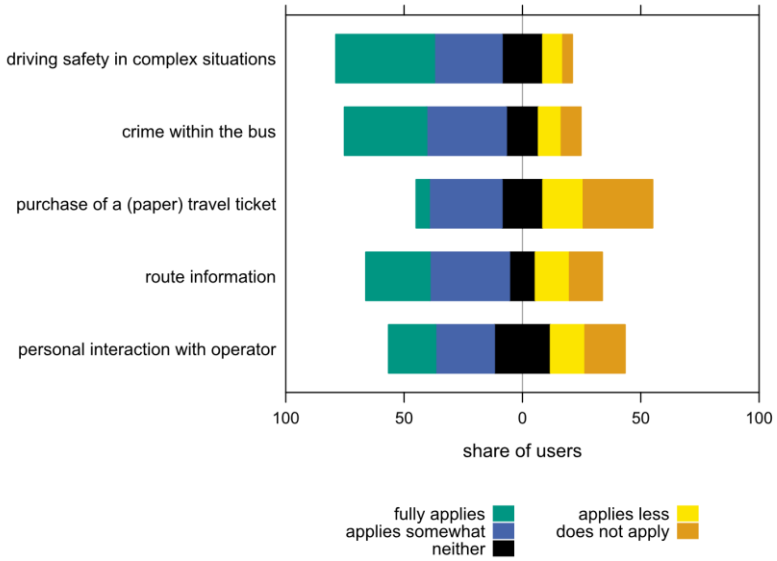

Figure 5-10: Key functions of operators from the perspective of users; N = 347

While the current technical state of operation poses a barrier for many non-users, there is potential in operational design to encourage these individuals to use the service. Approximately 30% of all non-users cite speed, just under 24% cite driving behavior, and 20% cite the current operating area as reasons for non-usage. Similar to users, safety concerns are not a factor for non-users and cannot be identified as hindering usage based on the available data. Figure 5-11 summarizes the responses regarding the reasons for non-usage.

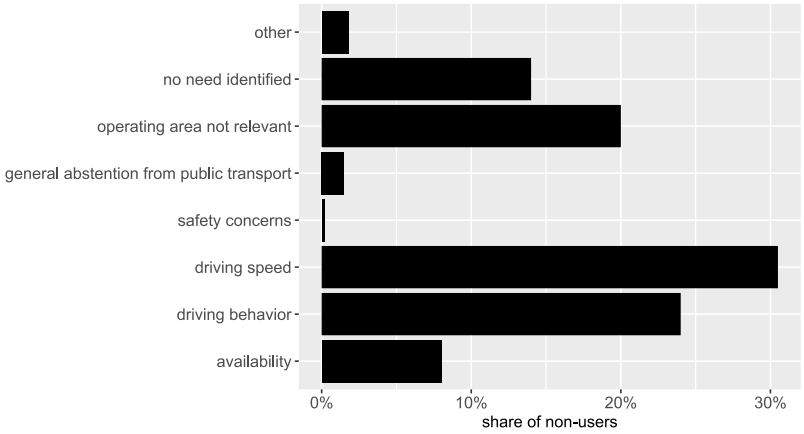

Figure 5-11: Reasons for non-usage from the perspective of non-users; N = 1,011

Future usage potential of automated minibus line A01

Nearly half of all non-users can envision using the automated minibus for everyday trips in the future. In order to describe the groups of (potentially) non-users in terms of their sociodemographic and mobility-related characteristics, two-sided, weighted t-tests were conducted again. The results can be found in Table 9.

Regarding the reasons for non-usage and their association with usage potential, it becomes apparent that non-users who are dissatisfied with the availability of the automated minibusses are more likely to see usage potential. All other reasons, such as driving behavior or the speed of the automated minibusses, show a negatively significant correlation. Younger, female, car-owning, or non-academic non-users also tend to be less likely to envision future usage. In contrast, public transportation-oriented individuals and those who are open to new mobility services but have not yet used the automated minibus generally show a willingness to use it in the future. This also applies to individuals with an academic degree. Additionally, full-time

employed individuals, those with moderate incomes, and individuals with at least one child in the household also tend to recognize usage potential.

