User experience of a self-driving minibus - reflecting vision, state and development needs of automated driving in public transport

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Abstract

Beside sharing, electrification of drives, and on-demand operations, the idea of using automated vehicles (AV) in public transport is one building block that is often included in conceptions of a sustainable and efficient future mobility system. If successfully implemented, it could allow new public transportation services where this is not economically feasible at present. The success of such services will crucially depend on their use by the population, which is in turn determined by perceptions of their usefulness, ease of use, safety, and attractiveness. We provide insights on user perceptions of an urban self-driving minibus service in the project HEAT (Hamburg Electric Autonomous Transportation) from the second phase of pilot operation in 2021. Based on data from passenger surveys (n = 446) that were conducted directly after the ride, we analyse the status of progress and identify further development needs from a user perspective. Results show positive attitudes towards using driverless vehicles in public transport, but also a need to further improve system performance in order to create a viable mobility alternative. We point out and discuss measures how performance could be increased.

Introduction

Vision of automated vehicles in public transport

The development of self-driving vehicles, in combination with electrification and shared mobility, is thought of as a potential way to make public transport more efficient, flexible and needs-oriented and to enhance the environmental compatibility of mobility overall (Fulton et al., 2017). Especially, the reduction of personnel costs is hoped to allow to offer public transportation where it is not economically feasible at present (Bösch et al., 2018). Municipalities and public transport operators worldwide are interested in exploring how these technologies can be used and in understanding their opportunities and constraints (UITP, 2016).

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Current Status

While autonomous driving has to some degree been successfully established in environments where separated lanes can be implemented (e.g., metro, light rail and certain shuttle bus applications; cf. Wang, 2016), it seems to remain a challenge in urban mixed traffic environments. In a review of European pilot projects with automated bus systems, Hagenzieker and colleagues (2021) found that the buses typically operate at low speeds, with 78% of pilots below 21 km/h and the most frequent category being 12-16 km/h. They are often slower than cyclists and other surrounding traffic and tend to stop, often suddenly, when any object comes within a certain distance, regardless of the relative trajectories (e.g., also when cyclists or cars are overtaking). These characteristics lead to many overtakings and other exceptional manoeuvres by other road users. So far, stewards on board have generally been indispensable, due to constraints in legislation, on the one hand, but also for solving situations that the automation cannot handle on its own.

Research goal

Introducing autonomous driving brings along a number of changes for transportation users as well as other road users interacting with the self-driving vehicles (Dreßler et al., 2019; Heikoop et al., 2020). The successful implementation of such systems will also depend on how well they fit human requirements, including how much they are perceived as useful, easy to use, and attractive by their (potential) users. System design should therefore be user-centred from the beginning of development (Nielsen, 2009; Wickens et al., 2004). The work presented here was part of the iterative user research in the project HEAT (Hamburg Electric Autonomous Transportation). It aimed to yield a comprehensive picture of how users experienced a self-driving shuttle piloted in a public road environment and what they conceived for the future use of this technology.

Theoretical and implementation background

Facets of user experience

Theories of user acceptance identify factors that predict the use of or the intention to use a product or service based on new technology and specify how these factors shape this intention (Madigan et al., 2016, 2017; Venkatesh et al., 2012). The factors represent dimensions of user experience, i.e., "a person's perceptions and responses that result from the use or anticipated use of a product, system or service" (ISO 9241-210). They can further be specified by distinguishing perceptions of instrumental (pragmatic) qualities, perceptions of non-instrumental (hedonic) qualities, and emotional reactions (Thüring & Mahlke, 2007).

The user surveys applied aimed to assess the most important facets of user experience, based on existing evidence in the context of self-driving vehicles and public transport (cf. Madigan et al., 2016, 2017). These included pragmatic qualities (perceived usefulness, safety, reliability, ease of use), hedonic qualities (perceived comfort and diversion•), and emotional reactions (self-assessments of valence and arousal; Russell, 1980). To qualify these assessments, the surveys contained further items to describe detailed aspects of user experience, such as perceptions of the driving style created by the autonomous driving functions and their interplay with potential actions on the part of the vehicle attendants.

Pilot operations

The project HEAT, funded by the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, ran from 2018 to 2021. Its aim was to explore the application of electric, self-driving shuttles in urban public transport. The project included two phases of test operations with passengers in the Hamburg district of HafenCity: the first one from October to November, 2020, serving a fixed route of 800 m length with two stops; the second one from August to October, 2021, on a fixed route of 1.8 km length with five stops (Figure 1). In both operation phases, there were vehicle attendants on board who supervised the autonomous shuttle's driving with an allowed maximum speed of 25 km/h on the public roads with speed limits of 30 km/h, and 50 km/h, respectively.

