Proceedings of the
Estonian Academy of Sciences
2025, **74**, 2, 212–216

https://doi.org/10.3176/proc.2025.2.23

www.eap.ee/proceedings
Estonian Academy Publishers

AUTONOMOUS VEHICLES

RESEARCH ARTICLE

Received 3 February 2025
Accepted 12 March 2025
Available online 19 May 2025

Keywords:
autonomous shuttle bus, autonomous vehicles, situational awareness, passengers, mobility

Corresponding author:
Krister Kalda
krister.kalda@taltech.ee

Citation:
Kalda, K., Koskinen, K. M., Sarv, L. and Sell, R. 2025. Situational awareness in autonomous shuttle buses. *Proceedings of the Estonian Academy of Sciences*, **74**(2), 212–216. https://doi.org/10.3176/proc.2025.2.23

Situational awareness in autonomous shuttle buses

Krister Kalda[a], Kari M. Koskinen[b], Lill Sarv[c] and Raivo Sell[a]

[a] Department of Mechanical and Industrial Engineering, Tallinn University of Technology, Estonia

[b] Department of Information and Service Management, Aalto University, Finland

[c] Department of Civil Engineering and Architecture, Tallinn University of Technology, Estonia

ABSTRACT

Autonomous shuttle buses provide a promising solution for the last-mile problem in various contexts. The removal of the human driver facilitates round-the-clock operations as well as transportation in locations that might otherwise be unfeasible for buses operated by a human driver. Trials have been conducted on these buses, and several companies aim to equip their vehicles with full self-driving capabilities. However, removing the human driver introduces several challenges, particularly in handling emergency situations. The absence of the driver, therefore, calls for increased passenger situational awareness, i.e., understanding of the environmental and contextual factors impacting the operations of the bus the passenger is on. It remains unclear to what extent bus manufacturers have considered these issues or integrated them into the design. This research seeks to shed light on the matter by studying the topic both from the industry's and users' perspectives.

1. Introduction

Autonomous transportation systems are being deployed into the public transportation ecosystem. As the architecture of autonomous transport modes represents a transformation of the role of the human driver to self-driving algorithms, they already pose formidable design challenges in terms of the deployed technology. No algorithm is entirely accurate. Numerous crashes of self-driving vehicles highlight the importance of human situational awareness (SA) in reacting to unintended behaviors of autonomous vehicle (AV) algorithms (Wang et al. 2020).

While the issue of SA has attracted a fair amount of research and practitioners' interest in relation to private passenger cars (Chandrasekaran et al. 2019), the matter has received little attention in other related research domains, such as autonomous shuttle buses (ASBs). A number of trials have been conducted with ASBs in various locations, and several companies have embarked on the challenge of developing these buses and their self-driving capabilities (Herrenkind et al. 2019; Launonen et al. 2021). In the trials, there is often a human agent inside the bus, ready to take over in case something unexpected occurs or the system fails to behave as intended. However, ultimately, the objective of these buses is to operate without having any human controller on board.

This raises the question regarding the required or expected SA of the passengers. Dealing, for instance, with unexpected situations may require passengers to adopt roles and tasks that have been so far delegated to the human driver/operator. Overall, technological systems such as AVs are, in essence, socio-technical, as their functioning and acceptance rely on different technological, social, and contextual factors that interact with and impact the system's ability to meet its objectives (Wang et al. 2020). In addition to solving the technological challenges, the development of fully autonomous ASBs is also dependent on a range of human factors, some of which are linked to and impacted by the passengers on board the vehicles as well as by people within their proximity.

This paper seeks to shed light on these other issues and challenges that so far appear to have obtained limited research interest. The research questions for this study are the following: how do different stakeholders view the level of SA required from passengers of shuttle AVs, and how is passenger SA factored into the design of the shuttles?

