The Role of Autonomous Shuttles for Inclusive Public Transport

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Abstract: *As autonomous shuttle services are gradually integrated into urban transport systems, assessing their impact on accessibility and equity is increasingly relevant. This study analyses the results of a survey of an autonomous shuttle operating in Esch-sur-Alzette (Luxembourg), focusing on user behaviour and perceptions, with special attention to vulnerable users such as aged adults and people with reduced mobility. Based on an online questionnaire collected on board, results show that the service is mainly seen as a valuable mobility service especially for elderly passengers and people with mobility impairments, and that its low operating speed is perceived positively by these users. Main reasons for using the shuttle include reducing walking distances, improving access to public transport, and reaching shopping areas, highlighting its role in overcoming mobility barriers. These results suggest that autonomous shuttles are not only an innovative solution but also a useful transport service to foster social inclusion and promote more equitable mobility.*

Keywords*:* Shared Autonomous Vehicles (SAVs), vulnerable users and aged population, mobility equity, sustainability

1. Introduction

Autonomous vehicles have gained a central role in the debate on sustainable mobility (Richter et al., 2022; Acheampong et al., 2021), in particular their service as Shared Autonomous Vehicles (SAVs). A specific subcategory of SAVs is represented by autonomous shuttles, small electrically powered autonomous vehicles designed to operate at low speeds along predefined routes. Due to their potential to enhance accessibility and sustainability, autonomous shuttles offer a tangible opportunity to increase their attractiveness, particularly in urban and peri-urban areas (Nordhoff et al., 2021, Rosell and Allen, 2020). The implementation of autonomous shuttles has the potential to generate a new range of transport options that could benefit the entire population (Hwangbo et al., 2024). Their impact is particularly significant for specific user groups, such as individuals with reduced mobility and the elderly, for whom access to traditional transport systems often represents a significant challenge (Bennett and Vijaygopal, 2024; Classen et al., 2023). These user groups are often disadvantaged within traditional public transport systems due to physical barriers, complex access procedures, or limited autonomy in their movements.
Autonomous shuttles, operating at low speeds along safe routes, often in dedicated lanes or pedestrian areas, can offer a more reassuring and user-friendly transport

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alternative. Their simple design, absence of architectural barriers, and predictable operation make them especially suited to individuals who might otherwise experience difficulty using conventional transit services. In this perspective, autonomous shuttles not only enhance physical (last/first-mile) connectivity with the existing public transport network but also act as an enabling factor for independent mobility. In particular, they can serve as a crucial link for those who would otherwise be excluded from public transport options due to physical or cognitive limitations, such as people with reduced or impaired mobility. As such, their integration into urban transport ecosystems can generate benefits beyond system efficiency, contributing to greater equity and social inclusion, and ultimately helping to reduce mobility-related inequalities.

With the goal of contributing to this line of research, this study investigates the perceived value of this service using an on-field survey collected in and around the operational area covered by an autonomous shuttle in the city of Esch-sur-Alzette, Luxembourg. The service, operated by the company Sales-Lentz for the Municipality of Esch-sur-Alzette, offers the citizens fare-free transport on a pedestrian street, and as first/last-mile connectivity to scheduled public transport services.

While the survey collected responses from a variety of user profiles, particular attention is devoted in this study to analysing the perceptions and experiences of elderly individuals and those with reduced mobility. By focusing on their satisfaction, perceived benefits, and usage motivations, the study aims to assess whether autonomous shuttles can serve as a viable and inclusive mobility solution. The findings provide insights into how such services may contribute to improving transport equity and fostering independent and dignified mobility for users who are often at risk of exclusion.

The paper is structured as follows: Section 2 provides an overview of the current state of the art. Section 3 describes the adopted methodology and data collection process. Section 4 presents and discusses the main findings. Finally, Section 5 summarizes the key conclusions, outlines the study's limitations, and proposes directions for future research.

2. Literature Review

To assess autonomous shuttle operations potential, numerous pilot projects have been launched worldwide (Nesheli et al., 2021) in various settings and environments such as university campuses, pedestrian zones (Anund et al., 2022), and, on a larger scale, in some cities centers like Helsinki, Vienna, and Brisbane (Golbabaei et al., 2022; Rehrl and Zankl, 2018). Findings from these pilots highlight opportunities and challenges for their large-scale deployment. One of their primary advantages reported in past studies is their ability to improve accessibility and integrate effectively with public transport systems, addressing the so-called "first/last-mile" problem. Several studies indicate that autonomous shuttles can bridge the gap between public transport stops and users' final destinations, facilitating mobility, particularly in urban areas (Gurumurthy et al., 2020; Becker and Axhausen, 2017).

