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# Requirements for automated micro-vehicles from the German public: a survey study

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**Abstract**

This study investigates public requirements for and acceptance of semi-sized automated micro-vehicles (AMVs) in urban traffic in Germany, addressing safety and functional expectations from both incidentally co-present persons and potential delivery customers. A two-step approach, combining qualitative pre-studies and a quantitative survey was employed. Qualitative research consists of interviews, focus groups, and expert workshops to identify requirements, which are quantified in a survey involving 1000 urban-dwelling Germans. The results show that safety-related requirements are paramount. The top priority is basic vehicle safety, such as "safe braking behaviour," "visibility," and "safety in all weather conditions". Autonomous behaviours for safety and delivery-specific attributes are also significant, though some autonomous functions received mixed responses. Social and sustainability requirements are also important—size and speed restrictions only moderately. The novelty of the research approach lies in focusing not only on the identification of acceptance factors, i.e. showing that size is important to public acceptance, but to study tangible requirements and accepted limits regarding vehicle design, behaviour and integration into public spaces, such as speed and size limits, evaluation of specific autonomous behaviours and technical details. The study emphasises the need for infrastructure, regulations, and trust-building efforts in AMV adoption.

**Keywords** Autonomous micro vehicles, Public requirements, Acceptance, Urban logistics

## 1 Introduction

There is a pressing need for innovative mobility solutions in urban logistics that is led by multiple trends. On the one hand, (last-mile) deliveries significantly impact traffic volume and carbon emissions in inner cities [2, 13, 45]. To combat the climate crisis and reach the European goal of net zero emissions by 2050, city logistics need to largely reduce emissions and become more sustainable [13, 44]. Additionally, space in cities becomes scarce for road-based traffic as cities are reshaped, and space is re-allocated to pedestrian zones in order to improve urban quality of life [44]. Consequently, delivery traffic is vying for limited road space with public and individual traffic, and, at the same time, many areas cannot be serviced with road-based vehicles anymore [14]. These developments come at a time when logistics companies are challenged by growing parcel volumes, personnel shortages, increasing customer demands for fast and flexible deliveries, inflation, and more [7, 42]. Here, conventional last-mile delivery solutions that rely on traditional delivery vehicles not only significantly contribute to traffic volume, noise pollution, and carbon emissions but also disrupt the smooth flow of urban road traffic, as seen in practices like double parking [3, 13, 31]. The transition to electrified delivery fleets reduces emissions and air pollution, yet it falls short of resolving critical challenges related to the limited road infrastructure. What is needed are novel mobility concepts tailored specifically for urban last-mile delivery, ensuring zero local emissions as well as integration into the (re-shaped) urban infrastructure.

One promising approach to solving these issues is the use of automated micro-vehicles (AMVs) [6, 9, 29, 34]. This term subsumes small side-walk delivery robots,

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automated bicycles, tricycles, and larger road-based vehicles up to 400 kg, which fall under the European vehicle category L (or below) [6]. Baum and colleagues (2019) classify different vehicle concepts according to their required infrastructure, vehicle type and use of human reference. They differentiate non-road and road concepts of automated bikes and delivery robots. While these autonomous vehicles are all electrically powered, freight cycle solutions (tricycles, cargo bikes) also use the rider's muscle power [e.g., 23, 27]. Such AMVs' smaller vehicle sizes facilitate seamless integration into urban environments and traffic infrastructure, minimising parking-related impediments while enabling navigation on non-road infrastructure, including bike lanes, sidewalks, and pedestrian zones. The automation of micro-vehicles introduces even new avenues for optimisation, such as the concept of mobile depots or mobile pickup stations. These innovations hold great potential for enhancing urban logistics and reducing environmental impact [4, 6, 12, 29]. However, fully autonomous delivery solutions face tremendous challenges to be approved for use in public traffic at present [48]. Also, these vehicles (or robots) are not yet capable of ringing doorbells or climbing stairs, thus, leaving the last steps of the delivery to the customer. This may be one of the reasons that deliveries with a human contact person are preferred over fully autonomous deliveries [36]. Therefore, another advantageous AMV solution involves semi-sized AMVs using a following approach [25, 35]. The size indication 'semi-sized' refers to a medium size such as autonomous cargo bikes, situated between large road-based AMVs and small sidewalk delivery robots. An example of such vehicles is the Ducktrain, a concept featuring Euro-palette-sized vehicles that follow the delivery person (on a bike or on foot) with speeds of up to 25 kph and the ability to form platoons with up to five vehicles following a single delivery person [39]. Such solutions combine several advantages: larger load capacities than, e.g. sidewalk delivery robots, the flexible use of the road and non-road infrastructure, and limited need for parking space, as well as the flexibility of quickly interchangeable vehicles.

However, for the successful roll-out of such new mobility technologies, it is imperative to understand people's needs, concerns, and requirements for acceptance [26, 33]. Regarding the acceptance of semi-sized AMVs used for deliveries, there are two crucial perspectives: First, the perspective of the delivery customer and their requirements to use (and even pay for) deliveries with AMVs is important. However, the acceptance and requirements of other road users, referred to as InCoP (incidentally co-present persons), are similarly vital when these new vehicles may be encountered in public [1, 24].

