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Benefits and Challenges of Integration of High-Capacity Autonomous Buses to Public Transport Operations

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Abstract

High-capacity autonomous buses can make bus travel safer, smoother, and more energy efficient. However, despite clear societal and environmental benefits there are still several challenges to be addressed. In this article we present the outcomes of two research projects focusing on the public acceptance of high-capacity autonomous buses. Results indicate high degree of trust towards automation safety. However, in certain conditions, such as driving alone at night, perceived security appears to be an issue. In such circumstances digital forms of assistance replacing drivers will most likely not guarantee a sufficient degree of security. The paper also argues that bus automation is not a silver bullet to make PT more attractive. Instead, it shall be seen as rather an enabler of new applications allowing to efficiently prioritize PT in traffic flows to make it an attractive choice.

Keywords: automation; public transport; high-capacity buses; acceptance

1. Introduction

Automated mobility has the potential to increase traffic efficiency, road safety, and ride comfort. However, in public transport (PT), removal of a driver has negative ramifications as the perceived role of drivers goes beyond vehicle control. By using results of two projects – KRABAT and of PAsCAL, we demonstrate why passenger acceptance of driverless automated buses is not only about vehicle safety (crash risk) but also security (crime risk), see Fig. 1.

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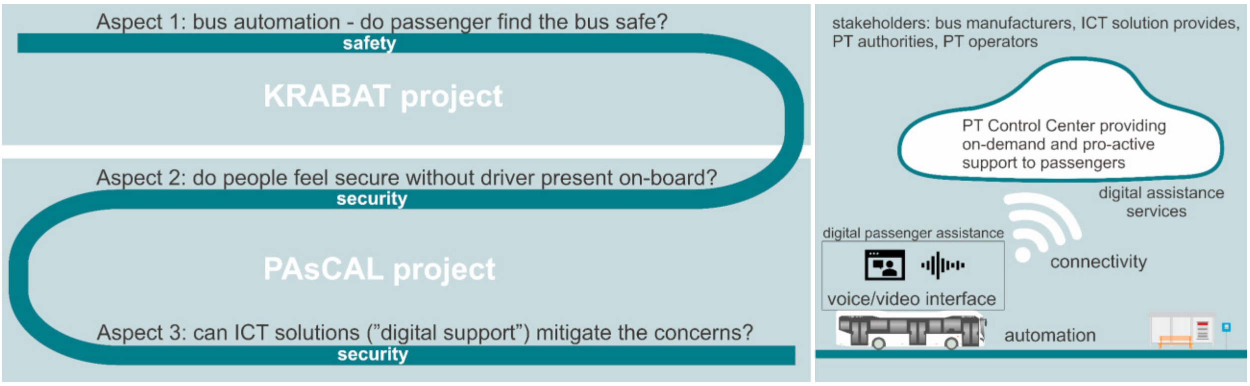


Fig. 1. Research questions: perception of safety, security, and ICT potentials.

We also explore potentials of ICT applications in mitigation of passengers' concerns related to the lack of a driver. To address the research questions KRABAT project used a full-sized (12m with a passenger capacity of 102) automated bus without safety driver behind the steering wheel. On the other hand, PAsCAL project relied on the Wizard of Oz (WoZ) approach (Kelley, John F. 2018). That is, a 12m bus (same model as in KRABAT) was prepared in a way that passengers believed that they travelled in an automated driverless bus. In KRABAT, 22 participants experienced the bus, while in PAsCAL, 8 different experiments with a total of 54 participants were carried out. To the best of the authors knowledge, both projects are the first user studies involving full-sized buses at normal PT speed. Past research mainly investigated low-capacity automated shuttles that travel at much lower speeds (below 20 km/h) as last mile connections (Rombaut E., et al. 2020). First, the paper presents related work. Results of the projects are presented in Sections 3. The last section summarises the findings.