However, the implementation of autonomous shuttles is not without obstacles, a main challenge being represented by their low operating speed and flexibility in terms of rerouting and rescheduling, which makes them less competitive compared to existing transport alternatives (Salonen et al., 2019; Nordhoff et al., 2018). The reliability of the technology is also a challenge, especially in complex urban environments or adverse weather conditions such as heavy rain or snow, which may compromise vehicle performance (Nesheli et al., 2021). Additionally, regulatory frameworks represent another bottleneck (Cascetta et al., 2022): many countries still lack clear legal structures for integrating autonomous shuttles into urban traffic (Shladover, and Nowakowski, 2019). Furthermore, in several nations, regulations mandate the

presence of an onboard human supervisor, further limiting their potential operational cost efficiency, as it is the case of the studied service in this paper.
Key factor for the success of autonomous shuttles is in the social acceptance (Cartenì, 2020, Santhanakrishnan et al., 2020; Stocker and Shaheen, 2018). This is strongly influenced by users' perceptions of safety, trust in the technology, and their level of familiarity with the service (Nordhoff et al., 2021). Recent studies suggest that while passengers may initially be sceptical of this technology, repeated exposure to the service tends to increase their confidence and acceptance (Golbabaei et al., 2022). Nonetheless, concerns remain regarding the absence of a human driver and the ability of shuttles to handle emergency situations (Anund et al., 2022).
While most of the literature has focused on the technical and operational aspects of autonomous shuttles, their contribution to social sustainability (de Paepe et al., 2023), equity and inclusion in mobility remains relatively underexplored. Autonomous transport solutions have the potential to benefit traditionally disadvantaged user groups, such as elderly individuals and those with reduced mobility (Golbabei et al., 2024; Petrović et al., 2022; Dianin and Cavallaro, 2019; Claypool et al., 2017). Several studies highlight that limited accessibility to public transport remains one of the primary barriers to mobility for these categories (Dadashzadeh et al., 2022; Pangbourne et al., 2020). In this context, autonomous shuttles can provide a concrete alternative by addressing the last-mile connectivity issue, reducing the need for extended walking distances, and offering a more inclusive transport option. Moreover, the absence of architectural barriers and the possibility of on-demand services could further improve the travel experience for users with specific needs.
To the authors' knowledge, several studies have analyzed the impact of autonomous vehicles on the lives of people with special needs (Kassens-Noor et al., 2021; Hwang et al., 2020; Chan, 2017), but very few have investigated the benefits of autonomous shuttles for vulnerable user groups, which is the main focus of this study.

3. Methodology and data collection

This study examines the fare-free autonomous shuttle service operating in Esch-sur-Alzette, Luxembourg. Launched in 2021 by the company Sales-Lentz in collaboration with the local municipality, this pilot project utilizes a Navya-operated shuttle along the main pedestrian street in the city center, covering a 1.2 km route. The vehicle operates at low speed and is designed to ensure safe, accessible, and environmentally friendly transport, especially for short-distance trips. On average, the service carries around 100 passengers per day, reflecting a consistent level of local usage.
This service, initiated as part of a broader program (thanks to the EU-H2020 project AVENUE and the Esch22 European Cultural Capital initiative), aims to assess the potential of autonomous shuttles in enhancing urban transport accessibility and sustainability, including vulnerable groups such as people with reduced mobility. Studies such as the one presented in this paper are essential not only for testing the technical feasibility of autonomous mobility solutions but also for promoting and facilitating public acceptance and gain deeper understanding of the value of such services. In particular, they offer valuable insight into which user groups are most likely to adopt and benefit from these services. Furthermore, by collecting direct feedback from passengers, pilot projects like this provide important data for operators and decision-makers, helping them to improve service design, adapt operational strategies, and address users' needs more effectively.
To collect the data for this study, a structured questionnaire was developed and administered in December 2024. The survey was conducted in person, directly onboard the shuttle during its operation, allowing for real-time data collection from

passengers while they were actively engaged with the service. This method ensured higher response quality and reduced the risk of misinterpretation, as interviewers were present to assist respondents and clarify any uncertainties. The immediacy of the context also allowed for capturing users' spontaneous reactions, perceptions, and levels of satisfaction based on a direct and recent experience.
The survey is still ongoing. The results presented in this paper are based on a preliminary sample of 42 valid responses (approximately 50% of the average daily passengers). The findings provide relevant insights, particularly regarding the experiences and perceptions of vulnerable user groups such as elderly passengers and individuals with reduced mobility.