Several empirical studies have already examined influencing factors on the acceptance of autonomous delivery robots (ADRs) as one subgroup of AMVs [e.g. 1, 33, 21, 46, 47]. Hereby, mainly the perspective of delivery customers has been studied. For example, [21] found that the most important factors for customer ADR acceptance are the delivery price and the performance expectancy (mainly the time between the order and the delivery). Also, perceived risk, innovativeness, social influence, and trust in the technology are among the important factors [22]. Regarding the acceptance of ADRs by InCoPs, the few available studies have taken less structured and less theory-driven approaches. In these, several areas of concern emerged: obstruction of space by robots, safety issues, privacy and social concerns (e.g. effects on labour force) as well as legal issues (e.g. liabilities in case of accidents) [20, 24, 28, 37, 38]. The only study yet examining the acceptance of semi-sized AMVs instead of ADRs confirms these concerns and adds doubts about the sustainability of the approach to the list [39]. The results mentioned above are crucial for understanding the needs of customers and InCoPs, particularly regarding delivery performance and safety. However, the limited studies on InCoPs' perspective on acceptance do not delve into the detailed requirements for AMVs. For instance, the issue of such vehicles obstructing space has become an important concern as shown above. However, there hasn't been any evaluation if there is a limit to the acceptable size of such vehicles and what the limit might be. Other research gaps include the accepted infrastructure use, accepted speed, or, in general, requirements regarding the integration of AMVs into traffic and society.

To address these research gaps, a two-stepped empirical approach was used to study detailed requirements on semi-automated micro-vehicles for urban deliveries—incorporating the perspective of InCoPs regarding the integration into traffic and society as well as the perspective of delivery customers. In qualitative pre-studies (n = 34), requirements by different stakeholder groups (InCoPs, technical experts, delivery personnel) were identified and then quantified in a succeeding online survey study (n = 1000). The novelty of this research approach lies in the focusing not only on the identification of acceptance factors, i.e. showing that size is important to public acceptance, but to study tangible requirements and accepted limits regarding vehicle design, behaviour and integration into public spaces while still evaluating their importance. Thereby, the aim is to enhance the understanding of public requirements for such innovative delivery vehicles, which may improve the sustainability of deliveries and the quality of inner cities. The insights into infrastructural, technical, and social requirements can not only inform developers and companies of how innovative delivery vehicles should be designed from a public standpoint but also inform policy and lawmakers of how such innovative vehicles should be regulated.

## 2 Method

This study aims to not only identify detailed requirements for semi-automated micro-vehicles but also to quantify their relevance. Thereby, the perspective of InCoPs as well as of delivery customers was taken into account to provide a holistic overview. The study took place in Germany. An exploratory two-stepped approach was chosen due to the lack of related work. In a first step, qualitative pre-studies using interviews, focus groups, as well as a workshop with logistics, traffic, and technical experts were used to identify a broad range of potential requirements. These were then quantified in a large survey study for which a census-representative sample of 1000 Germans, who live in cities, was acquired. The studies took place in 2021 during the Covid-19 pandemic.

In the following, the methodology of both empirical approaches is presented in detail.

### 2.1 Pre-studies

To identify road users' requirements for automated micro-vehicles in traffic and as delivery vehicles, interviews (n = 10) were combined with two focus group sessions (n = 15). In both approaches, the respondents were introduced to the concept of the Ducktrains as an exemplary AMV for delivery purposes using scenarios as well as visualisations. Then, the respondents were asked to discuss the advantages and disadvantages of these vehicles and consequent requirements, first, for their integration into traffic, and, in the later part of the interviews/focus groups, for them as potential delivery customers.

This assessment of requirements by the general public was mirrored in a workshop with technical, traffic, and logistics experts (n = 9). They were employees of local logistics companies (bike logistics, conventional logistics), transport planning scientists, and developers of automated vehicles. These experts first discussed requirements from their general point of view. Then, in interdisciplinary teams, they were asked to come up with potential conflict scenarios in traffic and formulate requirements to address these.

### 2.2 Survey design

Based on the identified requirements (cf. Sect. 2.1), an online questionnaire was designed (a translated version can be downloaded as supplementary information file). The questionnaire consisted of four parts. After a screening to acquire a census-representative sample of Germans regarding age and gender as well as to sort out people from rural areas, a general introduction to the survey was given and consent to data collection was asked. Then, the following individual information was assessed in order to describe the sample and understand their attitudes:

- demographic characteristics (age, gender, education),
- information about the place of residence (urban or suburban; perceived quality of place of residence [41]),
- mobility behaviour (frequency of choice of transport mode, preferred role in traffic),
- attitudes towards the environment (specific problem perception (environmental impact of car traffic) [19], tendency towards personal ecological responsibility [18]), and
- attitude towards mobility innovations (likelihood of being early adopters of mobility innovations [51]).

The main part of the questionnaire started with an explanation of the concept of the Ducktrain automated micro-vehicles for urban deliveries, which included visualisations of the Ducktrains in traffic. Then, the identified requirements from the qualitative pre-study were queried regarding their importance and agreement with how automated micro-vehicles should behave in traffic. Randomisation was used to eliminate order bias. All items were assessed using symmetric 6-point scales. The endpoints of the scales were either "I don't agree at all" (1) and "I fully agree" (6), or, "not important at all" (1) and "very important" (6), respectively.

### 2.3 Data cleaning and analysis

For the analysis of the qualitative pre-studies, audio recordings of the interviews and focus groups were transcribed and creative material (e.g. whiteboards with notes and results, conflict scenario descriptions) was digitised. A qualitative content analysis was used to extract the requirements named by the respondents.

For good data quality of the questionnaire data, speeders (criterion: length of interview < 0.5 Median) and participants answering quality questions incorrectly or giving contradictory or highly unlikely answers (e.g. age = 100 years) were excluded.

The main data analysis is descriptive. Because of the large number of requirements, these were manually allocated to different categories to better compare the importance of the different requirements within and between categories.