A major challenge for ASB developers is the lack of understanding of what real users consider important in practical situations and what they require to feel safe enough to step on board unmanned ASBs. Through a live pilot and a survey with over 100 residents in the pilot area, it is possible to answer vital questions that reveal both participants' attitudes and actual feelings. Open-ended questions also provide insight into ideas and visions that scientists working daily with ASBs fail to consider or just assume logically. But logic and people in traffic do not always go hand in hand.

The main aim of this research is to contribute towards a better understanding of the role of SA of passengers and how that is currently addressed by different actors in the sector. On the basis of these findings, we also put forward a research agenda. The data for this research are collected via interviews with ASB manufacturers and other representatives from the sector as well as via a survey conducted of the likely and actual users of these buses.

The main novelty in this research is the approach to look at SA from the angle of what is most important to the actual ASB users and generally to people in traffic with autonomous shuttles, considering the ultimate goal that there is no safety operator on board.

2. Literature on situational awareness and self-driving vehicles

SA can be defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley 1988). SA can be divided into three levels of responsiveness. Whereas the first level, perception, is seen as the basic level requiring recognition of cues in the environment, the second level, comprehension, calls for analysis and processing of different pieces of information and their interconnections to give meaning to what is being observed. The third level, projection, builds on the first two levels and refers to the person's ability to predict the future state of the environment or context that they are observing (Endsley 2019).

The different levels of responsiveness and the ability to react quickly are of particular importance in the automation of driving (Endsley 2017). Since full driving automation has not yet been achieved in open road transportation, the SA of drivers of self-driving passenger cars has received a fair amount of interest in research and industry. Car manufacturers such as Tesla have introduced so-called nags that remind the drivers to keep their hands on the steering wheel (Nordhoff et al. 2023) while also delivering contextual information to the driver. SA has been found to be impacted by human-specific characteristics such as trust towards automation, engagement and workload of the driver, and mental capacity, as well as more technology-related factors such as level of automation, technology complexity, and information salience (Endsley 2017).

The role of passenger SA has received significantly less attention. In passenger cars with self-driving capabilities, passengers have been studied, for instance, in relation to the effect passengers have on the SA of the driver (Chandrasekaran et al. 2019), how SA impacts the anxiety of passengers traveling in a self-driving vehicle (Lu et al. 2022), or how much SA is required to improve passenger trust towards automated vehicles (Chang et al. 2019). While SA may help passengers regarding certain psychological traits, such as gaining trust and relieving anxiety, they are not expected to have any direct role in maneuvering or managing the vehicle. In the context of a passenger car, this is somewhat understandable, as the main task of driving is split between the driver and the automation, assuming the vehicle has some capabilities regarding the latter.

However, in the case of ASBs, the aim is directly linked to the removal of the human operator, whose tasks are not limited to driving the bus alone but also include tasks such as dealing with unexpected situations in and outside the bus. As a result, the operations of a fully autonomous ASB are in some instances likely to depend on the passengers, which again calls for appropriate levels of SA from them. Current research on ASBs primarily focuses on the concerns and hopes that users have regarding these buses (Herrenkind et al. 2019; Launonen et al. 2021). The required level of passenger SA and its influence on ASB design remains unclear.

This is of importance as it links to other relevant questions on the role of passengers of ASBs, such as what kinds of tasks or control mechanisms might be given to them, how much information passengers should be provided, and in what format and with whom and how to interact in unexpected situations. Our research seeks to contribute to these questions by looking at ASBs concerning the SA of passengers as well as ASB users' views regarding the matter.

3. Methodology

Building on these insights, mixed methods were used in the current case study for investigating the different perceptions of SA in the context of AVs applied in real-life traffic situations and as part of public transport services (Udal et al. 2024). The descriptive case study method was applied as it is foremost concerned with questions such as "how" and "why" and permits differences between what was planned and what occurred.