2. Related work

Connected and automated mobility will increase the total PT system performance. This results in shorter travel times given the same demand, which in turn can lead to additional induced demand. Preliminary analysis of the impact of automated vehicles on travel demand suggests a 5% increase (Barth M., Wu G., and Boriboonsomsin K. 2016). Therefore, additional control measures such as congestion pricing for private cars will be required to manage demand. Overall implications of autonomous mobility are discussed in (Nahmias-Biran B., et al. 2021). Existing research focuses on autonomous shuttles (Gustafsson M., et al. 2021) (Paddeu D., et al. 2020), because high-capacity autonomous buses of today are at an early prototype stage. Generally, reported acceptance by those who have tried the shuttles is high, while the main concerns are very low speed and harsh braking (Gustafsson M., et al. 2021). In (Kassens-Noor E., Kotval-Karamchandani Z., Cai M. 2020) the authors found that about half of PT users were hesitant towards autonomous buses and shuttles due to safety concerns, lack of human driver, and distrust in the technology. However, the research was only based on random-sampling surveys. The experiments reported in this article stand out in that they covered high-speed driving of high-capacity PT buses. They also investigated ICT aspects and included experiments with visually impaired passengers as well as scenarios of passengers travelling alone and at night (both aspects not found in the literature). The next section presents results from the KRABAT project, which focused on passenger trust towards automation. Section 4 contains results of the follow-up experiments carried out in PAsCAL. They aimed at understanding security perception and ICT potentials to mitigate security-related concerns.

3. Trust towards automated buses – results from the KRABAT project

The objective was to investigate how passengers experience a full-length automated bus in everyday traffic situations. The experiment was conducted on a test course with nine everyday traffic situations often encountered. It encompassed 22 participants from two different cities in Sweden (Gothenburg and Borås).

3.1. Vehicle preparation

A Volvo 7900 plug in hybrid bus that looks like a regular bus both internally and externally was used in the experiment. The bus was equipped with a self-driving system that consisted of five lidar sensors with which a three-dimensional map of the test course had been created before the experiment. The system navigated by comparing data from the sensors with the earlier created map using a predefined route consisting in coordinate and velocity data stored in 25-50cm intervals. Even if the bus was only able to drive the specific test route, participants experienced it as a fully automated bus. The setup included two test leaders. One was controlling the self-driving system, i.e., activating and monitoring the system, sitting in the middle part of the bus behind a partially concealed computer screen. The second test leader acted as a safety-driver in case of emergency, i.e., ready to take over the driving task if the self-driving system failed, and was seated in the frontmost, right hand side passenger seat. No personnel were seated behind the steering wheel.

3.2. Participants and test course

Twelve male and ten female participants aged 21-70 (M=40.5, SD=16.5) took part in the experiment. They were recruited from the cities of Gothenburg and Borås (Sweden), all commuted daily with public transport, and had a positive attitude towards public transport in general. All participants were compensated with lunch and a voucher for 1000 SEK. The test course consisted of roads with normal road standards for bi-directional traffic, where the bus reached speeds of up to circa 35 km/h and a small urban area with a building, four-way intersections, road signs, zebra crossing, and a roundabout. The test route was 3.3 km, and the test runs took approximately 15 minutes. Each test run included nine traffic situations: (i) embarking bus at bus terminal; (ii) reversing bus out of bus terminal; (iii) stopping at intersection for pedestrian with baby; (iv) picking up a passenger at bus stop; (v) passing empty bus stop at rural turning point; (iv) stop for cyclist at intersection; (vii) stopping for car at intersection; (viii) dropping of passenger at bus stop; and (ix) disembarking bus at bus terminal.

3.3. Experiment setup

Each experiment started with a briefing, where participants were informed about the overall procedure and that they would experience an automated bus. The participants were then brought to a simulated bus terminal at the test course, where they waited for the automated bus to arrive. After embarking the automated bus, the participants got to experience the nine different everyday traffic situations. Then the participants were all interviewed individually at the simulated bus terminal. The interview included questions relating to how the participants experienced travelling with the bus, e.g., how did the bus conduct everyday traffic, and how the participants expected the introduction and implementation of automated busses into the public transport system to affect their future commuting. The data collection also included an acceptance questionnaire focusing on experience of traveling with the bus, perceived performance of the bus, and perceived usefulness of the bus, to complement the semi-structured interview. The interviews were transcribed and analysed using a thematic analysis, i.e., an analytical approach which aims to identify themes and patterns in qualitative data.