### 2.4 Recruiting and sample

The samples of the qualitative pre-studies were recruited using the social contacts of the authors (*convenience sampling*) with the aim to reach people from different age groups, genders, and preferences for transport choice, who live either in or on the outskirts of cities. The recruiting for the questionnaire was executed by an independent market research company. To ensure a more representative sample of the urban-dwelling German population census-representative quotes on age groups and gender were used and people from rural areas were excluded.

The sample after data cleaning consisted of N = 1000 participants between 18 and 86 years of age (Mean (M) = 48.68, Standard Deviation (SD) = 16.96) who live in urban or suburban areas in Germany (64.8% inner city, 32.4% city outskirts, 2.8% suburbs). Gender and education levels are balanced over the sample and age groups are census-representative (cf. Appendix A for a detailed tabular sample description). Most participants of this urban sample preferred to be pedestrians (42,0%) or car drivers (39,3%) in traffic. Some were cyclists (14.0%) or rather used other means of transport (4.7%). The quality of place of residence is perceived as slightly good (M = 3.93, SD = 0.89). Attitudes towards the environment are rather high on average (problem perception of the environmental impact of car traffic: $M = 4.16, SD = 1.14$; tendency towards personal ecological responsibility: $M = 4.28, SD = 1.02$). However, the likelihood of being an early adopter of mobility innovations is less pronounced ($M = 3.16, SD = 1.18$).

## 3 Results

In the following, an overview of the requirements that were discussed in the qualitative prestudies is presented, followed by detailed results regarding their importance based on the quantitative survey.

### 3.1 Identified requirements

Seven categories of requirements were identified in the qualitative pre-studies. These regard vehicle specifications, safe integration into traffic, autonomous behaviour in traffic, ethical, legal, and social requirements, and delivery requirements.

#### *3.1.1 Vehicle specifications*

One crucial topic in the discussions of the integration of AMVs into traffic was the question of which infrastructure (e.g. bike lane, sidewalk) they may use and how fast they may drive. Additionally, vehicle limitations of how many vehicles may convoy, their maximum payload, height, and the distance between vehicles, and vehicle and user, were seen as crucial points.

#### *3.1.2 Safe integration into traffic*

Another very important topic was the requirements for safe integration into traffic through safety functions, the safety of the vehicle itself, and clear communication toward other road users. Here, essentials like safe braking behaviour, visibility, and safety in bad weather conditions were named. Also, clear communication of the AMVs next moves (driving direction, braking, start, etc.) and an indication of the length of the convoy (how many AMVs in convoy) were desired.

#### *3.1.3 Autonomous behaviour in traffic*

The requirements for AMVs' autonomous driving behaviour also played an important role. Here, the discussions mainly surrounded potentially hazardous situations, as the vehicles were expected to follow the user in "normal" situations without the need for further rules or autonomous functions. Only the maintenance of sufficient distance from other people and objects was specified during undisturbed driving. However, in critical situations, the AMVs should be able to clear space (e.g. for rescue vehicles) and split the convoy in order to leave intersections clear and to let in overtaking bicycles. Also, autonomous reactions for unspecified unforeseen events and autonomous assessment of hazardous situations were discussed. Some participants also wanted the AMVs to follow traffic rules (e.g. no red light crossing)—even if the user disregards them.

#### *3.1.4 Ethical, legal, and social requirements*

Further important requirements to the participants of the qualitative pre-studies can be subsumed under the label *ethical, legal, and social requirements*—for the integration of the AMVs into traffic and as delivery service. On the one hand, this regards privacy protection of the delivery customer as well as the delivery person. Additionally, the participants require the AMVs to keep their promise of a *sustainable* delivery vehicle. Here, two important details in the discussion were the electricity source (optimally purely renewable sources to achieve $CO_2$ neutrality) and a fair production the vehicles itself and of the batteries—as electric vehicles have been criticised for the conditions under which the raw materials for batteries are mined. Also, AMVs should provide a better quality of life in cities than conventional delivery vans with a low noise pollution besides the lower local emissions due to electrification. Moreover, economic incentives for the delivery services were proposed to incentivise the change to a more sustainable delivery method.

#### *3.1.5 Delivery customers' requirements*

Changing the perspective, the participants also discussed the requirements they would have as delivery customers. These do not differ from the requirements delivery customers have regarding any other deliveries. Specifically, GPS tracking of the delivery, punctuality, high reliability, and fast delivery were named for convenience. Also, the load should be secured, protected against theft and damage, and hygiene standards should be complied with.