The questionnaire was divided into five sections:

- **Socioeconomic and personal data**: including gender, age, occupation, education level, and mobility impairments.
- **User satisfaction**: evaluating service features such as speed, onboard comfort, safety, the presence of a human supervisor, and the absence of a driver. A Likert scale was used, ranging from 1 (very dissatisfied) to 5 (very satisfied).
- **Perceived advantages and disadvantages**: Focusing on the impact of driverless technology, behavioral intentions, and user loyalty. A Likert scale was used, ranging from 1 (strongly disagree) to 5 (strongly agree).
- **Impact on public transport accessibility**: Assessing the shuttle's role in improving public transport access.
- **Future service features perceptions**: Exploring attitudes toward a fully autonomous shuttle service without onboard supervision and potential applications of on-demand mobility.

4. Result and Discussion

Preliminary findings from the data analysis reveal a particularly significant trend: autonomous shuttles have proven highly beneficial for elderly passengers and those with reduced mobility, confirming their potential in improving public transport accessibility for vulnerable categories. About 50% of respondents were over 60 years old, or reported mobility impairments, reinforcing the evidence that these services are particularly relevant for vulnerable user groups and highlighting the service's effectiveness in addressing the mobility needs of users who often face challenges in conventional transport systems. Furthermore, approximately 24% of the respondents reported experiencing mobility difficulties, and among them, over 70% described their condition as permanent. This indicates that the autonomous shuttle service is reaching and serving a segment of the population that typically faces persistent accessibility barriers, and which is often underrepresented in public transport planning. Such results further validate the inclusivity potential of autonomous mobility solutions in supporting vulnerable passengers.
Table 1 presents a summary of the key demographic and socioeconomic features of the respondents. A majority of users are women (55%), and 62% are aged over 40. Additionally, 50% of participants declared to be retired or currently unemployed, which further highlights the relevance of such services for non-working populations, who still maintain daily mobility needs.
The fact that a substantial share of users is not part of the active workforce but still choose to use the shuttle emphasizes its role beyond commuting, supporting essential activities such as shopping, health-related trips, and social participation. In this sense, autonomous shuttles may contribute to reducing inequalities in access to services and

opportunities, offering a convenient and equitable transport alternative for users who might otherwise experience isolation or restricted autonomy.
These early findings underscore the potential of autonomous shuttle services as a key strategy to enhance transport equity, especially by addressing the mobility needs of users who are often left at the margins of mainstream systems, particularly elderly, disabled, or otherwise vulnerable categories.

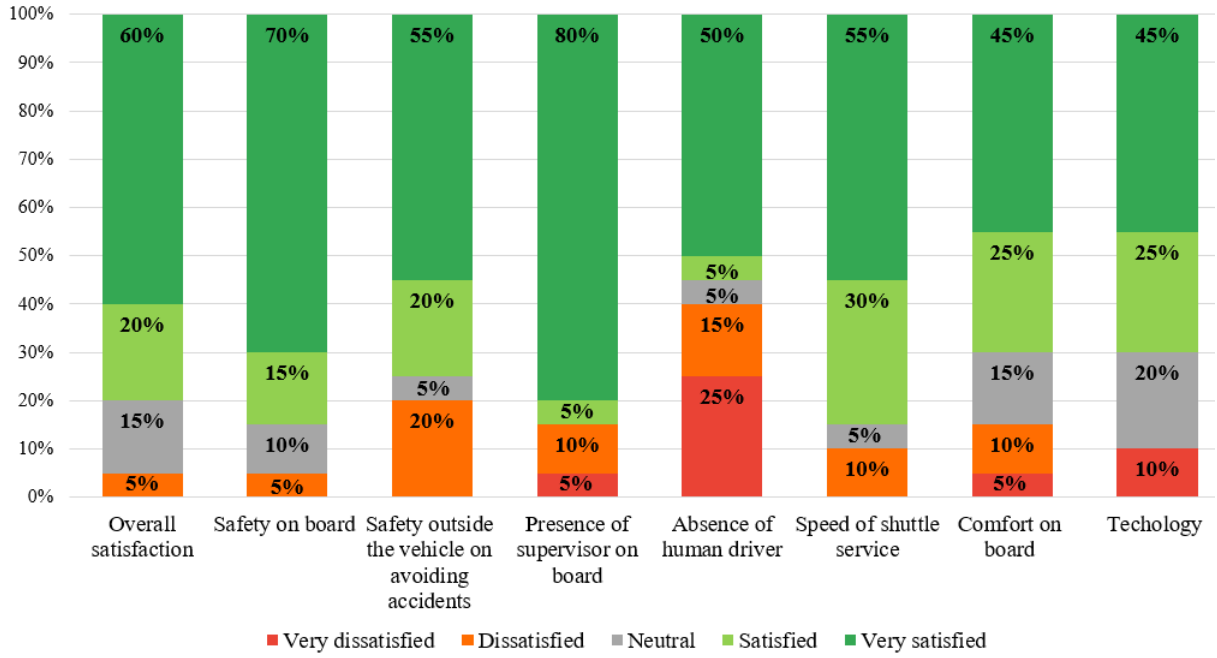
Table 1 : Survey results: socio-economic characteristics