A pilot test with a self-driving shuttle bus was conducted in Rae Parish (in Estonia) as an extension to the public transport system in the spring of 2023 (see Fig. 1). The AV used for the experiment was designed and manufactured in Estonia, under the iseAuto project (Sell et al. 2024; Sell, et al. 2021). The particular vehicle was a commercial version of the iseAuto. The overall project was connected to wider future transportation solutions – MaaS XT (Kalda et al. 2024), offering seamless integration of different mobility-related services, including self-driving minibuses and on-demand transportation. The aim of the survey was to assess the attitude of suburban residents towards self-driving vehicles after experiencing shared traffic situations with ASBs, as well as after using ASBs as a local last-mile service. Before conducting the survey (2022–2023), interviews with ASB manufacturers and service providers were conducted to assess

Fig. 1. Autonomous shuttle bus – iseAuto – used for the case study in Rae Parish. Photo taken by the authors.

their consideration of user experience and SA. The interviews are described in more detail at the end of this chapter and in the next one.

The online survey (https://forms.gle/tsEMxU2LSAPjihe28) was conducted among residents after the month-long ASB demo was finalized (dissemination was done in collaboration with the local government), with the main scope being to understand the perception of ASBs and SA from several angles.

A mixed-method approach was used, conducting semi-structured interviews with representatives of either self-driving vehicle technology or software developers, as well as with research centers focusing on AV development and application. The interviewees were selected mostly among Estonian and Finnish AV developers, as the interviews were analyzed in the context of the user survey. The interviews were open-ended, and guiding questions were sent beforehand.

The questions mainly focused on the design of internal communication in the ASB with passengers and the intended role of the passenger (either active and able to take over driving actions, active only in emergency situations, passive without any communicative actions, or passive with a possibility to communicate with remote operators). Additionally, there were questions regarding the amount of information provided to passengers in everyday situations and in cases of disruptions. The aim was to understand how much regard was given to communication-related potential challenges.

The main objective of the questions was to determine how much and at what level of complexity communication with passengers and SA had been considered while designing either the AV or a service using AVs. The interviews were adapted based on the interviewee to maximize their relevance.

4. Experiment results

Based on the interview answers, nine recurring topics were distinguished: transparency, universality of interpretation of gestures (cultural differences), the role of government/authorities, the form of communication used, the preference for making changes to the environment to enable AVs to function better rather than making AV design more human-centric, whether ASBs were considered the same as buses but without drivers, the passenger role as active or passive, technology readiness, and the relevance of the trust factor.

Some interviewees leaned towards providing some information but saw full transparency as counterproductive, potentially leading passengers to worry about factors that were not important. Others appeared not to have given much thought to issues linked to passengers' SA and increased responsibilities. The general assumption seemed to be that ASB passengers were comparable to those of a human-driven bus.

Another challenge that emerged was the variability of human behavior, gestures, and actions across different cultures. Some saw most human gestures and actions as universal, while others considered this a significant challenge. Points were made regarding how strictly people follow traffic rules and the differences in interpreting human signs. Similarly, it appeared that little thought had been given to the service design or business models around ASBs. Some doubts were expressed about whether last-mile transportation alone would be sufficient for a profitable business, and ideas such as using the buses for monitoring parking violations or gathering other types of data for additional purposes were mentioned.

The user survey included a multiple-choice questionnaire with some open-ended questions, totaling 35 questions. Among the 165 respondents, 53.9% had been in traffic with an AV, but significantly fewer had actually used one (only 28.7%). However, 86.5% expressed interest in using AVs in the future. Only 11% of survey participants considered AVs unsafe (see key results on survey in Fig. 2).

When asked whether they would use an ASB as their daily commute, responses were categorized as "yes", "no", and "don't know". When asked what kind of everyday mobility option they would replace with AV use, most respondents answered personal cars (65.5%), followed by public transport (41.8%) and taxis (30.9%). Only 15% of respondents considered it unsafe to be a passenger on an ASB in traffic. In an open-ended response, one participant stated:

"There is no reason to feel unsafe in an AV because I presume that AVs are technologically reliable like an elevator, and surely the manufacturers have thought it well through on how to provide help in case of malfunctions or accidents."