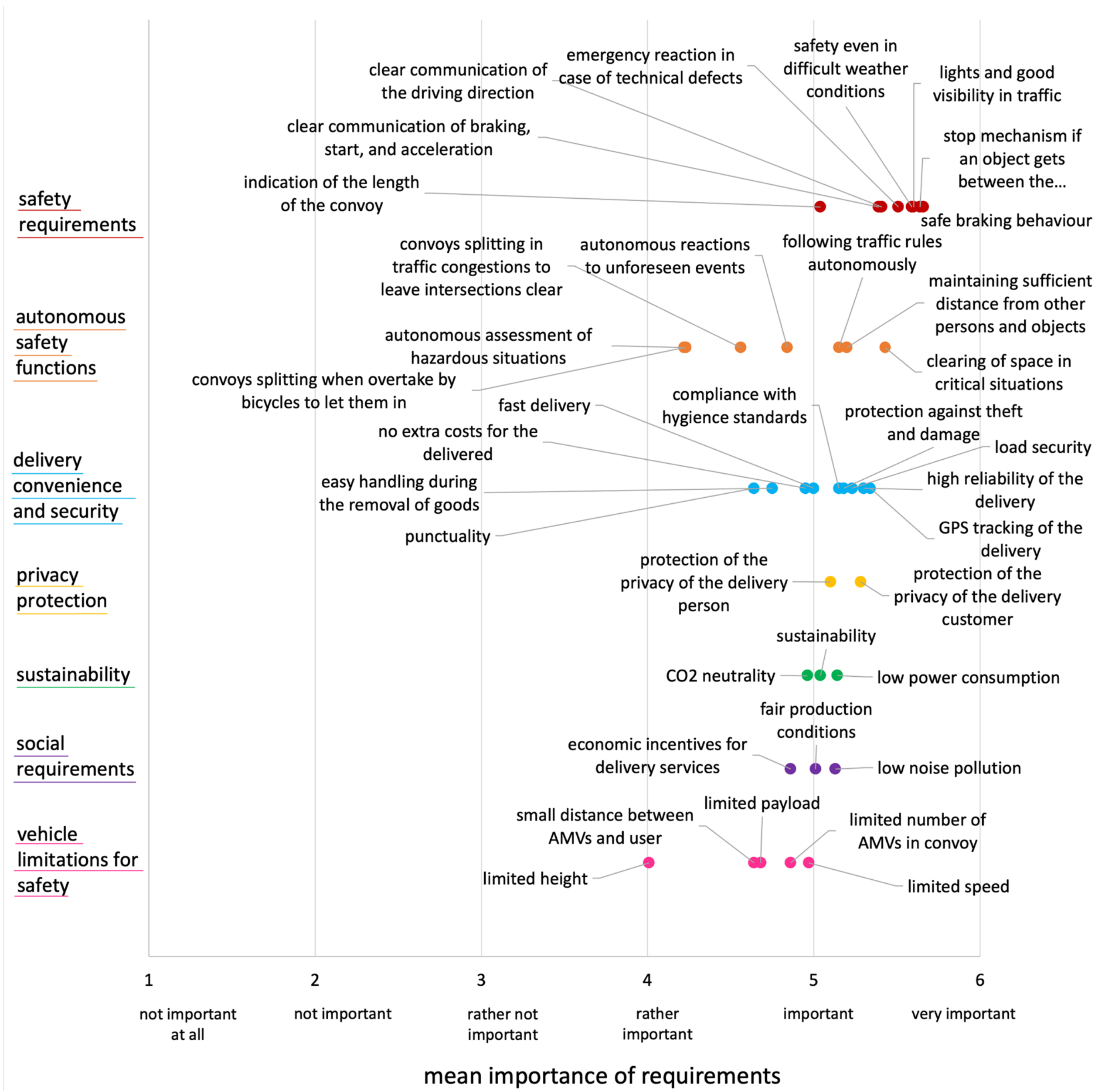


**Fig. 1** Average importance of all identified requirements compared between categories in order of most important requirement (n = 1000, min = 1, max = 6)

Easy handling during the removal of goods was also discussed in case the user removes the goods from the vehicle. Another topic was the costs of the delivery. Many participants stated that they would be willing to pay extra for a more sustainable delivery with AMVs, while others disagreed with extra costs for the delivery.

### 3.2 Relevance of requirements for automated micro-vehicles

The mean importance of the identified requirements is depicted in Fig. 1. The appendix provides a tabular overview of importance ratings with standard deviations and confidence intervals.

Overall, **safety requirements** are most important. The most important requirement is *safe braking behaviour* ($M = 5.66, SD = 0.69$), followed by a *stop mechanism if objects come between vehicles (or vehicle and user)* ($M = 5.64, SD = 0.73$), *visibility* ($M = 5.6, SD = 0.72$) and *safety in all weather conditions* ($M = 5.59, SD = 0.72$). Also, *emergency reactions in case of defects* ($M = 5.51, SD = 0.76$) and the *clear communication of driving direction* ($M = 5.42, SD = 0.83$) and *manoeuvres like braking and starting* ($M = 5.39, SD = 0.82$) are very important. Only the *indication of the length of the convoy* is "only" important ($M = 5.04, SD = 1.02$) and outweighed by other requirements.

In contrast to the high relevance of all safety requirements, the importance of **autonomous behaviours** differs largely. With *clearing of space in critical situations* ($M = 5.43, SD = 0.98$), the most accepted of these is also highly safety-relevant as is *maintaining a sufficient distance from other persons and objects* ($M = 5.2, SD = 0.98$) as second most important in this category. Autonomous behaviours like the *convoys splitting to let overtaking bicycles in* ($M = 4.22, SD = 1.52$) or *convoys splitting to leave intersections clear* ($M = 4.56, SD = 1.41$) are less accepted and the sample is rather ambiguous regarding their acceptance as shown by the higher standard deviations. This is also true for *autonomous assessment of hazardous situations* ($M = 4.23, SD = 1.35$). However, *autonomous reactions to unforeseen events* are seen as less sceptical and ambiguous within the sample ($M = 4.84, SD = 1.17$).

The category with the next most important requirement is **delivery convenience**, especially *GPS tracking* ($M = 5.34, SD = 0.86$) and *reliability* ($M = 5.3, SD = 0.92$) as well as the protection of the load (*load security* ($M = 5.23, SD = 0.92$), *protection against theft and damage* ($M = 5.18, SD = 1.01$), *hygiene standards* ($M = 5.15, SD = 1.01$)) are important from this category. Least important within this category is the *punctuality* ($M = 4.64, SD = 1.25$) and *easy handling during removal* ($M = 4.75, SD = 1.08$). *Not to pay extra costs* for deliveries with AMVs and to have a *fast delivery* are also rated as important ($M = 4.95, SD = 1.14$, and $M = 5, SD = 0.98$, respectively) but not as important as other requirements.