Gender	
Male	38.10%
Female	54.76%
No-binary	2.38%
Prefer not to say	4.76%
Age	
Under 18 years	9.76%
18-29	12.20%
30-39	17.07%
40-49	14.63%
50-59	12.20%
60-70	9.76%
>70	24.38%
Main Activity	
Employed	36.84%
Student	13.16%
Unemployed/Pensioned	50.00%
Trip frequency	
Every day	21.43%
Occasionally (less than once a week)	33.33%
Several times a week	14.29%
This is my first time	30.95%
Presence of mobility limitations	
Yes	23.81%
No	76.19%
Total sample size	**100.00%**

Analyzing the **results for users over 60 or with reduced mobility**, a generally positive picture emerges: 80% of the respondents report being satisfied or very satisfied with the service provided. A particularly significant finding concerns the presence of a supervisor on board and the speed of the vehicle, aspects that were highly appreciated by 85% of the respondents in these categories (Figure 1). These results highlight the importance for the users of having a human figure on board, ready to offer assistance when needed, which is still perceived as essential by especially the vulnerable users. Confirming this, the lowest satisfaction levels were recorded for the

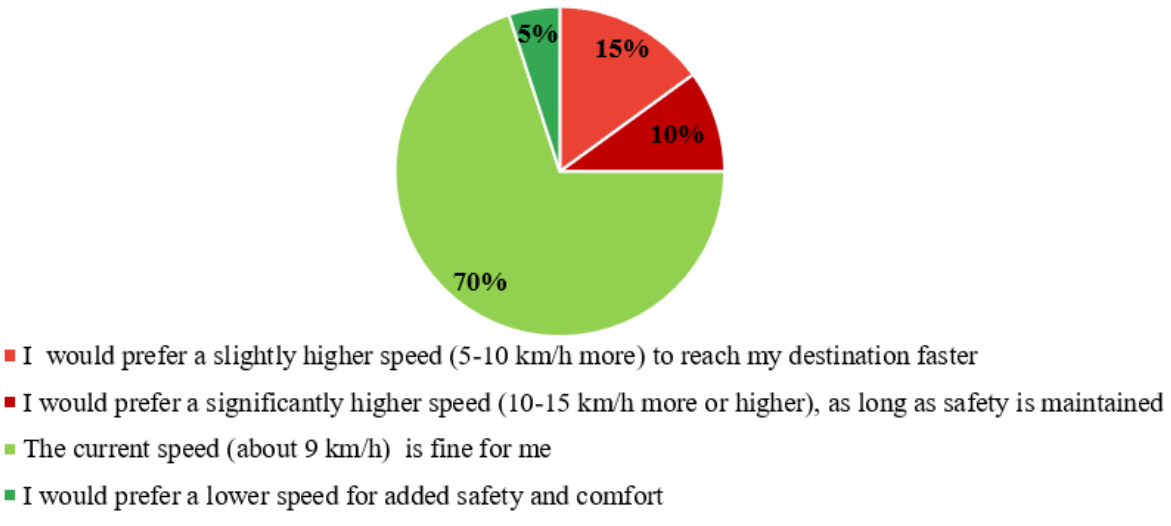
absence of a human driver, with only 55% of users in this group expressing satisfaction or high satisfaction with this feature.
Another interesting aspect concerns the perception of the speed of the autonomous shuttle. While a reduced speed is generally considered a limitation for autonomous shuttles in terms of competitiveness with other modes of public transport, for older users or those with reduced mobility, it represents an added value. A lower speed is indeed associated with greater safety and comfort, contributing to making the service more accessible and acceptable, and increasing its usage.

Figure 1 : Examples of results: level of satisfaction for users over 60 or with reduced mobility



The satisfaction with the relatively low speed of the autonomous shuttle, as reported earlier, is further confirmed by the results of the specific question regarding the shuttle's speed (Figure 2).