3.4. Findings

Most participants experienced the ride with the bus as very positive, exciting, and interesting, even if it felt strange in the beginning, especially seeing the steering wheel turning without having a driver behind it. The majority also found the bus and its driving behaviour as trustworthy, mostly since they experienced the bus as being competent, handling the simulated everyday traffic situations in a positive manner. The participants' overall positive experience of traveling with the bus is also reflected in the results of the acceptance questionnaire (see Fig. 2). Furthermore, the participants expected that the introduction of automated busses, like the one that they had just experienced, would have several benefits on the public transport system. The two most mentioned benefits and the ones that participants considered most important were improved efficiency and safety, since they expected that the automated bus would drive in a more consistent and safe way than a human driver generally would.

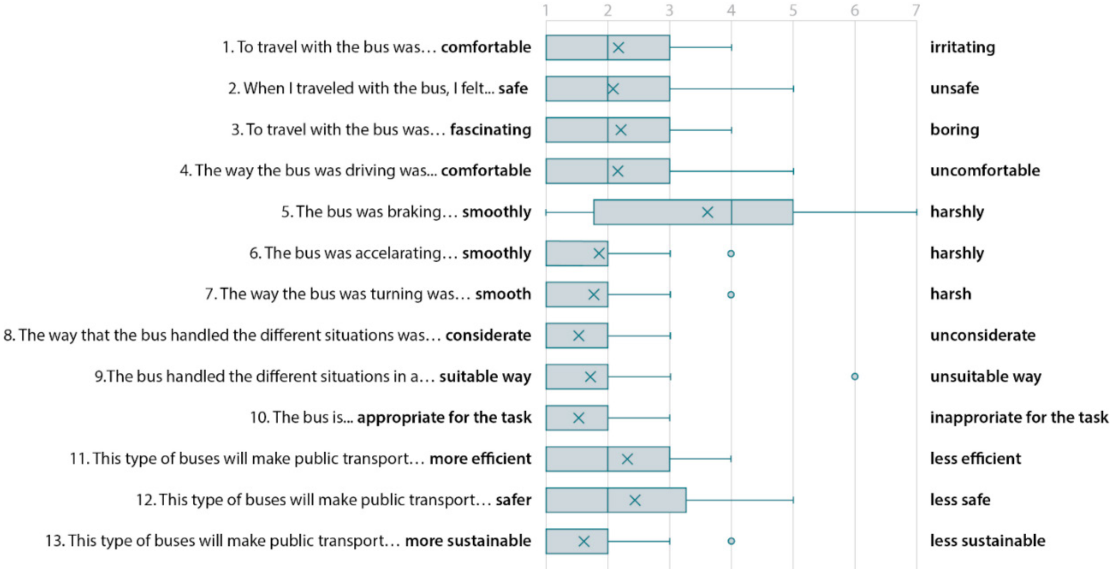


Fig. 2. Acceptance questionnaire response

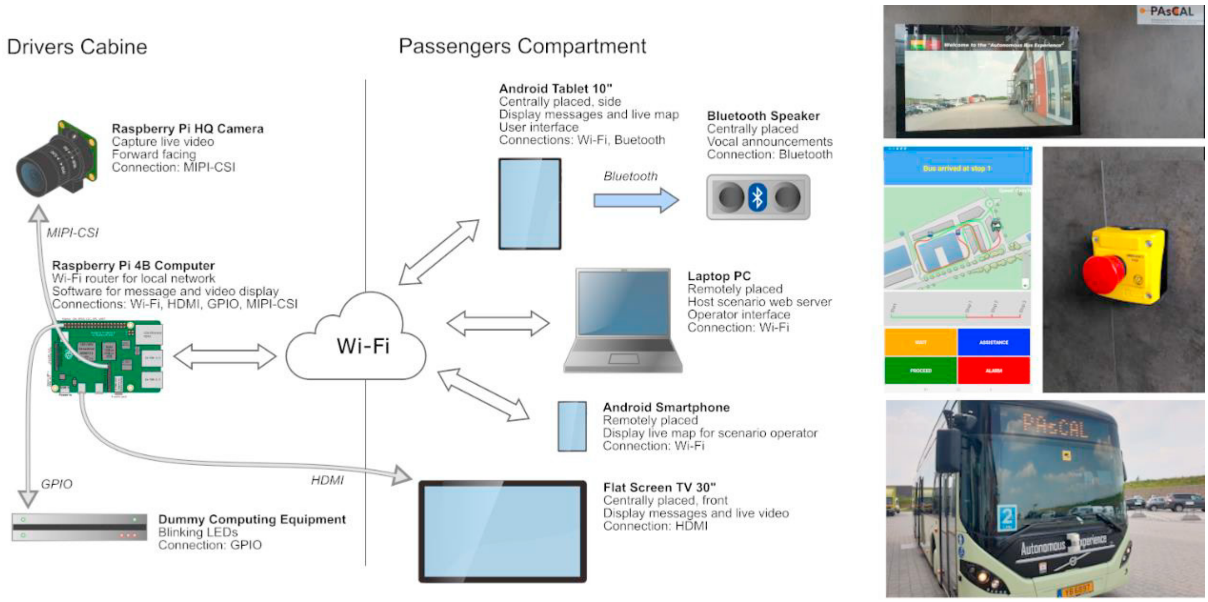
Participants also believed that automated buses would make the travel slightly more comfortable and some also mentioned that public transport would be more inclusive for older passengers and people with disabilities since they thought it would overall perform the docking better than human drivers. Moreover, some participants thought that not having to have a driver in all buses would decrease the cost of public transport and that the precision in the automated buses' driving behaviour would lead to less wear and tear on the buses. However, participants also believed that the introduction of automated busses could have some negative consequences on the public transport system. Some believed that the implementation of automated buses would result in a negative development by taking away a good job (bus driver), but many believed that the development would not necessarily be negative for the system since it would create new professions. Participants also believed that the absence of a bus driver would have negative affect on passengers' experience of commuting with the bus. This, since if the driver disappeared, it would no longer be possible to ask about information, for example, the route or bus stops. It would also feel a bit less secure, especially when traveling during night, due to not having an authority figure present in the bus. Finally, even though participants experienced the automated bus positively and saw several benefits with the implementation of it, they did not believe that automated buses would change their traveling behaviour to a great degree. The