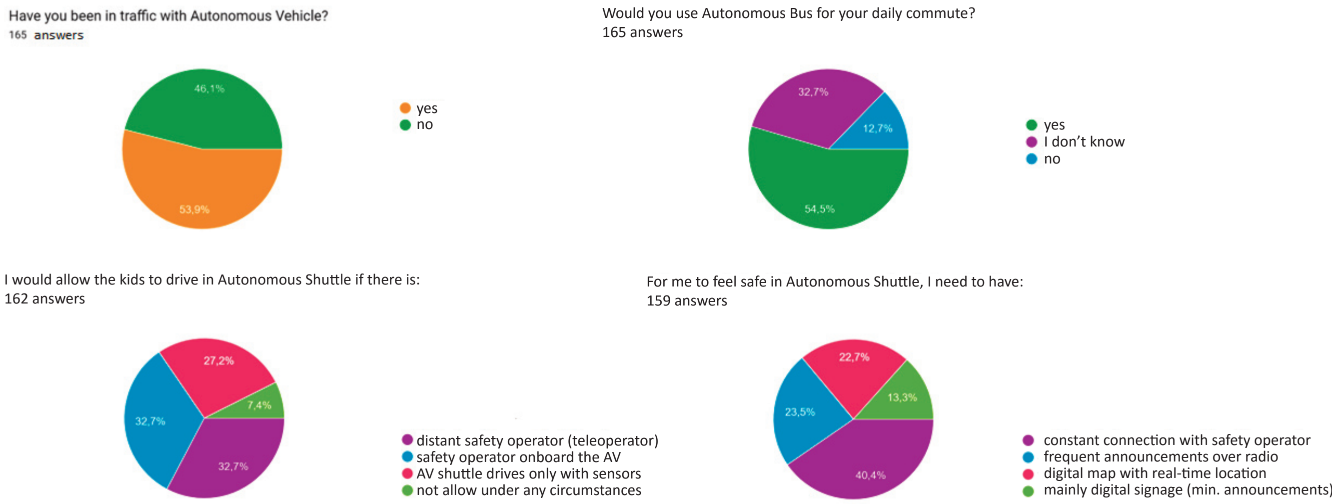

Fig. 2. Key results on survey.

Almost an equal percentage of people considered it safe for an ASB to be either remotely operated or driven only by sensors. Specifically, 20.5% considered it safe only with an operator on board, while 7% said they would not agree to use an ASB under any circumstances.

Regarding SA inside the bus, 64.8% considered it most important to have access to a digital map showing the location and movements of the ASB. Meanwhile, 37.7% preferred undisturbed rides with minimal information, except in emergencies or occasional operator interventions. A similar percentage (36.5%) stated that to feel safe, it was important to have constant communication with an operator during the ride, while 21.4% felt that a continuous flow of information was necessary to ensure safety.

5. Discussion and conclusions

The findings show that the key focus of ASB manufacturers is on solving the technological challenge of enabling fully autonomous driving of the buses. While understandable, it makes the development process of ASBs overwhelmingly technology-centric and runs the risk of ignoring human-related factors that are important for the success of ASBs. Despite technological advancements, user trust in AVs remains contingent on clear communication, and perceived safety is based on the assumption that the manufacturers and service providers have thought through how to assist passengers in case of accidents. It was quite surprising that a large number of people preferred to be minimally informed while riding with the ASB, and the most important communication measure, according to the user survey, was a real-time map showing the location of the ASB. Less important was the constant connection with the operator.