Table 9: Results of t-tests between socio-demographic and mobility-related characteristics of non-users and their future usage potential

	Non-users without usage potential	Non-users with usage potential
← Increasing significance	income between 6.000 € – 7.000 €	UF long-distance bus, IC, ICE
	vocational qualification	bikesharing membership
	high school diploma	dissatisfaction due to availability
	woman	UF regional train
	14 – 20 years old	UF bikesharing
	security concerns as a passenger	30 – 39 years old
	aversion to public transportation	UF conventional bus
	car ownership	UF ridepooling, -hailing, -sharing
	individuals without explicit usage need	UF tram, subway
	dissatisfaction due to speed	full-time employee
	dissatisfaction due to driving behavior	income between 2.000 € – 3.000 €
		child(ren) in household
		carsharing membership
		Monheim-Pass holder
		ridepooling membership
		academic degree

UF = Usage frequency ***N = 1.011***

Furthermore, during the survey, users and non-users with usage potential were asked to evaluate various expansion measures to increase willingness to use the service. It was found that almost all (potential) users would use the automated minibus more frequently if it were deployed as a feeder service to other public transportation offerings (e.g., to the train station in 'Langenfeld'). The majority also supported further expansion measures, with increasing ride comfort being mentioned the least as an expansion measure. This suggests that there is already a high level of satisfaction regarding comfort, which is

also consistent with the findings from the operator interviews (see Figure 5-12).

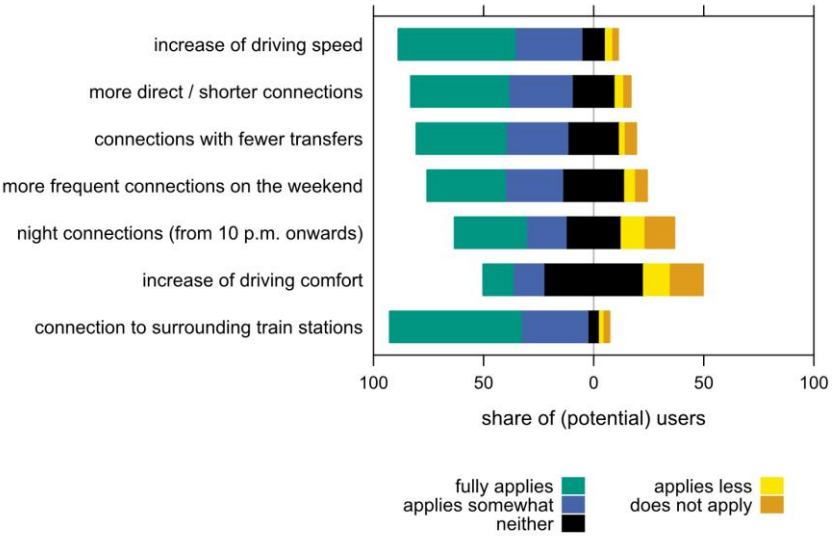

Figure 5-12: Evaluation of expansion measures to increase usage potential among (potential) users; N = 863

In evaluating various deployment options for the automated minibusses on regularly trips, (potential) users also indicated that they are most likely to consider using them for shopping and leisure trips. In the case of business appointments, where punctuality or reliability is of greater importance, about three-quarters deem the automated minibus unsuitable (see Figure 5-13). Additionally, a large majority can particularly envision using the automated minibusses on routes that have been traditionally traveled by public transportation.

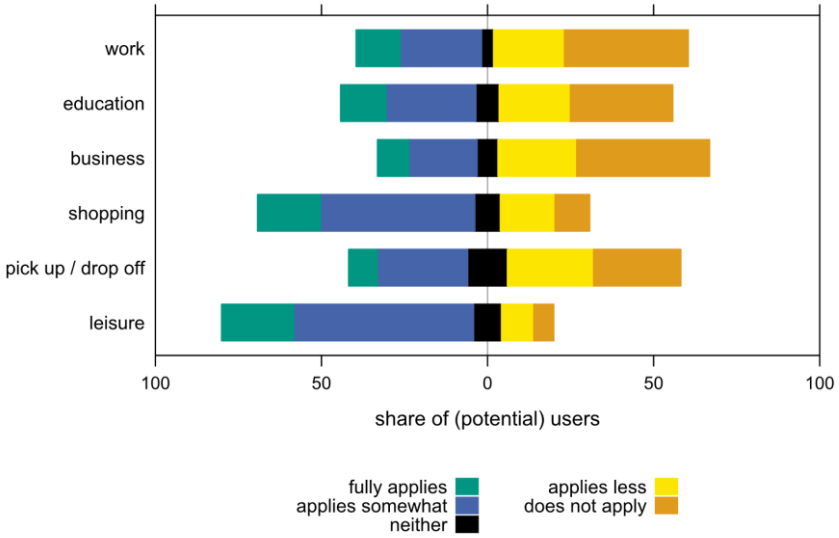

Figure 5-13: Deployment options based on previous trip purposes; N = 863

Insights from the choice experiment

To quantify the influences on mode choice, a multinomial logit model was estimated based on mode choice decisions in the choice experiment. For the analysis of the choice experiment, the software R was used, applying the "Apollo" package (Hess and Palma 2019). The focus of the analysis is on the two operating modes of automated minibusses, namely the line operation (referred to as automated minibus line) and the ridepooling or on-demand operation (referred to as automated minibus on-demand), and their evaluation compared to the conventional bus service. The following figure shows the distribution of mode choices in the entire experiment, with ten choices captured from a total of 1,300 participants eligible for the choice experiment.