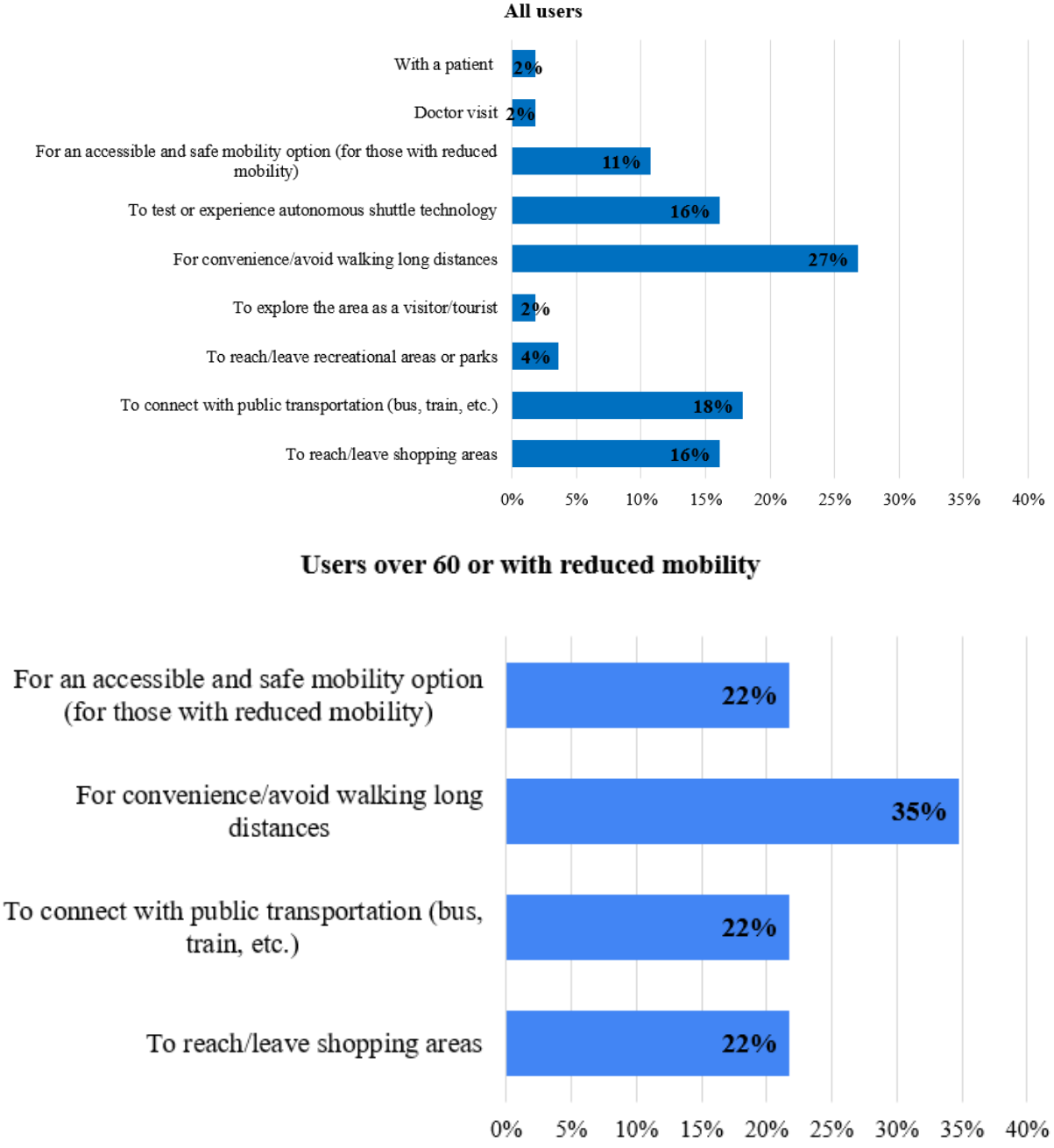
Figure 2 : Examples of results: opinion about the shuttle speed for users over 60 or with reduced mobility



As many as 70% of users aged over 60 or reporting to have reduced mobility report preferring the current speed, reinforcing the perception that a lower speed is seen as a positive feature for these categories. An additional 5% of respondents would even prefer a lower speed, while only 25% express a preference for a higher speed. This finding aligns with the general perception, already highlighted, that a reduced speed enhances safety, comfort, and accessibility, making the service more suitable for the needs of this user group.

These findings highlight one more time the critical role autonomous shuttles play for more vulnerable users, such as the elderly and people with mobility impairments. For these categories, the autonomous shuttle is not just a mode of transport but a valuable resource that allows them to navigate through crowded areas, such as shopping districts, with less stress and effort. Moreover, it improves accessibility to public transport, promoting greater social inclusion and more equitable mobility, especially in contexts where other transportation options may be less accessible or feasible.