reason was twofold. First, merely implementing automated buses instead of buses operated by humans would not better fulfil their travel needs (number of departures and stops), which were to a great extent already fulfilled. Second, they also believed that the positive effects of automated buses were expected to be counteracted by other human road users. However, although many participants did not expect that automated buses would affect their own public transport travel behaviour to any significant degree, many thought that such a system could improve travel in other use areas, e.g., rural areas, and that the automated technology could facilitate new services that could improve public transport, e.g., floating bus stops.

4. Security perception of driverless operations: results from the PAsCAL project

The objective of the experiments was to firstly examine passenger attitude towards security of driverless high-capacity buses and secondly explore the potentials of ICT assistance in mitigating the determined concerns. A Wizard of Oz approach was used – that is a 12m bus was prepared in a way that passengers believed that they travelled in a driverless automated/autonomous bus. This allowed to execute advanced scenarios that would not be feasible using today's state of automation. Activities near the bus were not restricted, i.e., other traffic near the bus was allowed during the experiment.

4.1. Vehicle preparation

Vehicle preparations are shown in Fig. 3. All windows in the separated front part of the bus were covered with a 3mm dark plexiglass cut-to-shape. Combined with curtains around the driver seat to prevent light from shining through, the driver was effectively invisible. In addition, several devices were installed inside the bus to convey the impression of a fully automated vehicle. The core of the scenario control consisted of a web application served on a web server running on the Laptop PC. While exposing a web service consumed by the mobile app on the tablet, it also provided a web interface to the test leader who advances the scenario steps. The passenger ICT support was implemented via a tablet installed next to the middle doors. It was running a mobile app that acted both as a user interface and was responsible for playing the messages, videos and sounds defined in the scenario over a Bluetooth speaker. A Raspberry Pi mini-computer was central in providing connectivity as a local on-board Wi-Fi access point as well as connecting camera, TV and dummy computing equipment. The latter was meant to attract attention if participants would try to peek inside the driver's cabin from the outside.



a) b)

Fig. 3. Vehicle preparation: Onboard hardware overview(a); Software and modifications (b).