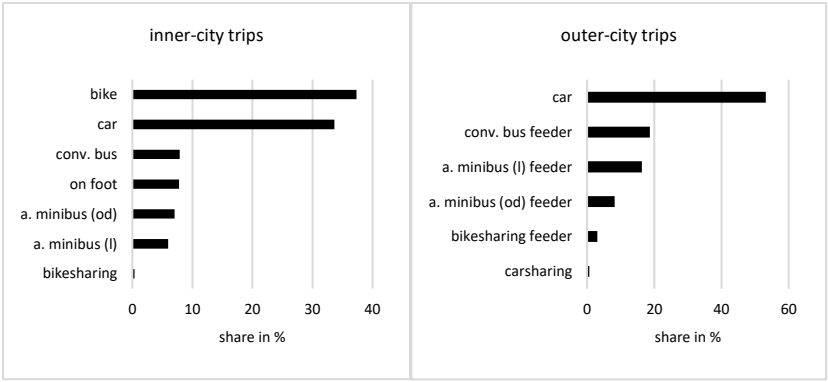

Figure 5-14: Distribution of mode choice decisions; N = 13,000

It becomes evident that the car is significantly preferred for both inner- and outer-city trips, while the bike was most preferred for the former. Bike- and carsharing, however, were hardly considered in the decisions.

The model results illustrate that participants rate the travel time in the automated minibus in line operation (parameter = -0.029; t-value = -4.93) similarly to the travel time in the conventional bus (parameter = -0.026; t-value = -4.3) or the train (parameter = -0.029; t-value = -9.33). The time required for access and egress to public transportation was not identified as a significant influence on mode choice. The costs for on-demand operation (parameter = -0.173; t-value = -4.93) were rated similarly to the costs of using a private car. Additionally, participants showed less sensitivity to waiting time or frequency, as no significance was found for either factor. The following table summarizes the results of other influences on mode choice.

Table 10: Results of socio-demographic and mobility-related influences on mode choice

variables	inner-city trips (automated minibus as primary mode)			outer-city trips (automated minibus as feeder)		
	conv. bus	a. minibus line	a. minibus on-demand	feeder conv. Bus	feeder a. minibus line	feeder a. minibus od
alternative specific constants	1.64***	-0.54	-1.03*	0.16	-1.25***	-1.9***
car ownership	-2.08***	-2.35***	-1.96***	-1.75***	-1.58***	-1.78***
woman	-	-	-	0.26**	-	-0.32*
Deutschland-Ticket holder	0.6**	-	-	1.41***	0.66**	0.93***
academic degree	-	-	0.68***	-	0.51***	0.5***
Monheim-Pass holder	-	0.98*	-	0.7**	0.83**	1.36***
trip purpose: Business		-0.94**	-	-	-0.37**	-
trip purpose: Shopping	-0.81***	-	-	-	-	-0.6*
student	-	-	-	0.74***	0.78***	-
trainee / pupil	-	-	-	-	-	1.1**
mobility impaired	-	0.67*	-	-0.72***	-	-
carsharing membership	-	-	0.46**	-	0.62***	0.94***
bikesharing membership	-	1.01***	-	-	0.59**	-
employed	-0.43***					

1) car is the reference mode of transportation 2) N = 13000, Adj. R2= 0.32, LL(0) = -24135.36; LL(final) = -16313.67, BIC = 33423.06
3) * = significant; ** = very significant; *** = highly significant

For inner-city trips, the automated minibus in line operation was more likely to be chosen by individuals with a bikesharing membership, a Monheim Pass, or mobility impairment. For outer-city trips, on the other hand, there was an increased preference among individuals with a Deutschland-Ticket, a carsharing membership, or an academic degree. Additionally, for those trips, no increased inclination was observed among individuals with mobility restrictions to choose the automated minibus in line operation.

The automated minibus in on-demand operation was more frequently chosen for inner-city trips by individuals with an academic degree or carsharing membership. For feeder trips, Monheim Pass holders, Deutschland-Ticket users, trainees, as well as students were identified as preferred user groups. Furthermore, negative probabilities of usage were observed for shopping trips and among women.