Figure 3 : Examples of results: Reasons for Using the Autonomous Shuttle, all users vs users over 60 or with reduced mobility



A large majority of all respondents agree that autonomous shuttle services can be a valuable mobility solution for individuals who are unable to drive, such as the elderly or persons with disabilities: 80% either agree or strongly agree with this statement (Figure 4). Similarly, 80% believe that autonomous shuttles help them reach their destination more comfortably, reinforcing their role in providing accessible and user-friendly transport. Moreover, 75% agree that autonomous shuttles represent a useful extension of the current public transport system, suggesting that the service is not only appreciated for individual convenience, but also seen as a meaningful part of a broader mobility strategy. Finally, 75% of these users consider the shuttle useful for their daily travel needs, confirming that its practical role goes beyond occasional use. These findings align with previous results showing that the shuttle is particularly appreciated by elderly and mobility-impaired users for its comfort, low speed, and ability to improve access to public transport and commercial areas.

Figure 4 : Examples of results: Perceived relative advantages for users over 60 or with reduced mobility

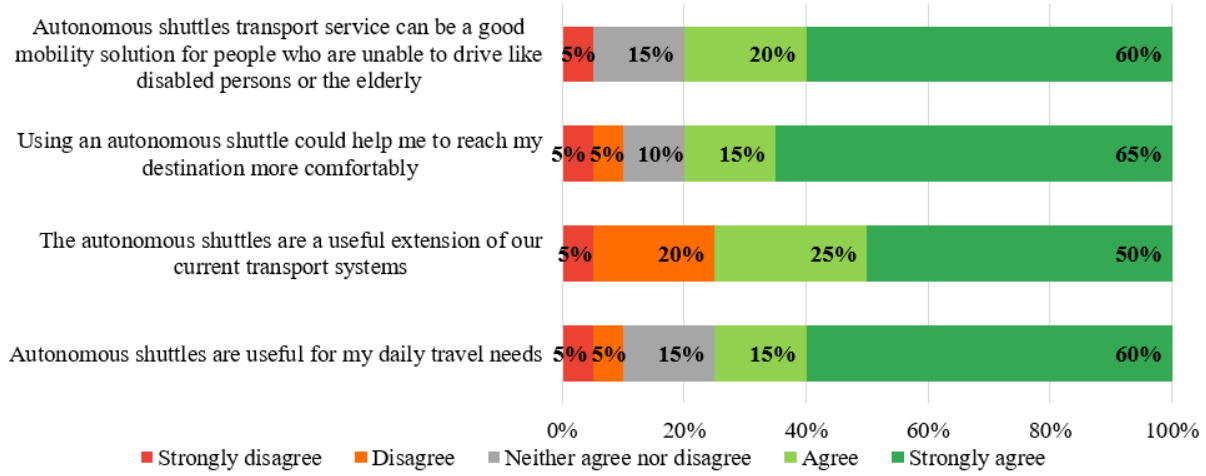
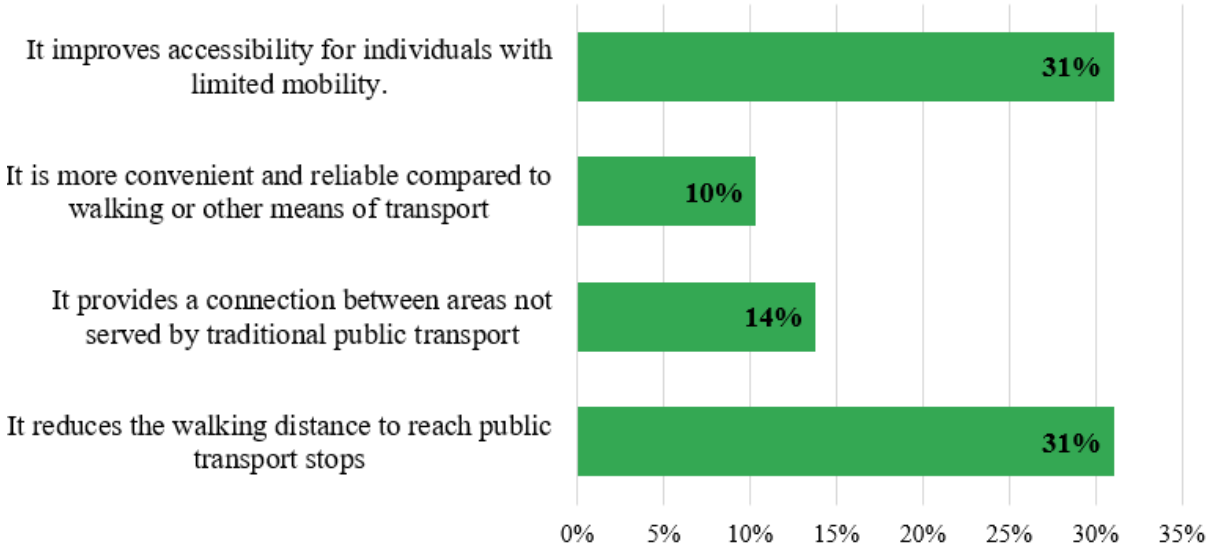