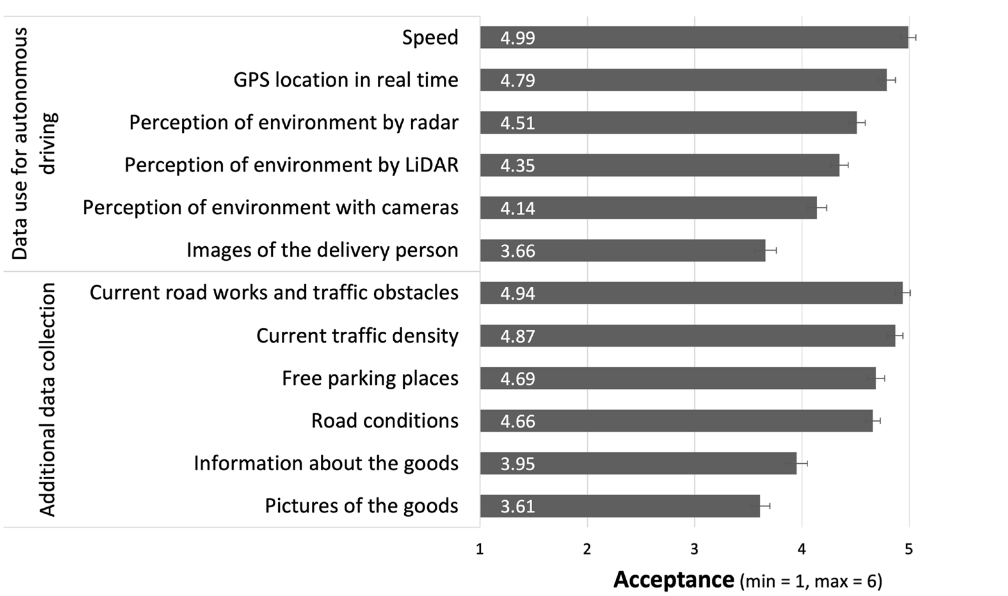


**Fig. 2** Acceptance of data collection for autonomous functions (upper half) and additional uses (lower half) (N = 1000); error bars depict 95% confidence intervals

***Privacy protection*** *of the delivery customer* is also important ($M = 5.28, SD = 0.92$) and more important to the public than the *privacy protection of the delivery person* ($M = 5.1, SD = 1.01$). Besides the general importance of privacy protection, the acceptance of data collection (for autonomous driving as well as additional data for other services) was surveyed in detail in the survey. Data collection for autonomous driving (e.g. GPS, Radar, LiDAR), as well as data collection for additional uses (e.g. current traffic obstacles, free parking places), is mostly well accepted ($M > 4$, cf. Fig. 2). Here, the use of cameras to perceive the environment is less accepted than other options to perceive the environment. The collection of pictures of the delivery person as well as information and pictures of the transported goods is not really accepted: the average acceptance is close to the neutral midpoint of the acceptance scale (3.5).

Only after privacy protection follow **sustainability requirements** in their mean relevance. Most relevant from this category is a *low power consumption* ($M = 5.14, SD = 1.00$), followed by *sustainability* in general ($M = 5.04, SD = 1.09$) and $CO_2$ *neutrality* ($M = 4.96, SD = 1.20$). Still, these requirements are also seen as important ($M\ 5$). **Social requirements** like a *low noise pollution* ($M = 5.13, SD = 1.01$), *fair production conditions* ($M = 5.01, SD = 1.05$), and *economic incentives for delivery services* ($M = 4.86, SD = 1.15$) are also rated as important on average. However, their importance is less than that of most safety requirements as well as some autonomous functions and delivery requirements.

**Limitations of the vehicle** are rated as “rather important” ($M = 4$) to “important” ($M = 5$). *Limitation of speed* ($M = 4.97, SD = 1.10$) is the most important followed by the *limitation of number of AMVs in convoy* ($M = 4.86, SD = 1.07$). *Limited payload* ($M = 4.68, SD = 1.23$) and keeping a *small distance between AMVs and user* ($M = 4.64, SD = 1.12$) is also agreed on as important, again underlining the limitation of size of the AMVs as a requirement. However, *limitation of height* of the AMVs ($M = 4.01, SD = 1.37$) is overall the least important requirement with a rating as “rather important” ($M = 4$).

In the survey, detailed acceptance of infrastructure use, speed, and number of vehicles in convoy was assessed because it was one of the main topics in the pre-studies (for results see Fig. 3). The quantitative data shows that semi-sized AMVs are most accepted on roads ($M = 3.7, SD = 1.57$) which is closely followed by bike lanes ($M = 3.64, SD = 1.58$). The use in pedestrian areas is seen as ambivalent ($M = 2.37, SD = 1.58$), and use on sidewalks is rather rejected ($M = 3.17, SD = 1.42$). For use on roads, a maximum speed of 19.39 kph (12.05 mph) ($SD = 8.05 kph$) and convoy length of 2.62 ($SD = 1.53$) AMVs in convoy are accepted on average. On bike lanes, the accepted maximum speed is 11.76 kph (7.25 mph) ($SD = 6.78 kph$) with 2.04 ($SD = 1.19$) vehicles in convoy. On roads and bike lanes, this would be much less than the speed of cars, or bicycles, respectively. On sidewalks and in pedestrian areas, other road users accept a