Figure 1. Test operations with passengers 2020 and 2021: routing and stops.

The vehicle (2.95 t) had room for one wheelchair and was technically permitted to transport up to seven passengers (sitting and standing). Due to COVID-19, only three passengers were allowed to ride simultaneously. The shuttle was developed to drive the test route, including the crossing of traffic lights, completely automated. However, in case other vehicles parked on the lane had to be passed, the shuttle attendant had to approve this manoeuvre manually before the shuttle carried it out automatically as it involved a deviation from the defined driving lane. Before riding, passengers were required to register (including acceptance of carriage conditions and privacy policy) using the HEAT app or by filling out a paper form.

• meaning a sense of fun or entertainment, e.g., due to the novelty of the experience (cf. Madigan et al., 2017)

Figure 2. The autonomous vehicle applied in the test operations.

Methods

Structure of the user survey

The survey consisted of 30 items, covering two pages in its paper-pencil-version, with the following sections: informed consent and introduction referring to the most recent ride on the shuttle, use context (purpose, date and time, position taken in the shuttle, prior experience), physical user experience (cabin temperature, air quality), experience of the shuttle's way of driving (frequency, kind and valence of unexpected experiences) in four situation categories, overall user experience (emotional valence and arousal; perceived safety, usefulness, reliability, ease of use, comfort and diversion), qualitative feedback (aspects liked and disliked about the design; wishes for improvement), kind and assessment of information sources used, introduction of potential role of driverless shuttles in the future, respondent's intention to use such shuttles and applications deemed useful, individual characteristics (e.g. gender, prior experience with other driverless vehicles), personal technological innovativeness (based on Goldsmith & Hofacker, 1991), and a final, free-text item that asked if there was anything else the respondent would like to communicate regarding the shuttle.

Data collection

The survey existed in a paper-pencil and an online version (SoSciSurvey). One or two pollsters were present at the main shuttle stop and approached passengers with the survey after their ride. Respondents participated on a voluntary basis without compensation. On-site data collection was carried out in accordance with safety rules due to the COVID-19 situation. As an alternative to the paper-pencil version, the link to the online questionnaire was distributed via the HEAT app and postcards with a QR code available in the vehicle.

Results

For brevity, the presentation of results focuses on the second phase as the patterns of results were mostly similar in both phases while the number of participants was higher in the second phase, and the route had reached its final expansion then.

Sample characteristics

The survey was completed by 446 passengers, aged 8 to 82 years (M = 39.7, SD = 17.2). There were more male (54.7%) than female (32.5%) respondents (other gender: 0.9%, no response: 11.9%). Despite the extension of the route in comparison to the first trial phase, only 4 respondents (0.9%) reported having used the shuttle for transportation purposes (“to get from A to B”). Most (89.2%) still took the ride for curiosity, in order to try out the new technology (no response: 7.4%; “other” purpose: 2.5%).

Ride experience

Perceptions of driving style
Figure 3 shows the reported frequencies of unexpected experiences in four situation categories. Most unexpected experiences were associated with braking behaviour: Altogether, 78.4% of respondents reported at least one unexpected experience regarding braking. In accelerating and driving around bends, the shuttle’s driving appeared more consistent with expectations, as only 6.0% and 8.9% of respondents indicated unexpected experiences, while 70.6 and 74.2% did not notice anything unusual, and 17.9 and 18.4% did not respond to the item. Finally, regarding any other driving situation, around 12.8% of respondents reported one or more unexpected experiences.

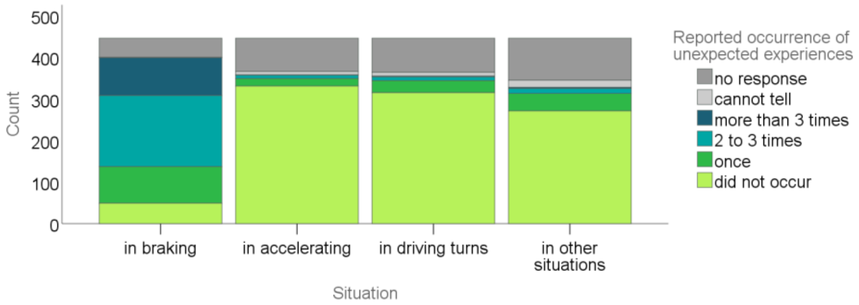

Figure 3. Reported frequency of unexpected experiences regarding the shuttle’s way of driving in four manoeuvre / situation categories.