The factor of car ownership influences mode choice more strongly in favor of the car and to the detriment of automated minibus operations, especially line operation, for inner-city trips. Conversely, the possession of a Deutschland-Ticket only has a positive effect on the choice of the automated minibus in feeder transportation. It is likely that this observation is related to the specific situation in Monheim am Rhein, where local public transportation is already free; thus, the Deutschland-Ticket shows its positive influence primarily on longer distances. Furthermore, individuals with a carsharing membership show a stronger preference for the on-demand operation of automated minibusses for feeder trips. They also prefer the line operation of automated minibusses over using their own car. Additionally, students tend to rate the automated minibusses in line operation as feeder more positively compared to their evaluation as main modes of transportation.

6 Results synthesis and Discussion

The preceding presentations of results have provided a comprehensive insight into the usage motives of the automated minibus line A01 in Monheim am Rhein. Each of the three applied surveys has revealed different perspectives on the acceptance of the automated minibus line A01. Due to the various methods, the aim of this chapter is to synthesize the results of the quantitative passenger survey, qualitative operator interviews, and representative household survey to identify commonalities, differences, and patterns in the perception of the automated minibus line A01 between users and non-users. Furthermore, the obtained results are contextualized within the existing literature.

Sociodemographics of users

In both quantitative survey methods, it was shown that the automated minibus line in Monheim am Rhein is predominantly used by female, older, and/or mobility impaired individuals, who are also more often retired than non-users. One of the most frequently mentioned reasons for usage was that the trip would otherwise have been "too long or arduous." Thus, the automated minibus line A01 in Monheim am Rhein particularly serves as a 'mobility enabler' for older and mobility impaired individuals. This role is supported by the presence of an operator during the automated minibus journey, who can assist passengers boarding and alighting, and can more easily accommodate individual needs than in conventional buses. Similarly, Lee and Kockelman (2022) demonstrate in their study that an automated minibus service provides the greatest benefit for this specific demographic group. However, past studies on automated minibus services often identify the contrasting demographic group, young, male, and non-mobility impaired, as the main user group of an automated minibus (Kassens-Noor et al. 2020;

Dong et al. 2019; Portouli et al. 2017). Based on the findings of Barthelmes et al. (2022), this is because numerous pilot projects of automated minibus services are implemented as on-demand services, where access barriers, especially for older people (e.g., the requirement to book a ride via an app), are too high. The chosen form of line operation in Monheim am Rhein, integrated into the city's existing bus line system, eliminates these barriers. This makes the service equally accessible to everyone, unlike on-demand services, but at the same time, it generates stronger usage by demographic groups disadvantaged by other new mobility services, especially in the on-demand sector. Similar findings are reported by Wintersberger et al. (2020), who examined the acceptance of an automated minibus line pilot project in 'Bad Birnbach'.

Mobility behavior of users

Both in the passenger survey and household survey, it was shown that users of the automated minibus line A01 have a strong affinity for public transportation and use it more frequently than non-users. That the offering of an automated minibus is more accepted by public transport users has also been demonstrated in other studies (Kostorz et al. 2020a; Klinkhardt et al. 2023). However, the accompanying research on the automated minibus operation can also provide initial indications that the offering of the A01 minibus line in Monheim am Rhein leads to an additional increase in the use of other public transport services. Approximately one in four individuals stated in the passenger survey that they use public transport more frequently since the introduction of the automated minibus line A01. Two reasons, in particular, account for this observation. Firstly, the automated minibus line A01 fills a gap in the city's existing bus line network by connecting the old town to the bus terminal, an area of Monheim am Rhein where conventional bus operations are not feasible, thus making public transport accessible to more people through the new offering. Secondly, the sociodemographic influences of the user group, as described in the preceding paragraph, play a role. The seamless integration of the automated minibus line A01 into

Monheim's existing bus line network means easier access for older and mobility impaired individuals to the city's public transport system, thereby supporting these individuals in using it.

While the automated minibus line A01 was initially tested by the population out of curiosity and interest, acceptance of the offering has increased over the course of its operation. Over time, passengers have begun to integrate the automated minibus line A01 more into their everyday mobility and use it for typical trip purposes rather than just trying out the automated minibus. Similar, though less pronounced, results were observed in one of the first pilot projects of an automated minibus line in Trikala, Greece (Portouli et al. 2017). Nevertheless, existing studies on the introduction of automated minibusses often find that the predominant trip purpose is "testing the service," especially for on-demand offerings (see Barthelmes et al. (2022)). Thus, the introduction of the automated minibus line in Monheim am Rhein as a permanent offering seems to have had a positive effect on its integration into the passengers' everyday mobility. Additionally, the route alignment with a direct connection to the bus terminal and, thus, numerous connections to other public transport modes positively impacts the integration of the automated minibus into everyday mobility. In future studies of automated minibus operations, the durability of the offering and the specific offering design must be considered in assessing service acceptance.