4.2. Experiment setup

As in KRABAT, each experiment started with a briefing, during which participants were explained they will drive two distinct buses, and after the two rides they will be asked questions about the second ride (Fig. 4). The first bus was a normal vehicle (to generate base-line experience), while the second one was the staged autonomous bus (WoZ). Each participant received a personal itinerary related to the second bus drive. The itinerary differed in the destination stop (two options were prepared). Participants were not aware of what type of vehicles they would drive. After the experiment, the participants' experiences were collected via interviews and questionnaires. Three scenarios were defined – a "normal scenario" (i), an "event scenario" without ICT passenger support (ii), and an "event scenario" with ICT support (iii). The "normal scenario" had no issues. The "event scenario" included the following technical and operational issues: "long idling", "doors issue", and "car blocking the path of the bus". In all experiments information about stop arrival/departure and doors opening/closing was announced via the speaker, which also served as cues for the concealed driver. A permanent audio connection with the test leader was maintained, but not needed. The ICT support used in the third scenario was providing additional assistance during the events to handle the situation.

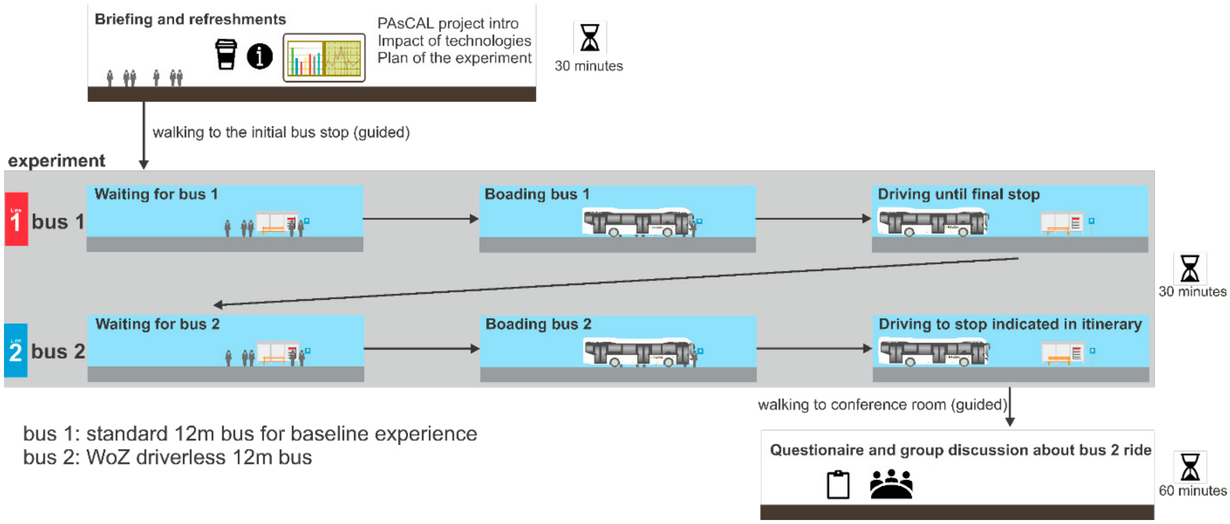


Fig. 4. Experiment plan – briefing, followed by two bus rides, questionnaire, and group discussion.

A pro-active video-call from the control center was launched during the "long idling" event in the third scenario, whereas passengers were left un-informed in the second scenario. In the second scenario, during the "doors issue" event, the doors opening is announced at bus stop 1, but they fail to open. As a result, a staged passenger cannot enter the bus, and no-one is able to intervene. In the third scenario however, the staged passenger travels in the bus and attempts to leave it at stop 1. When the doors do not open, he launches a video-call with the control center to report the problem. The doors are then opened remotely by the control center and the passenger leaves the bus.

A total of 5 main experiments involving 51 participants were carried out. There were 25 female and 26 male participants with an average age of 46 and 40 respectively. The youngest participant was 18 years old, the oldest 73. Five passengers with visual impairments experienced scenario 1. Two special experiments focusing on driving alone and at night were carried out involving 3 additional participants. An overview of the experiments is given in Table 1.