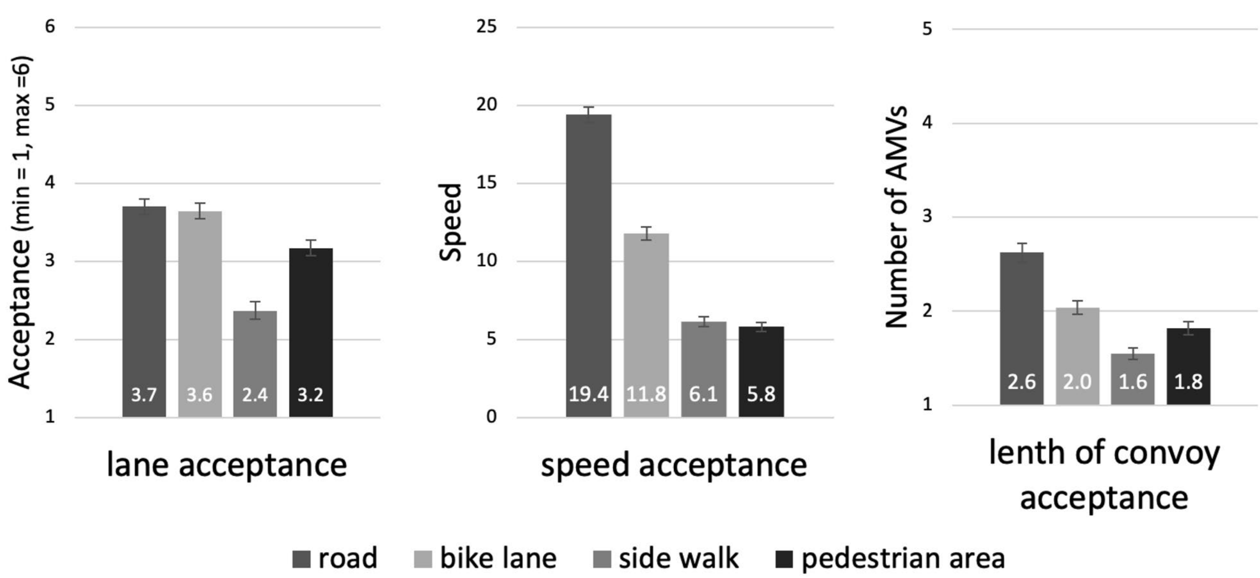


**Fig. 3** Average acceptance ratings for lane use, maximum speed, and number of vehicles in convoy depending on lane (N = 1000); error bars depict 95% confidence intervals

maximum speed similar to pedestrians' speed ($\approx$ 6 kph (3.73 mph) ($SD = 4.7 kph$)) and less than 2 AMVs in convoy ($M = 1.82, SD = 1.18$).

## 4 Discussion

AMVs are a promising technology to combat challenges in urban delivery like carbon emissions and pollution, lack of space and bans for road-based traffic in inner cities, and customer demands for fast and flexible deliveries [4, 27, 34]. The public acceptance of such new innovative technologies is a prerequisite to their successful mass roll-out [26, 42]. However, there is limited knowledge available regarding specific requirements for integrating AMVs into traffic and society. This study took an exploratory approach to identify requirements for the integration of (semi-sized) AMVs and to quantify and compare their importance. Thereby, both the perspective of InCoPs (incidentally co-present persons) and the delivery customers' perspective was taken into account.

The results indicate that safety is the public's top priority when integrating innovative autonomous vehicles, aligning with existing safety standards. Automated functions like stop mechanisms during near-accidents and maintaining distance from others are also valued. However, less familiar autonomous functions, such as convoy splitting to minimise traffic obstructions, were met with mixed acceptance and uncertainty about their necessity. As people gain hands-on experience with novel autonomous behaviours, opinions may evolve. For now, these unexpected novel autonomous behaviours should be introduced cautiously and only when necessary. If used, the vehicle's intentions must be clearly communicated, ensuring that other road users can interpret and respond to them appropriately.

The limitations of such vehicles in size and speed is not among the most relevant requirements (however, it is still rated as "important"). This is especially surprising, as such limitations were one of the crucial discussion points in the qualitative pre-studies and related work highlighted the concern of InCoPs that AMVs may be a traffic obstacle and even endanger other road users [20, 37, 38]. This may stem from the different type of AMV examined in this study. Most previous acceptance studies focused on small delivery robots for sidewalks—often overlooked—or larger delivery robots meant solely for road use [e.g. 21, 48, 1, 42]. In contrast, the semi-sized Ducktrain concept evaluated here is designed for flexibility and can operate in areas designated for pedestrians, bicycles, or cars.

The detailed results on accepted size, speed, and infrastructure reveal a cautious public attitude. Notably, the mean accepted speed on bike lanes and roads is significantly slower than that of other lane users. This aligns with concerns from other studies that AMVs could become traffic obstacles needing to be overtaken. A possible explanation for these contradictory demands is the lack of trust in autonomous driving and safety concerns regarding fast-moving vehicles, as trust is a key factor in acceptance [8, 49, 50].

Moreover, the results indicate that delivery requirements like reliability, tracking, and load safety are more important on average than legal, sustainability, and social issues like privacy protection, $CO_2$-neutrality, or fair production. However, the comparison is limited as all requirements were rated at least "rather important," with no outright rejection. The reported averages mask the variability in importance among individuals with different attitudes. Despite the lower average importance of ethical, legal, and social issues in public opinion, these concerns remain crucial for protecting against discrimination, illegal activities, and privacy breaches.