The use of the automated minibus line in Monheim am Rhein primarily occurs on leisure or return-to-home trips. Even previous non-users of the service are most likely to consider using it for leisure or shopping trips. In contrast to other trip purposes, such as commuting to work, these are trip purposes that often have no or only minimal external time constraints. Here, a connection to the sociodemographics of the automated minibus line A01 users becomes evident. As mentioned earlier, these are predominantly older individuals who are often retired. In contrast to other studies, increased usage of the automated minibus line A01 by middle-aged individuals engaged in home-based work was also identified in the household survey in Monheim am

Rhein. Both groups typically have greater flexibility in scheduling their daily activities than, for example, employed individuals. This finding is particularly relevant for further research, as well as for the medium- and long-term design of the automated minibus offering in Monheim am Rhein. The current travel speeds of the automated minibusses are still low. Speed was also cited as one of the major disadvantages of the service. If the travel speeds of the automated minibusses are increased in the future, an increase in usage on trips with greater time constraints, such as work or service trips, as well as by individuals with higher time sensitivities, can be expected.

Characteristics and perception of the automated minibus line

In the accompanying research, high overall satisfaction with the existing automated minibus service in Monheim am Rhein was demonstrated across all three data collection methods. This is evident, firstly, in the comparatively large number of automated minibus line A01 users. More than one-fifth of Monheim residents use the A01 line; on average, 1 to 3 times per month. Additionally, the fact that nearly half of non-users indicate a willingness to use the service confirms the positive view of the automated minibus service. Other studies have also shown that the population tends to have a positive attitude toward automated minibusses, regardless of whether the automated minibus has been used (Christie et al. 2016). However, the literature also indicates that satisfaction tends to increase after an usage experience (see Azad et al. 2019; Kostorz et al. 2020b; Bernhard et al. 2020). The findings from this study can further generalize this statement. The repeated passenger surveys demonstrate a more positive assessment of the automated minibusses with increasing usage experience. The increase is particularly notable in the evaluation of the automated minibusses' performance characteristics. With more usage, passengers become familiar to the specific features of the automated minibusses and adjust to them. When passengers are aware beforehand, for example, that the speed is lower than in conventional buses and there may be uncomfortable braking, over time, this

is perceived less negatively as passengers board the vehicle with appropriate expectations.

However, for the further development of automated minibus services, it is not sufficient to rely solely on the adaption effect. Wicki and Bernauer (2020) emphasize in their study that a positive attitude towards automated minibusses is an important prerequisite for their acceptance and, consequently, willingness to use them. Therefore, the offering must be so attractive that individuals are motivated to use it for the first time and find it consistently attractive. Points of criticism, where users and non-users of the automated minibus line in Monheim am Rhein see potential for improvement, must therefore be addressed.

According to Alessandrini et al. (2016), travel time and fare costs are the main arguments for accepting an automated minibus service. The travel time for the current form of the automated minibus line in Monheim am Rhein is still low and is perceived negatively. Therefore, technical improvements to the vehicle must aim for higher travel speeds in the future. This could allow current users of the automated minibus line A01 to use it for other trip purposes where they have time constraints. Furthermore, an increase in speed is expected to enhance the attractiveness of the automated minibus line A01 for current non-users, making them more likely to consider using it. Technical improvements in vehicle behavior could also contribute to an increase in acceptance in both groups. By improving vehicle behavior as well as increasing speed, other road users will also perceive the automated minibus service more positively. While car drivers are currently slowed down by the automated minibus and must follow it at significantly reduced speeds until there is an opportunity to overtake, increased automated minibus speeds could contribute to a much smoother traffic flow. This could lead to the automated minibus being perceived less as a traffic hindrance and more as an equal participant in traffic.

Fare costs as a second acceptance driver are not a hindrance to usage in the operational design in Monheim am Rhein. While other automated minibus

operations frequently invoiced passengers separately after a free trial period, the automated minibus operation in Monheim am Rhein has an advantage in its seamless integration into the existing public transport system. Usage is possible with traditional public transport passes. This reduces the complexity of usage and ensures easy access. It also reduces usage costs. The Monheim Pass or other transit passes for public transport are valid on the automated minibus. Likewise, with day or single tickets, there is a simple transition to other public transport lines.

Based on a study by Etminani-Ghasrodashti et al. (2021), the flexibility and reliability of an automated minibus service are further relevant factors for acceptance. Improvement potential regarding reliability was particularly highlighted in the passenger survey. In terms of punctuality, passengers perceived decline over time as the only issue. This should be improved to avoid any loss of acceptance of the automated minibusses in the future.