Figure 5 : Examples of results: Reason the autonomous shuttle service improves accessibility to public transport for users over 60 or with reduced mobility



Additionally, 90% of users over 60 or with reduced mobility report that the shuttle significantly contributes to improving public transport accessibility. In particular, 31% appreciate its role in reducing the walking distance required to reach bus or train stops, an aspect especially relevant in urban areas where long walking segments can represent a barrier. Another 31% highlight its importance in supporting individuals with limited mobility, for whom navigating the pedestrian area independently can be challenging. Furthermore, 14% of respondents recognize the shuttle's role in bridging gaps between areas not served by traditional public transport, thus enhancing network connectivity. A smaller share (10%) considers the shuttle more convenient and reliable than walking or using other available transport modes (Figure 5). These results confirm the shuttle's function as a complementary and inclusive mobility option, especially for those facing physical or accessibility limitations.

5. Conclusion

The preliminary results in this study indicate that autonomous shuttles are not only an innovative transport solution but also a technology for enhancing social inclusion in public mobility. The significant presence of elderly passengers and individuals with reduced mobility among users reflects the ability of these services to meet specific accessibility demands.

Integrating autonomous shuttles into public transport networks represents a promising strategy for promoting more inclusive and sustainable mobility. The collected data indicate that such services not only address the specific needs of vulnerable populations but also contribute to reshaping public transport with a greater focus on equity and accessibility.

This study highlights the need to consider the distinct perspectives of different user groups in the future design, and implementation of autonomous shuttles. The inclusivity of this study, spanning different age groups and disabilities, provides valuable insights for all autonomous shuttle stakeholders, including policymakers, manufacturers, and service providers. These findings emphasize the importance of integrating inclusive strategies into the design, and deployment of autonomous shuttles to ensure they are accessible and beneficial to all potential users.

In the context of growing attention to sustainability and social inclusion, autonomous shuttles emerge as a key enabler for improving quality of life by expanding mobility opportunities for all, particularly for those often excluded from traditional urban transport systems.

However, it is important to acknowledge that the findings presented in this study are based on a relatively limited sample size and on a specific service. As data collection is still ongoing, future developments will focus on expanding the user base to strengthen the robustness and reliability of the results. A larger and more diverse sample will allow for deeper insights and more comprehensive conclusions on user perceptions, needs, and expectations related to autonomous shuttle services. Moreover, future steps will include collecting data from other autonomous shuttles operating in different environments.

Bibliography

Acheampong, R. A., Cugurullo, F., Gueriau, M., & Dusparic, I. (2021). Can autonomous vehicles enable sustainable mobility in future cities? Insights and policy challenges from user preferences over different urban transport options. Cities, 112, 103134.

Anund, A., Ludovic, R., Caroleo, B., Hardestam, H., Dahlman, A., Skogsmo, I., ... & Arnone, M. (2022). Lessons learned from setting up a demonstration site with autonomous shuttle operation–based on experience from three cities in Europe. Journal of Urban Mobility, 2, 100021.

Becker, F., & Axhausen, K. W. (2017). Literature review on surveys investigating the acceptance of automated vehicles. Transportation, 44(6), 1293-1306.

Bennett, R., & Vijaygopal, R. (2024). Exploring mobility and transportation technology futures for people with ambulatory disabilities: A science fiction prototype. Technovation, 133, 103001.

Cartenì, A., (2020). The acceptability value of autonomous vehicles: A quantitative analysis of the willingness to pay for shared autonomous vehicles (SAVs) mobility services. Transportation Research Interdisciplinary Perspectives, 8, 100224.

Cascetta, E., Cartenì, A., & Di Francesco, L. (2022). Do autonomous vehicles drive like humans? A Turing approach and an application to SAE automation Level 2 cars. Transportation research part C: emerging technologies, 134, 103499.

Chan, C. Y. (2017). Advancements, prospects, and impacts of automated driving systems. International journal of transportation science and technology, 6(3), 208-216.

Classen, S., Sisiopiku, V., Mason, J. R., Stetten, N. E., Hwangbo, S. W., Kwan, J., & Yang, W. (2023). Barriers and facilitators of people with and without disabilities before and after autonomous shuttle exposure. Future transportation, 3(2), 791-807.

Claypool, H., Bin-Nun, A., & Gerlach, J. (2017). The Ruderman White Paper–Self-Driving Cars: The Impact on People With Disabilities. Ruderman Family Foundation; Securing America's Future Energy.

Dadashzadeh, N., Woods, L., Ouelhadj, D., Thomopoulos, N., Kamargianni, M., & Antoniou, C. (2022). Mobility as a Service Inclusion Index (MaaSINI): Evaluation of inclusivity in MaaS systems and policy recommendations. Transport policy, 127, 191-202.