As seen from the interviews, not much consideration was given to the roles and tasks of the passengers nor to the optimal SA level of passengers or ideal communication channels to reach that level. The form of passenger communication or provided information was not based on conducted research but more on how these matters were organized in human-driven buses. This is unsurprising given the limited research on the topic. To address these differences and to establish the correct level of passenger SA of ASBs, we have identified three research areas that need to be investigated further. These areas are based on the data collected for this research and seen as of importance for the successful deployment of ASBs.

First, to establish the correct level of SA of ASB passengers, there is a need to clarify what is expected from them in different scenarios that may occur for the shuttle. Clear examples of these scenarios are accidents that an ASB might be involved in but also situations that can possibly lead to unwanted outcomes and may require passenger vigilance. These scenarios help to evaluate how active or passive the passengers are expected to be in relation to the buses' operations and set the basis for the required SA. This has also further implications for the transparency of information that is provided to the passengers on the ASB: should all available information be provided or only the bare minimum so that the passengers can fulfill the roles falling to them? Related to this, how much control of the buses' operations should passengers have, and through what kinds of channels and in which format should the information be provided?

Second, depending on location, results can vary not only geographically but also culturally, infrastructurally, and in terms of existing regulations. As a result, established passenger roles, required levels of SA, the most suitable amount of information, and preferred communication channels and formats may differ from one context to another. This calls for any research conducted on SA and ASBs to more generally consider how applicable the research findings are to other areas and cultures. Especially in situations marked by human-machine interaction, it is crucial for the machines to understand what different signs, gestures, and behavioral patterns may mean in that context. Similarly, it may well be that the best approaches to factors such as required SA evolve over time as technology develops, but also as people become more accustomed to the ASBs and their use.

Finally, as the focus is largely on solving the technological challenges of equipping the buses with fully autonomous driving capabilities, it seems that there has been less consideration of the service dimension or business model of the buses. This is linked to requirements on the level of passengers' SA. As noted above, this impacts the required trust of the passengers. Future research should expand on user expectations in different cultural and regulatory contexts, including ASB designers and manufacturers, as well as to better map the non-driving-related tasks that are currently done by the human driver. Our intention is also to continue research on the three research areas identified above to establish the requirements and contextual implications for SA of passengers inside ASBs.

Data availability statement

All data are available in the article.

Acknowledgments

This research has been supported by the European Union's Horizon 2020 Research and Innovation Programme, under the grant agreement No. 856602. The publication costs of this article were partially covered by the Estonian Academy of Sciences.

References

Chandrasekaran, L., Crookes, A. and Lansdown, T. C. 2019. Driver situation awareness – investigating the effect of passenger experience. *Transp. Res. F: Traffic Psychol. Behav.*, **61**, 152–162.

Chang, C.-C., Grier, R. A., Maynard, J., Shutko, J., Blommer, M., Swaminathan, R. et al. 2019. Using a situational awareness display to improve rider trust and comfort with an AV taxi. *Proc. Hum. Factors Ergon. Soc. Ann. Meeting*, **63**(1), 2083–2087.

Endsley, M. R. 1988. Situation awareness global assessment technique (SAGAT). In *Proceedings of the IEEE 1988 National Aerospace and Electronics Conference, Dayton, OH, USA, 23–27 May 1988*. IEEE, **3**, 789–795.

Endsley, M. R. 2017. Autonomous driving systems: a preliminary naturalistic study of the Tesla model S. *J. Cogn. Eng. Decis. Mak.*, **11**(3), 225–238.

Endsley, M. R. 2019. Situation awareness in future autonomous vehicles: beware of the unexpected. In *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)* (Bagnara, S., Tartaglia, R., Albolino, S., Alexander, T. and Fujita, Y., eds). Springer, Cham, **824**, 303–309.