Furthermore, a sense of safety in the automated vehicle is discussed as an important prerequisite for the acceptance of an automated minibus service in the literature. Numerous studies already indicate a high sense of safety among passengers of automated minibusses (Bernhard et al. 2020; Bellone et al. 2021; Mouratidis and Serrano 2021). The accompanying research on the automated minibus line in Monheim am Rhein confirms the high sense of safety among passengers. Emergency braking of vehicles plays an important role in this. Although passengers perceive these negatively, they contribute to an increased sense of safety. Existing studies attribute the high sense of safety mainly to the presence of accompanying personnel (Guo et al. 2020). For example, Dong et al. (2019) found that only 13% of respondents would use the automated minibus if no accompanying personnel were present. In Monheim am Rhein, the accompanying personnel contribute to an increased sense of safety, according to the respondents, either by ensuring driving safety in complex traffic situations or preventing crime on the automated minibus. However, the concern about traveling without accompanying personnel is significantly less pronounced. In the household survey, 9 out of

10 users stated their willingness to use the automated minibus in the future without accompanying personnel. Among them, more than half said they had no concerns about fully automated minibus operations.

Role of the accompanying personnel

Although the majority of Monheim residents would also use the automated minibus without accompanying personnel, their support of passengers, such as assistance with boarding and alighting or providing schedule information, contributes to the positive perception of travel comfort by passengers. This is particularly relevant in terms of long-term customer loyalty, as evidenced by the results of Chee et al. (2020). The presence of accompanying personnel must, therefore, be considered by the population as a relevant factor for the acceptance of such an automated service, even without safety concerns.

The accompanying research in Monheim am Rhein shows that customer loyalty is currently working well. There is a deeper personal relationship between passengers and accompanying personnel than in conventional bus lines. This is apparent in lively communication between passengers and accompanying personnel, as well as among passengers themselves. The seating arrangement in the automated minibus supports communication. While this results in passengers rating privacy in the vehicle lower than other criteria, the results of a Dutch accompanying research on automated minibus operations, in which passengers sometimes perceived proximity to accompanying personnel negatively as surveillance, cannot be confirmed in Monheim am Rhein (cf. Winter et al. (2019)). Rather, the accompanying personnel report a core group of passengers with whom a personal relationship has developed over the duration of the service offering.

In their self-perception of their role as accompanying personnel, the surveyed operators in Monheim am Rhein emphasize their role as service providers to passengers. For this function, adequate replacement must be provided in the event of progressive automation and the associated potential elimination of

accompanying personnel, to avoid disrupting customer loyalty. However, the surveyed operators view the elimination of the role of accompanying personnel for their own future as unproblematic. In other studies, the prospect of job loss for bus drivers has led to a negative perception of the service by residents (cf. Papadima et al. (2020)). However, the accompanying research in Monheim am Rhein shows that this concern is unfounded. The surveyed accompanying personnel of Bahnen Monheim have no fear of the future or fear of job loss and can also imagine alternative employment opportunities outside of driving duties.

Additional insights from non-users

Through the household survey, especially non-users of the automated minibus service (approximately 74% of the respondents) could be reached. This group is characterized by young adults and individuals aged between 40 and 60, who are more likely to own one or more cars or have an affinity for motorized individual transport. Their predominantly negative attitude towards the current operation is mostly attributed to the current driving behavior of the automated minibusses and the resulting high travel time due to their speed. The influences of both characteristics have already been adequately discussed in previous sections. In particular, the influence of speed on willingness to use was also confirmed by Guo et al. (2020), who found a more negative perception of speed among non-users than users in accompanying research on an automated line operation in Stockholm, Sweden. Contrary to the statements of Soe and Müür (2020), based on accompanying research on an automated minibus operation in Estonia, the aspect of driving safety hardly contributes to non-use. Nevertheless, non-users see interaction problems with other road users as the biggest disadvantage. As mentioned earlier, an increase in vehicle speeds and an improvement of technical systems, in general, could reduce interaction problems and thereby increase acceptance among non-users.

However, even today, about half of the non-users are generally willing to use the automated minibus for everyday trips in the future. Similar to users, this includes, in particular, individuals with an affinity for public transport but also for sharing services. In contrast to current users, full-time employees, and families also show increased interest in future usage, thus forming a new, potentially accessible user group.

To realize the potential use by these individuals, various measures are necessary. As previously described, these include technical improvements such as increasing the speed of the automated minibusses. However, operational expansion measures can also increase willingness to use among both users and non-users. Users indicated in the passenger survey that they would like to see an expansion of the service in neighborhoods where older people live. This includes areas like ‘Baumberg’. But even current non-users can imagine using the service if it is more widely available. The greatest potential for such operational expansion measures, according to respondents, lies in using the automated minibus line as a feeder service to the surrounding train stations (‘Langenfeld’/’Berghausen’).