De Paepe, L., Van Acker, V., Witlox, F., (2023). To Share or Not to Share, by Whom Is the Question. Acceptability and Acceptance of Shared Transport Services by Vulnerable Groups. Transport Reviews.

Dianin, A., & Cavallaro, F. (2019). Automation and urban transport planning: policy recommendations and best practices. WIT Transactions on Ecology and the Environment, 627-638.

Golbabaei, F., Dwyer, J., Gomez, R., Peterson, A., Cocks, K., Bubke, A., & Paz, A. (2024). Enabling mobility and inclusion: Designing accessible autonomous vehicles for people with disabilities. Cities, 154, 105333.

Golbabaei, F., Yigitcanlar, T., Paz, A., & Bunker, J. (2022). Understanding Autonomous Shuttle Adoption Intention: Predictive Power of Pre-Trial Perceptions and Attitudes. Sensors, 22(23), 9193.

Gurumurthy, K. M., Kockelman, K. M., & Zuniga-Garcia, N. (2020). First-mile-last-mile collector-distributor system using shared autonomous mobility. Transportation Research Record, 2674(10), 638-647.

Hwang, J., Li, W., Stough, L., Lee, C., & Turnbull, K. (2020). A focus group study on the potential of autonomous vehicles as a viable transportation option: Perspectives from people with disabilities and public transit agencies. Transportation research part F: traffic psychology and behaviour, 70, 260-274.

Hwangbo, S. W., Stetten, N. E., Wandenkolk, I. C., Li, Y., & Classen, S. (2024). Lived Experiences of People with and without Disabilities across the Lifespan on Autonomous Shuttles. Future Transportation, 4(1), 27-45.

Kassens-Noor, E., Cai, M., Kotval-Karamchandani, Z., & Decaminada, T. (2021). Autonomous vehicles and mobility for people with special needs. Transportation research part A: policy and practice, 150, 385-397.

Nesheli, M. M., Li, L., Palm, M., & Shalaby, A. (2021). Driverless shuttle pilots: Lessons for automated transit technology deployment. Case studies on transport policy, 9(2), 723-742.

Nordhoff, S., Malmsten, V., van Arem, B., Liu, P., & Happee, R. (2021). A structural equation modeling approach for the acceptance of driverless automated shuttles based on constructs from the Unified Theory of Acceptance and Use of Technology and the Diffusion of Innovation Theory. Transportation research part F: traffic psychology and behaviour, 78, 58-73.

Nordhoff, S., de Winter, J., Madigan, R., Merat, N., van Arem, B., & Happee, R. (2018). User acceptance of automated shuttles in Berlin-Schöneberg: A questionnaire study. Transportation Research Part F: Traffic Psychology and Behaviour, 58, 843-854.

Pangbourne, K., Mladenović, M. N., Stead, D., & Milakis, D. (2020). Questioning mobility as a service: Unanticipated implications for society and governance. Transportation research part A: policy and practice, 131, 35-49.

Petrović, Đ., Mijailović, R. M., & Pešić, D. (2022). Persons with physical disabilities and autonomous vehicles: The perspective of the driving status. Transportation research part A: policy and practice, 164, 98-110.

Rehrl, K., & Zankl, C. (2018). Digibus: results from the first self-driving shuttle trial on a public road in Austria. European Transport Research Review, 10, 1-11.

Richter, M. A., Hagenmaier, M., Bandte, O., Parida, V., & Wincent, J. (2022). Smart cities, urban mobility and autonomous vehicles: How different cities needs different sustainable investment strategies. Technological Forecasting and Social Change, 184, 121857.

Rosell, J., & Allen, J. (2020). Test-riding the driverless bus: Determinants of satisfaction and reuse intention in eight test-track locations. Transportation Research Part A: Policy and Practice, 140, 166-189.

Salonen, A. O., & Haavisto, N. (2019). Towards autonomous transportation. Passengers' experiences, perceptions and feelings in a driverless shuttle bus in Finland. Sustainability, 11(3), 588.

Santhanakrishnan, N., Emmanouil, C., Antoniou, C., (2020). Shared autonomous vehicle services: a comprehensive review. Transportation Research Part C: Emerging Technologies 111, 255–293.

Shladover, S. E., & Nowakowski, C. (2019). Regulatory challenges for road vehicle automation: Lessons from the California experience. Transportation research part A: policy and practice, 122, 125-133.

Stocker, A., Shaheen, S., (2018). Shared automated vehicle (SAV) pilots and automated vehicle policy in the U.S.: Current and future developments. In: Meyer, G., Beiker, S. (Eds.), Road Vehicle Automation 5. 143, pp. 131–147 Cham: Springer. Lecture Notes in Mobility.