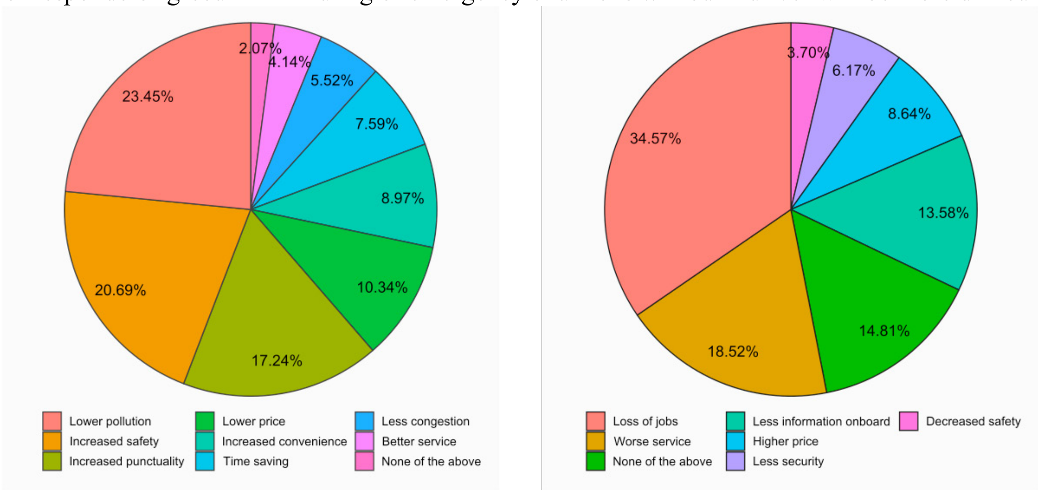
Table 1. Overview of experiments.

Experiment number	Number of participants	Scenario	Date
1	13	1 (normal)	10/06/2021
2	8	1 (normal)	24/06/2021
3	14	2 (events no ICT)	01/07/2021
4	11	3 (events with ICT support)	08/07/2021
5	5 (visually impaired)	1 (normal)	20/09/2021
7	2	Special 1 - driving alone	15/12/2021
8	1	Special 2 - driving alone at night	15/12/2021

4.3. Findings

When it comes to overall attitude towards using driverless buses, all except one person declared that they would be willing to use them and let family and close ones use them. This confirmed high degree of trust towards automation reported in the KRABAT project. Among the positive responses, 54% would certainly use such buses, 24% probably and 22% would use it conditionally, depending on how the technology evolves. Perceived benefits and drawbacks of automation are given in Fig. 5. Increased safety and lower pollution were among the highest perceived benefits (20.69% and 23.45%). One must note that electric buses have no tailpipe emissions. Hence, passengers most likely interpret pollution in wider environmental scope that includes GHG emissions and energy consumption. On the other hand, loss of jobs and a worse service level were among the top perceived drawbacks of automation. Lower expected safety was reported only by 3.7% responders. In the explicit questions related to unusual situations (Fig. 6) a majority

(68.63%) of responders agreed that handling of emergency situations without a driver will be more difficult.



a) b)

Fig. 5. Perceived benefits (a) and drawbacks (b) of PT automation.

Although, the lack of access to information via a driver was not an issue to 41.18% responders, it was reported as stressful by a relatively large group (35.29%). Risk of decreased safety (violence, pickpocketing, etc.) was noted by 43.14% participants, with almost 20% of them being undecided. Almost everyone agreed (98.04%) that on-demand contact with a control center is important.