Another result of the household survey is that users and non-users of the automated minibus line feel well-informed about the technology and concept of automated driving. However, studies show that the population often has higher expectations when it comes to the introduction of automated minibusses than can be realized due to current technological progress. Therefore, the reported awareness of technology and the concept of automated driving in the household survey is based on the subjective perception of the respondents and could be lower under objective evaluation criteria. Additional information and communication campaigns by Bahnen Monheim and the city of Monheim am Rhein could, therefore both normalize the population's expectations, for example, regarding the speed and driving behavior of the automated minibusses and address the technical and operational development path of the automated minibusses in a targeted

manner to foster greater acceptance of current weaknesses in the automated minibus service.

Prospective use of automated minibusses

Building on the target scenario in which the automated minibus attains the speed of conventional buses, the acceptance of two operating modes of an automated minibus was quantitatively evaluated using a choice experiment and compared to conventional bus operation. A central result of the choice experiment is that travel time in the automated minibus in line operation is perceived similarly to that in conventional buses. Unlike other studies such as Pernestål et al. (2018) and Chee et al. (2020), which identified frequency as an important influencing factor on the choice of automated minibusses, in our experiment, besides boarding and alighting times and waiting time for the automated minibus in on-demand operation, frequency did not significantly influence the mode choice. Assuming a convergence of ordinary travel speeds, this means that an automated minibus line is perceived similarly to conventional bus service in terms of travel characteristics and schedule.

Furthermore, car owners are less averse to on-demand or ridepooling operations on urban routes than to line operations. In parallel, the cost of using a car is perceived similarly by car owners compared to on-demand automated minibus operations. Car-affine individuals are, therefore, more likely to consider using an on-demand automated minibus service than one in line operation. Due to the more flexible routing of an on-demand service, similar individual travel preferences can be accommodated as with a car, making this option more attractive for car-affine individuals. It is also worth mentioning that mobility impaired individuals tend to use the minibusses for inner-city trips. However, line operation is significantly more accepted on outer-city trips, especially among holders of a transit pass, members of car-/bikesharing, students, and individuals with an academic degree. Except for students, the mentioned groups also tend to use on-demand operation as a feeder service, which women, in general, are less averse to.

7 Conclusion

As part of the mobility transition in Germany, the expansion of public transportation is aimed at making sustainable modes of transport more attractive. A part of this expansion is the introduction of automated minibusses, which are smaller, more efficient, and more flexible than conventional buses, offering improved environmental friendliness. With a stronger consideration of individual needs, they are intended to reduce the disadvantages of existing public transportation services compared to private cars and thus make public transportation more attractive.

Since February 2020, Germany's first automated minibus fleet has been in regular line operation in Monheim am Rhein. The city's goals behind the introduction include improving connectivity in public transportation, especially for the historic old town, as well as increasing traffic safety. Additionally, the city aims to promote acceptance and understanding of automated driving and make digitalization tangible. Over a period of two years, the Institute for Transport Studies at the Karlsruhe Institute of Technology accompanied the introduction and operation of the automated minibus line A01. The findings of these studies are presented in this report. The focus was on the acceptance of the new service and its impact on mobility behavior, using various survey methods such as passenger surveys, interviews with accompanying personnel, and a household survey. The linkage of the different survey components enabled the assessment of the impacts and acceptance of the new mobility service in Monheim am Rhein.

Typical users of the automated minibus line A01 are predominantly female, older, and/or mobility impaired individuals who are often retired. Therefore, the automated minibus line A01 plays an important role as an enabler of mobility for these groups of people. In contrast to many test operations of automated minibusses, which are based on on-demand services and disadvantage older people due to high access barriers, the service in

Monheim am Rhein is easily accessible due to line operation without such barriers.

Furthermore, studies on the mobility behavior of users show a pronounced public transport affinity among automated minibus users. In particular, the integration of the automated minibus line A01 into the city's existing bus network has helped make public transportation accessible to more people and promote its use. Initial curiosity has evolved over time into a stable integration of the automated minibus line A01 into the everyday mobility of passengers, with usage primarily occurring on leisure and return-to-home trips. Increasing the travel speeds of the automated minibusses could also promote usage on trips with time commitments, such as commuting or work trips, and by individuals with higher time sensitivities.