Of the respondents who reported at least one unexpected experience in braking, 62.9% also gave some qualification of what the experience was about. Many responses referred to the onset of braking which was qualified as abrupt or unexpectedly sharp in certain cases. The causes of braking were mostly recognizable to passengers and mostly involved other motorized vehicles or bicyclists coming near, e.g., in standing very near the lane and/or partly protruding into the lane (e.g., side mirror), parking out, or overtaking. In a number of cases, the cause was not obvious to the respondent.

Of all passengers who felt surprised by the shuttle’s braking at least once, the majority did not classify this experience as unpleasant. However, 22.6% stated that the braking felt unpleasant to them, which corresponds to around every sixth of all passengers who took the survey. Few events were marked as unpleasant in the other three driving situation categories. The five instances reported in the acceleration category were all associated with sudden braking, which also occurred in some of the eight instances in the turning category, while the rest involved slow cautious advancement around the bend. Of the users who reported unexpected experiences in other driving situations, twelve indicated that these also felt inconvenient to them. The experiences were about waiting due to obstacles in the lane (incorrectly parked vehicles), the behaviour of other road users (e.g., car coming too near in overtaking), and, in three cases, unexpected positioning behaviour of the shuttle (e.g., late lane change for turning, with car passing on the right).

Use experience
The distributions of user assessments concerning use experience (boxplots) are shown in Figure 4. For analysis, the coding of mirrored scales was reversed, for all scales to point in the same direction.

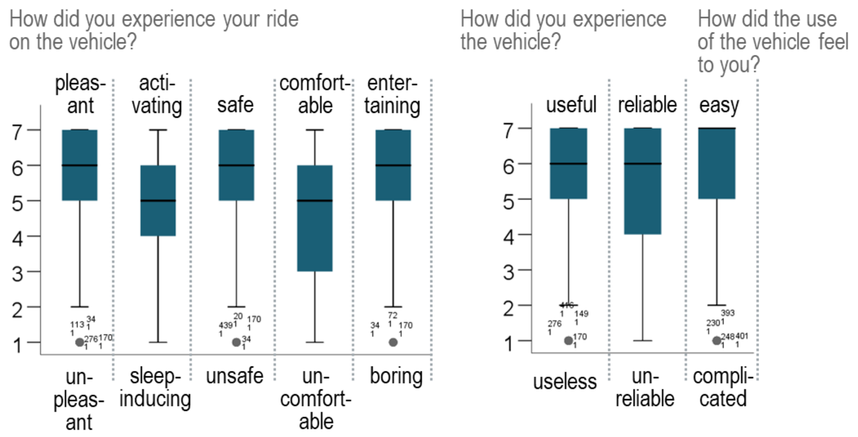

Figure 4. User assessments concerning emotional valence and arousal, perceived safety, comfort and hedonic quality of the ride (left) and perceived usefulness, reliability and ease of use of the shuttle (right).

Overall, passengers reported positive emotional experience of the ride, with a mean assessment of M = 5.9 (SD = 1.3) on the scale from 1 – unpleasant to 7 – pleasant. The arousal associated with this valence was experienced as normal to slightly activated (M = 4.8, SD = 1.5). Regarding the dimensions of pragmatic quality, passengers felt safe on the ride (M = 5.6, SD = 1.5) and perceived the shuttle as useful (M = 5.6, SD = 1.6). Perceived ease of use was high (M = 5.8, SD = 1.6). Perceived reliability (M = 5.2, SD = 1.7) was slightly lower, with more variation in the individual assessments. Concerning hedonic quality, passengers expressed high levels of fun associated with the ride (M = 5.9, SD = 1.4, from 1 – boring to 7 – entertaining). Perceived comfort was slightly above the middle of the scale on average and showed more variation in individual scores (M = 4.7, SD = 1.7).