In the future, it is expected that public spaces, sidewalks and roads will be used by a multitude of different autonomous vehicles, be it road-based delivery robots, AMVs for goods or passenger transport, or service robots (e.g. for garbage removal, sweeping, snow removal) [16]. It is therefore not only necessary to regulate individual vehicles like the Ducktrain AMV, but to agree on tightly-communicated behaviours and guidelines to resolve spatial conflicts and to govern and manage the limited public space, for example through reservation management systems for loading/unloading places. For the data-driven management of these autonomous vehicles and robots, the ISO 4448 is being prepared [16]. It shall standardise operating data, procedures and machine behaviours for publicly operated, automated passenger vehicles, robotic vehicles and service robots. Grush and Coombes (2022) also describe guiding principles for the operation of robots in public spaces to be included in the ISO 4448. In these, similarities to the results of this study can be found, showing agreement between public opinion and international standardising efforts. For example, the importance of safety itself, the maintenance of sufficient distance and clearing of space in critical situations, and communication between AMVs or robots and humans are consistent. Other principles are not relatable to this study, as they concern the governance of a multitude of AMVs and robots in public spaces.

When interpreting the resulting requirement catalogue and cartography, several limitations have to be considered. First of all, the origin of the data is limiting the generalisability, because all studies have been conducted in

Germany and during the Covid-19 pandemic. People differ in their requirements and acceptance of new mobility concepts between countries as the road regulations and thereby the experienced traffic situations differ [5, 10, 15, 30]. Therefore, the results cannot be directly transferred to other countries and traffic cultures with different road regulations and traffic situations. Furthermore, the pandemic has altered traffic especially during the public lock-downs. In general in the pandemic years, public spaces and roads were less crowded. This probably also altered people's opinions on sharing public space. At the same time, e-commerce and, consequently, parcel deliveries experienced a large increase due to hygienic reasons and public lock-downs, which may have increased the perceived importance of innovative delivery solutions. However, the online retail volume since the pandemic has only slightly decreased [17], which still spotlights the need for urban last-mile delivery solutions, especially when considering the again increased overall traffic [11]. Therefore, the situation might not be that much altered, however, future work needs to consider other traffic cultures and needs post-pandemic data.

Another limitation concerns the lack of hands-on experience with AMVs. While all participants were introduced to the AMV concept Ducktrain per verbal and visual descriptions as well as videos in the pre-study, only some of the participants of the pre-study and none of the participants of the survey have experienced a comparable vehicle in real traffic. Therefore, many biases may have been introduced due to a lack of hands-on experience and imagination of such vehicles in traffic. Future studies should include hands-on approaches or at least video-based simulations of autonomous vehicles (e.g. [40]). In the same vein, most Germans lack experience with autonomous vehicles in general. However, experience with other autonomous vehicles may change perceptions and trust of AMVs for deliveries. Therefore, attitudes and requirements for AMVs may change with more experience with autonomous vehicles in general. Additionally, technology will surely improve in the future, again building a more trustful public attitude which may change requirements as well.

The qualitative pre-study delivered a wide range of requirements from both perspectives, delivery customers and InCoPs, but due to this exploratory and data-driven approach, the results are less easy to compare to standardised theory-based results from other studies [e.g. 47, 48]. Also, the approach to query the importance of such a large number of requirements as stated preference using Likert-scales has disadvantages. Firstly, such stated preferences are prone to response biases (e.g. acquiescence bias, courtesy bias [43]), therefore, the absolute values need to be interpreted with caution. Secondly, the comparison of the importance ratings is based on very small differences, here, the rating scale showed the typical low differentiation. Moreover, in this study, the requirements were evaluated independent from one another. In reality, there are trade-offs between conflicting requirements. For example, the public, on the one hand, wants to limit AMVs' speed for safety, but, on the other hand, this may lead to AMVs impeding traffic as other road users need to overtake the slower vehicles. Another example are the requirements for privacy protection of the delivery person and a high importance of GPS tracking of the delivery, which need to be balanced in detail using technical protection mechanisms. In future research, other questionnaire forms could be useful to further distinguish the importance of the requirements and outline the trade-offs inherent for their acceptance, e.g. maximum-difference scaling (best-worst scaling) or Choice-Based Conjoint approaches [32]. For example, the use of adaptive Choice-Based Conjoint could also deliver information on No-Go and Must-Have factors.

In conclusion, this paper delivered a catalogue of requirements for semi-sized AMVs from a German perspective. It showed that safety is the most important factor for public acceptance when integrating a new mobility/vehicle concept into traffic. Safety requirements override all other requirements in their mean importance. Regarding semi-sized AMVs, basic safety is most important; additional autonomous safety functions that are unfamiliar to most road users are seen as more ambiguous. Limitations in size are less important than limitations in speed. This provides useful information on the public's attitudes toward the design and regulation of such innovative vehicles to improve public acceptance as an essential prerequisite for successful diffusion. Future work should delve into trade-offs between important requirements and examine the influence of real-world experience with autonomous vehicles.

## Appendix A Detailed sample description

See Table 1.