Furthermore, the accompanying research demonstrated high overall satisfaction among users and a clear willingness to use among non-users. The results indicate that passengers become familiar to the characteristics of the automated minibusses and evaluate them more positively with increasing usage experience. Nevertheless, it is important to continuously improve the attractiveness of the service, especially regarding travel time and driving behavior, by making technical improvements to increase travel speeds and improve driving behavior. Through these measures, acceptance can be further increased among current and non-users and contribute to a more positive perception of the service by other road users. The full integration of the automated minibus line A01 into the city's public transportation system, including at the fare level, reduces the complexity of use and increases acceptance of the line. Cost reasons are, therefore, not a reason for non-use.

Additionally, the study demonstrates a high sense of security among passengers, to which the accompanying personnel contribute significantly with their presence. Nevertheless, the household survey shows a clear willingness to use the automated minibus even without accompanying personnel, indicating increasing acceptance and trust in autonomous technology. The accompanying research in Monheim am Rhein was able to

provide further insights into the role of accompanying personnel. The presence of accompanying personnel increases passenger comfort by assisting them during boarding and alighting, among other tasks. At the same time, accompanying personnel contribute to long-term customer loyalty through close contact with passengers. In particular, regular passengers develop a personal relationship with the accompanying personnel over time. Should accompanying personnel no longer be needed due to technological progress in the future, operators see the biggest challenge in determining who will fulfill the service role for passengers. The accompanying research could not identify fear of job displacement resulting from the elimination of the task of driving.

The household survey also provided insights into the reasons for non-use of the automated minibus service, with many citing current driving behavior and bus speed as criticisms. Interaction problems with other road users are seen as a disadvantage, especially among non-users, yet every second non-user is generally willing to use the automated minibus in the future. Among users and non-users with usage potential, potential usage is recognized especially for everyday trips, leisure and shopping trips, in the event of increased travel speeds and/or deployment as a feeder to train stations.

With regard to the prospective alignment of the travel speed of automated minibusses with that of conventional buses, the results of the mode choice experiment show that travel time is perceived similarly in both automated and conventional buses. Car owners also show less aversion to future on-demand operations, while individuals with mobility restrictions are more likely to prefer the automated minibus line in urban areas.

In summary, the results of the accompanying research on automated minibus operation in Monheim am Rhein show that the automated minibusses there already represent a promising mobility option for a selected group of people, increasing the attractiveness of public transportation. Not only the positive feedback from users but also the high willingness to use among non-users can attest to this. The high level of awareness of the automated minibus line

underscores the city's and Bahnen Monheim's achievement of the goal of making digitalization and automated driving tangible with the introduction of an automated mobility service. The increase in connectivity to the city's other public transportation services was also demonstrated. The conducted studies and analyses have provided further important insights into the introduction and prospective operation of automated minibusses in public transportation. In order to reach further users in the future with the offer of an automated minibus line, an increase in travel speed is necessary. Additionally, the intermodal use as a feeder service to surrounding train stations has been identified as a promising measure within the framework of the accompanying research. In addition, information campaigns can help standardize the population's understanding and expectations regarding automated driving, as well as automated minibusses in particular. This applies to both the current acceptance of weaknesses and the communication of future potentials of automated minibusses.

8 Literature

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Appendix

A. Parameter variations in the choice experiment

Table 11: Variations of mode-specific parameters in the choice experiment (monomodal section)

Parameters	on foot	bike	car	conv. bus	a. mini-bus line	a. mini-bus od.	bikesharing
travel time*	15 – 40	5 – 20	4 – 14	6 – 21	6 – 21	6 – 21	5 – 20
access time*	-	-	1 – 3	3 – 8	3 – 8	-	3 – 8
egress time*	-	-	2 – 4	3 – 8	3 – 8	-	-
waiting time*/ frequency*	-	-	-	10 - 30	10 - 30	4 – 11	-
travel costs**	-	-	1,1 - 3,1	-	-	0 - 4,5	0 – 2,5

*in minutes ** in €

Table 12: Variations of mode-specific parameters in the choice experiment (intermodal section)

Parameters	car	carsharing	bikesharing → train	conv. bus → train	a. minibus l. → train	a. minibus od. → train
travel time main mode	20 – 45 min	20 – 45 min	16 – 41 min	16 – 41 min	16 – 41 min	16 – 41 min
travel time feeder			6 – 16 min	6 – 16 min	6 – 16 min	6 – 16 min
access time	1 – 3 min	5 – 15 min	4 – 10 min	4 – 10 min	4 – 10 min	-
egress time	2 – 4 min	-	-	-	-	-
waiting time*/ frequency*	-	-	-	-	-	4 – 12 min
travel costs main mode	3 – 6 €	6 – 10 €	2,2 – 4,6 €	2,2 – 4,6 €	2,2 – 4,6 €	2,2 – 4,6 €
travel costs feeder	-	-	0,5 - 2,5 €	-	-	3,5 - 5,5 €