Herrenkind, B., Brendel, A. B., Nastjuk, I., Greve, M. and Kolbe, L. M. 2019. Investigating end-user acceptance of autonomous electric buses to accelerate diffusion. *Transp. Res. D: Transp. Environ.*, **74**, 255–276. https://doi.org/10.1016/j.trd.2019.08.003

Kalda, K., Sell, R. and Kivimäe, M. 2024. Enhancing mobility as a service with autonomous last-mile shuttles and data exchange layer for public transport. *AIP Conf. Proc.*, **2989**(1), 020006. https://doi.org/10.1063/5.0189880

Launonen, P., Salonen, A. O. and Liimatainen, H. 2021. Icy roads and urban environments. Passenger experiences in autonomous vehicles in Finland. *Transp. Res. F: Traffic Psychol. Behav.*, **80**, 34–48. https://doi.org/10.1016/j.trf.2021.03.015

Lu, Y., Yi, B., Song, X., Zhao, S., Wang, J., and Cao, H. 2022. Can we adapt to highly automated vehicles as passengers? The mediating effect of trust and situational awareness on role adaption moderated by automated driving style. *Transp. Res. F: Traffic Psychol. Behav.*, **90**, 269–286.

Nordhoff, S., Lee, J. D., Calvert, S. C., Berge, S., Hagenzieker, M. and Happee, R. 2023. (Mis-)use of standard autopilot and full self-driving (FSD) Beta: results from interviews with users of Tesla's FSD Beta. *Front. Psychol.*, **14**, 1101520.

Sell, R., Soe, R.-M., Wang, R. and Rassõlkin, A. 2021. Autonomous vehicle shuttle in smart city testbed. In *Intelligent System Solutions for Auto Mobility and Beyond. AMAA 2020. Lecture Notes in Mobility* (Zachäus, C. and Meyer, G., eds). Springer, Cham, 143–157. https://doi.org/10.1007/978-3-030-65871-7_11

Sell, R., Malayjerdi, M., Pikner, H., Razdan, R., Malayjerdi, E. and Bellone, M. 2024. Open-source level 4 autonomous shuttle for last-mile mobility. In *2024 IEEE 29th International Conference on Emerging Technologies and Factory Automation (ETFA), Padova, Italy, 10–13 September 2024*. IEEE, 1–6. https://doi.org/10.1109/ETFA61755.2024.10710975

Udal, A., Sell, R., Kalda, K. and Antov, D. 2024. A predictive compact model of effective travel time considering the implementation of first-mile autonomous mini-buses in smart suburbs. *Smart Cities*, **7**(6), 3914–3935. https://doi.org/10.3390/smartcities7060151

Wang, J., Zhang, L., Huang, Y. and Zhao, J. 2020. Safety of autonomous vehicles. *J. Adv. Transp.*, **2020**, 1–13.

Olukorrateadlikkus autonoomsetes minibussides

Krister Kalda, Kari M. Koskinen, Lill Sarv ja Raivo Sell

Autonoomsed minibussid pakuvad lahendust viimase miili transpordiprobleemile, võimaldades ööpäevaringset teenindust ka keerukates keskkondades. Juhi puudumine tõstab aga reisijate olukorrateadlikkuse tähtsust, kuna ootamatutes situatsioonides võib vastutus langeda neile. Uuring keskendub sellele, kuidas on reisijate rolli ja teadlikkust arvesse võetud autonoomsete busside disainis ja arenduses. Intervjuud tootjate ja kasutajatega näitasid, et keskendutakse peamiselt tehnoloogiale, kuid vähem reisijate rollidele ja informeeritusele. Kasutajauuringust selgus, et paljud usaldavad autonoomseid busse, kuid eelistavad minimaalset teavet. Peamine soovitud teabeallikas oli digitaalne kaart bussi asukoha ja liikumise kohta. Uuring toob esile kolm olulist uurimisvaldkonda: reisijate ootused eri stsenaariumides, kultuurilised ja regulatiivsed erinevused ning teenuse ja ärimudeli arendamine. Edasised uuringud keskenduvad reisijate olukorrateadlikkuse optimaalsele tasemele ja sobivatele kommunikatsioonikanalitele autonoomsete busside kontekstis.