**Table 1** Detailed characteristics of the sample

| | | **N = 1000** |
|---|---|---|
| Age | 18–30 years | 19.2% |
| | 31–40 years | 16.2% |
| | 41–50 years | 17.4% |
| | 51–60 years | 17.5% |
| | 61–70 years | 19.1% |
| | 71–80 years | 9.5% |
| | > 80 years | 1.1% |
| Gender | Women | 50.6% |
| | Men | 49.4 % |
| Education | No certificate | 0.1% |
| | Certificate of secondary education | 10.8% |
| | General certificate of secondary education | 30.1% |
| | General qualification for university entrance | 25.7% |
| | University degree | 30.9% |
| | Other | 2.4% |
| Residential area | Suburbs | 2.8% |
| | City outskirts | 32.4% |
| | Inner city | 64.8% |
| At least weekly use of transport | Private or company car | 63.8% |
| | Car-sharing | 2.9% |
| | Motorcycle | 7.8% |
| | (Electric) bicycle | 45.1% |
| | eScooter | 4.0% |
| | Public transport | 46.5% |
| | On foot | 93.3% |
| Perceived quality of place of residence: M (SD) | | 3.93 (0.89) |
| Specific problem perception (environmental impact of car traffic): M (SD) | | 4.16 (1.14) |
| Tendency towards personal ecological responsibility: M (SD) | | 4.28 (1.02) |
| Likelihood of being early adopters of mobility innovations: M (SD) | | 3.16 (1.18) |

## Appendix B Importance ratings of all queried requirements

See Table 2.

**Table 2** Mean importance ratings of the requirements with standard deviation and 95% confidence intervalls based on bootstrapping

| Category | Requirement | Importance | | | |
|---|---|---|---|---|---|
| | | M | SD | 95% CI | |
| Safety | Safe braking behavior | 5.66 | 0.69 | 5.61 | 5.7 |
| Requirements | Stop mechanism if an object gets between the vehicles (or the user and a vehicle) | 5.64 | 0.73 | 5.59 | 5.69 |
| | Lights and good visibility in traffic | 5.6 | 0.72 | 5.55 | 5.65 |
| | Safety even in difficult weather conditions | 5.59 | 0.72 | 5.54 | 5.63 |
| | Emergency reaction in case of technical defect | 5.51 | 0.76 | 5.46 | 5.55 |
| | Clear communication of the driving direction | 5.41 | 0.83 | 5.35 | 5.46 |
| | Clear communication of braking, start, and acceleration | 5.39 | 0.82 | 5.34 | 5.44 |
| | Indication of the length of the convoy | 5.04 | 1.02 | 4.98 | 5.11 |
| Autonomous behavior | clearing of space in critical situations (e.g., for rescue vehicles) | 5.43 | 0.98 | 5.36 | 5.49 |
| | Maintaining sufficient distance from other persons and objects | 5.2 | 0.98 | 5.14 | 5.26 |
| | Following traffic rules autonomously | 5.15 | 1.14 | 5.08 | 5.21 |
| | Autonomous reactions to unforeseen events | 4.84 | 1.17 | 4.76 | 4.91 |
| | Convoys splitting in traffic congestion to leave intersections clear | 4.56 | 1.41 | 4.47 | 4.65 |
| | Autonomous assessment of hazardous situations | 4.23 | 1.35 | 4.13 | 4.31 |
| | Convoys splitting when overtake by bicycles to let them in | 4.22 | 1.52 | 4.13 | 4.31 |
| Delivery requirements | GPS tracking of the delivery | 5.34 | 0.86 | 5.28 | 5.39 |
| | High reliability of the delivery | 5.3 | 0.92 | 5.23 | 5.35 |
| | Load security | 5.23 | 0.92 | 5.17 | 5.28 |
| | Protection against theft and damage | 5.18 | | 5.12 | 5.25 |
| | Compliance with hygiene standards | 5.15 | 1.01 | 5.08 | 5.21 |
| | Fast delivery | 5 | 0.98 | 4.93 | 5.05 |
| | No extra costs for the delivered | 4.95 | 1.14 | 4.87 | 5.01 |
| | Easy handling during the removal of goods | 4.75 | 1.08 | 4.68 | 4.82 |
| | Punctuality | 4.64 | 1.25 | 4.56 | 4.71 |
| Privacy | Privacy protection of the delivery customer | 5.28 | 0.92 | 5.22 | 5.34 |
| Protection | Privacy protection of the delivery person | 5.1 | 1.01 | 5.04 | 5.16 |
| Sustainability | Low power consumption | 5.14 | 1.00 | 5.07 | 5.2 |
| | Sustainability | 5.04 | 1.09 | 4.97 | 5.11 |
| | $CO_2$ neutrality | 4.96 | 1.20 | 4.88 | 5.03 |
| Social requirements | Low noise pollution | 5.13 | 1.01 | 5.05 | 5.19 |
| | Fair production conditions | 5.01 | 1.05 | 4.94 | 5.07 |
| | Economic incentives for delivery services | 4.86 | 1.15 | 4.78 | 4.93 |
| Vehicle limitations | Limited speed | 4.97 | 1.10 | 4.91 | 5.04 |
| | Limited number of AMVs in convoy | 4.86 | 1.07 | 4.79 | 4.93 |
| | Limited payload | 4.68 | 1.23 | 4.6 | 4.76 |
| | Small distance between AMVs and user | 4.64 | 1.12 | 4.57 | 4.71 |
| | Limited height | 4.01 | 1.37 | 3.91 | 4.09 |

### Abbreviations

| | |
|---|---|
| ADR | Autonomous delivery robot |
| AMV | Automated micro-vehicle |
| InCoPs | Incidentally co-present persons |

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### Author's contributions
ES and VL contributed to the study conception and design and data collection. Data was analyzed by ES. The first draft of the manuscript was written by ES and reviewed and edited by VL. MZ provided funding, project administration and supervision. All authors read and approved the final manuscript.

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**Availibility of data and materials**
The dataset supporting the conclusions of this article is available in the Open Science Framework repository, https://osf.io/p7ukn/?view_only=2349e958ffa7403dae3a2cc159b6ece8.

## Declaration

**Competing interest**
The authors have no conflicts of interest to declare that are relevant to the content of this article.

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## Publisher's Note