Qualitative feedback

59.0% of respondents used the free text field to give an indication of what they liked about the design of the shuttle. The most frequent category of mentions (n = 141) referred to aesthetic aspects of design, including topics such as clear, simple or functional design; modern, futuristic or distinctive design, attractive design, and light colours. The next most frequent category (n = 85) referred to spatial design aspects, including large windows on all sides ("without advertisement"), good panoramic view and lightness in the cabin as well as a spacious interior•. Some respondents named the compact size of the vehicle. A number of statements (n = 23) dealt with technological aspects, most frequently the electric drive, which was liked mostly for its silence and partly for the aspect of environmental protection. A smaller number of statements mentioned the aspect of autonomous driving or the monitors inside the shuttle where route information was displayed. Two further considerable categories concerned seat design (n =11; aspects: comfortable, material wood, and belts) and accessibility (n = 17), including suitability for wheelchairs and low access height.

Looking at aspects not liked about the design of the shuttle, 42.2% of respondents gave some qualitative information. The most frequent category of mentions (n = 66) addressed the design of the seats, which were characterized as hard or uncomfortable by around half of these remarks. A smaller number of mentions revolved around the safety belts that some seats were equipped with, with different foci (not available on all seats, unclear where using belt is required, unnecessary or provisional, not wide enough for users with large body girth). Individual mentions referred to a low height of the seats or the orientation. The next most frequent category involved spatial aspects of design (n = 63). Most of these referred to aspects of capacity, with topics like (too) small size, few seats or little space. A smaller number of remarks dealt with the availability of handles to hold on to (too few, or unfavourable arrangement). A number of statements (n = 33) referred to characteristics of driving (mostly braking). Individual statements involved aspects of accessibility, namely a rather narrow space for turning a wheelchair inside the shuttle, the usability of the ramp (probably referring to the steepness of the angle) and the low auditive perceptibility of the shuttle for road users.

Of the respondents 41.9% provided a statement on what they would consider desirable to improve the design of the shuttle. The most frequent category of mentions (n = 67) involved technological aspects. Around half of these concerned the further development of the driving functions, in order to, for example, reach a higher velocity, smoothen the driving by avoiding sudden breaking, or enable fully automated operation. Ideas not mentioned before include using the shuttle's connectivity to enable phased green traffic lights for the shuttle. The suggestions concerning seat design (n = 40) and spatial design (n = 47) mostly take up the criticism presented above, by proposing softer or more comfortable seats, vessels with higher capacity, more seats overall, more seats in direction of driving, and enhanced possibilities to hold on to a handle, e.g., in standing, sitting down/getting up or getting on/off the vehicle, and a bit more space for turning wheelchairs or prams inside.

• Mind the maximum number of passengers of three (plus two vehicle attendants).

Intention to use self-driving shuttles in public transport

The item to assess passengers' intention to use self-driving public shuttles in the future had three response options: besides *yes, definitely* and *no way*, passengers had the possibility to choose *yes if* ... and then qualify the conditions in a free text field. 68.4% of respondents indicated they would definitely use driverless shuttles. 18.8% expressed a use intention given certain conditions. Within these, the most frequent category of mentions (n = 34) involved that the technology be fully tested, developed and safe. A related topic (n = 14) concerned the further development of performance, often mentioning higher velocity, but occasionally also aspects such as a bigger fleet or network, smooth driving or higher transparency of the technology. Ten respondents (2.2%) stated they would not use driverless shuttles, and 10.5% did not respond to the item.

Discussion

Limitations

Our goal was to capture a comprehensive picture of user experience in passengers who had experienced a self-driving shuttle and could base their opinions on this. As we can suppose that most of our respondents tried the HEAT shuttle based on their own interest and motivation, the results apply to persons who are generally open to using this technology and may differ for persons who are not.

Importantly, the results must be considered in the light of the presence of vehicle attendants on board. This means that the user assessments and requirements that were collected can be applied, but certain additional requirements concerning an autonomous operation without an attendant on board did most probably not become obvious. Prior research in the HEAT context has shown that drivers of public transport vehicles fulfil additional functions from a user perspective, including that of a system expert providing helpful information, an instance of supervisory control and a contact person in case of exceptional situations (Dreßler et al., 2019). Design of autonomous shuttles must propose alternative solutions to enable the same, e.g., through proactive passenger information, safety and security measures, or the possibility to get in contact with a service or control centre (cf. Grippenkoven et al., 2019).

Moreover, the focus of the project was on piloting the technology and giving the public an opportunity to try it. Thus, the shuttle operations were not integrated in the regular public transport offers. This was reflected, e.g., in that the shuttle could be used for free and did not appear as part of travel chains proposed in public transport information systems. This trial character needs to be considered, too, when interpreting the user experience results: As most of the users tried the shuttle for curiosity, the demands and expectations were probably lower than they would be in using the shuttle as part of a regular travel chain. Finally, the trial had to be carried out under particular conditions due to the COVID-19 situation (e.g., only three passengers could use the shuttle at a time, nose-mouth covers were worn), which may have changed user experience in certain respects compared to the conceived normal operations.