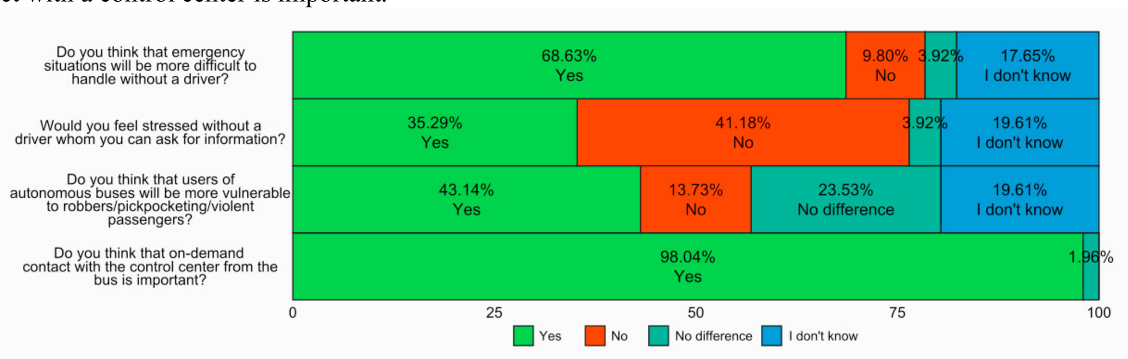


Fig. 6. Emergency situations, information, security, and on-demand contact with PT control center.

The outcome of focus group discussions was that digital support will most likely be sufficient to replace a driver in daytime driving. However, there was a consensus that when driving alone, especially at night, monitoring by and connection with a control center will not provide a sufficient degree of safety. This was confirmed by three additional experiments that involved driving alone and driving alone at night. Group discussions also revealed some scepticism towards automation. Certain claims, for instance, that an autonomous bus will not have higher commercial speed than today's buses, indicate that unless automation is used to improve bus prioritisation, it will not make PT more attractive. Passengers with visual impairment were the only group that appreciated the smoother ride. They reported much stricter requirements on the implementation of digital passenger support. Touch displays without tactile feedback or voice over functionality are not practicable, and reliance on personal devices is limited due to holding the cane. Common fear reported by the group was that there is not enough time to leave the bus without a driver that normally notices passengers requiring additional support. Finally, the WoZ approach was validated through a simple questionnaire after each experiment. It turned out to be effective – only one person suspected that the vehicle might not have been driverless as it performed to good given today's state of automation.

5. Summary

Trust towards automation is only a pre-requisite for passenger acceptance of automated buses in public transport. Experiments carried out in KRABAT project confirm that passengers generally accept the technology and appreciate safety and environmental benefits. The main perceived drawbacks are loss of jobs and lower service quality due to the lack of a driver present on the bus. However, one can expect that digitalisation will be able to fill in the service-quality gaps – the market for mobile apps facilitating seamless intermodal travel is constantly growing and will most likely be able to provide innovative solutions to driverless bus operations. One must note special requirements by passengers with disabilities, who will need additional forms of communication with the bus that include requirements such as dwell time extension. As driver shortages is a common issue in PT, the job impact might be lower than generally perceived. Moreover, new jobs will be generated with the rise of autonomous bus operations. Results of the PAsCAL pilot indicate that drivers play an important role that goes beyond operating the vehicle. They are expected to assist in various situations as to guarantee a certain degree of experienced safety in relation to other passengers. However, it appears that in typical daylight operations with several passengers on board, the on-demand and proactive support provided by a control center will be sufficient. Mobile applications can act as an additional personal interface between an operator and passengers. However, they cannot replace in-vehicle systems due to people with disabilities that might have limited access to personal devices. Night-time driving, where passengers are often alone in the bus requires additional studies. It appears that in such cases, the lack of a driver is a significant issue. Moreover, ICT will not always be able to provide sufficient support in the required timeframe given severe threads and emergency situations. However, when automation technology is available, one can expect that public transport operations will be organized in a much more efficient way, adjusting vehicle’s capacity and routes dynamically according to the demand. This means, that low-demand operations will be served by small on-demand autonomous shuttles. Future work should further focus on passenger acceptance of shared driverless vehicles in night conditions. In addition, work on novel passenger authentication methods, interaction with a control centre via voice commands and gesture control needs to be carried out to ensure passenger safety and swift reaction times when needed. Finally, one must keep in mind that the technology alone is not a silver bullet in making PT more attractive. An autonomous bus operating in mixed traffic will only be marginally more attractive than a conventional bus (potentially smoother operations). Hence, PT automation shall be seen as rather an enabler of new applications developed within a C-ITS framework to efficiently prioritize PT in traffic flows to make it an attractive choice.

Acknowledgments

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