Conclusions

Passengers experienced the vehicle and the ride on it in a positive way overall. The vast majority expressed their willingness to use self-driving shuttles if these were a readily available transport option. Notably, this was the case even though passengers experienced imperfections in the vehicle’s way of driving that mostly concerned occasional “jerky” driving due to braking. The overall pattern of user assessments including the observation that technological aspects were rarely mentioned under dislikes, but more often under ideas for improvement shows that passengers obviously took account of a to-be-expected development status in their evaluation. They were positive about the technology overall and understanding about some current constraints, but they also expect that these be resolved in future applications to make self-driving shuttles a competitive transport option.

The most important optimization potential in the current system, both from a user perspective and with regard to the interactions of the vehicle with surrounding traffic, is the further advancement of the anticipation capability and performance of the autonomous driving functions. It is necessary in order to enable a fluent driving style and avoid abrupt braking reactions as well as waiting times of both the automated vehicle and the surrounding traffic due to mutual obstruction of the way. In addition to high-definition maps and the recognition of environment features for positioning, the current AV shuttles mostly exploit trajectory information of surrounding objects for manoeuvre planning. Some are also connected with elements of the road infrastructure to get more information, e.g., on the status of traffic lights, or additional trajectory information of surrounding objects from road infrastructure sensors, as in the case of the HEAT shuttle. However, while the systems need to interact with human-operated vehicles and vulnerable road users, the exploitation of trajectory information as it is currently done does not seem to lead to satisfactory performance. The vehicles behave rather reactive and lack the anticipatory skills that characterize expert human drivers who exploit predictions about the further course of events based on knowledge of situation categories and including additional cues, as for example the reversing lights of other vehicles. With regard to the achieved speed and autonomy, the HEAT system was already rather advanced within current trials of AV in public transport. However, user feedback concerning use intention and research findings on perceived usefulness (Madigan et al., 2016) clearly shows that efficiency needs to be further advanced if AV in public transport is to become a viable transport option for a large number of users. Beside the enhancement of autonomous driving functions, additional measures may help to improve overall system performance. One of them is the thoughtful identification and/or design of a suitable operation environment and the stopping points with regard to infrastructural conditions. In a video analysis that was also conducted in the HEAT project, much less conflicts in association with waiting (due to other vehicles or the HEAT vehicle itself representing obstacles), passing and overtaking were observed on roads with at least two lanes per direction (Wissen Bach, 2021). In addition, the quality of interactions between AV and surrounding traffic can probably be enhanced by additional means of information and communication, for example a more prominent marking of the vehicle as being autonomously driving as well as being a vehicle of public transport (associated with entry and exit of passengers, necessity of taking care in passing). Dynamic display of the current status and the pending next manoeuvre (e.g., obstacle ahead, planning to drive around it automatically/manually; duration) and maybe also recommendations may further help other road users to understand and anticipate the vehicle's actions and interact in a safe way.

The results give hints to what users require in public transport in general and underscore the insight that perceived usefulness is the most important criterion in choosing a means of transport. While part of the user feedback referred to autonomous driving, a major portion dealt with general aspects of service quality in public transport that are independent of automation level. These include basic aspects such as availability and reliability, but also respect for user needs and human factors such as accessibility, practicability (e.g., in the transport of luggage and other items) and the need for comfort and aesthetics (see suggestions for improvement in results part).

In the first visions of using autonomous vehicles in shared transport with flexible routes, the systems were conceived to be readily available by now. The results of current pilots highlight that autonomous driving functions the way they are configured currently are not mature to blend in smoothly into mixed traffic environments. Research and development strive to conquer new ground concerning the operational design domains and find solutions for challenging environments. Given the observation that the development is progressing slower than originally thought and the urgency of transforming transportation for sustainability, municipalities, transport operators and policy makers should not wait for automated driving functions to be fully mature to implement innovative transport services in mixed-traffic environments, but in parallel develop concepts how digitization and user-centred design can be used to enhance the availability of public transport and stimulate sharing. This includes the use of automated driving in more constrained environments and the exploration of how flexible on-demand transport with human operators can be made possible today already.

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