Sohjoa Baltic
The Roadmap to Automated
Electric Shuttles in Public Transport

User Experience and Impact on Public Transport

Sami Mäkinen, Tommi Kantala, Taina Haapamäki, Janne Olin, Milla Åman Kyyrö (eds.)

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Publisher: Metropolia University of Applied Sciences

Editors:

Sami Mäkinen, FLOU Solutions Ltd.
sami.makinen@flou.io
+358 40 529 6434

Taina Haapamäki, FLOU Solutions Ltd.
taina.haapamaki@flou.io

Tommi Kantala, FLOU Solutions Ltd.
tommi.kantala@flou.io

Janne Olin, Forum Virium Helsinki
janne.olin@forumvirium.fi

Milla Åman Kyyrö
milla.amankyyro@metropolia.fi

Authors:
- FLOU ltd (Finland)
- Forum Virium Helsinki (Finland)
- City of Gdańsk (Poland)
- Chalmers University of Technology (Sweden)
- Finnish Transport and Communication Agency Traficom (Finland)
- IKEM (Germany)
- Kongsberg Municipality (Norway)
- Metropolia University of Applied Sciences (Finland)
- Tallinn University of Technology (Estonia)
- Tallinn Transport Department (Estonia)
- Vejle Municipality (Denmark)
- Zemgale Planning Region (Latvia)

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This publication has been made in the Sohjoa Baltic project (2017-2020) funded by Interreg Baltic Sea Region Programme. The aim of the project was to bring knowledge and competence on organizing environmentally friendly and smart automated public transport, provides guidelines on legal and organizational setup needed for running such a service in an efficient way.

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Foreword

In this volume we examine the potential implementation of automated shuttles in the public transport network, and possible interactions with other public transport modes.

This volume is intended for decision-makers and organizations planning to adapt or pilot automated shuttle buses, especially as a part of the existing public transport system. The volume concentrates on requirements by end users and public transport authorities, followed by derived technological requirements necessary for fulfilling the user needs. The practical guide is divided into three sections:

- User requirements
- Technological requirements
- Implementation of automated public transport.

The volume aims to aid piloting and implementing automated shuttles in the public transport sector in the short time frame of 2020 – 2025. Prospects and possible impacts are forecasted for a longer time frame as the technology is rapidly evolving and most of the more promising applications will not realize in the shorter time frame. The projected future scenarios are essential to aid the short-term decision-making.

The volume provides practical advice and recommendations from practice for practice.

"What did we learn about passenger experience and acceptance from the pilot?"

"What are the user and technology requirements for using automated shuttle buses in real world applications?"

About Sohjoa Baltic

The Sohjoa Baltic project developed the knowledge and competences required to organise environmentally friendly and smart automated public transport through research, promotion and piloting automated driverless electric minibuses as part of the public transport chain, especially for the first/last mile connectivity. It also provides guidelines on the legal and organisational frameworks needed to operate a service of this kind in an efficient way. The Sohjoa Baltic consortium comprises partners from Finland, Estonia, Sweden, Latvia, Germany, Poland, Norway and Denmark with knowhow in transportation planning as well as legal expertise combined with a strong technical understanding.

With a run time from 10/2017 until 09/2020, the Sohjoa Baltic project was funded by the Interreg – Baltic Sea Region programme.

Executive Summary

This is the fifth volume in the “Sohjoa Baltic - The Roadmap to Automated Electric Shuttles in Public Transport” publication series, named “User Experience and Impact on Public Transport”, and it is targeted at persons or organizations planning automated shuttle bus pilots or commercial implementation. Automation of public transport is a disruptive phenomenon, which has the potential to dramatically change the public transport offering and cost structure. The applications for automated shuttle buses in the short-term future are complements for existing services, improving service levels. For the technology to be suitable for more disruptive applications, it needs to mature further. Various stakeholders pose a multitude of requirements for automated shuttle buses; these need to be fulfilled in order to take the technology into wide-scale use.

In the project, pilot cities’ officials were asked to identify priorities for improving public transport. Highest priority was set for enhancing flexibility and responsivity to demand, reduce operational costs, acquire new users, increase passenger service level, improve punctuality, and cut capital costs. Surveys also show that personnel represent the main cost category and a major contributor for disruption in public transport. During the pilots, a user experience survey was organized for the passengers. User experience as well as passenger and traffic safety received high grades in all four completed pilots, indicating high acceptance for automated shuttle buses by end users. The pilots also revealed some necessary improvements – passengers would for example like the buses to have more seats, more room and higher speed. Further, braking maneuvers of the bus were in some cases perceived as too aggressive, causing discomfort for passengers.

A number of technological requirements for automated shuttle buses can be derived from the user requirements. Currently, automated shuttle buses have a very limited degree of independence, and they struggle to operate smoothly in dynamic environments. Advancements in sensors, resilience, speed, traffic behavior and security are needed to fully utilize their potential.

Based on the above-mentioned requirements and limitations, there are potential use cases for automated shuttle buses. With the current maturity of automated shuttle buses and self-driving technology, first commercial applications territories for automated buses are likely to be in large closed areas, such as hospital environments, university campuses, or industrial parks. Automated shuttle buses are a promising solution for first/last mile public transport, which is difficult to provide cost-effectively with current solutions. Automated shuttle buses could form feeder lines for trunk lines. It is unlikely that automated shuttle buses could replace other modes in most scenarios due to low capacity and high capital costs. Low demand areas pose certain potential for automated shuttle buses to replace traditional bus lines and provide better service. Also, service level outside the rush hours can be expected to increase, as the public transport operators have incentive to increase operating hours to reduce unit costs for operation. In the future, automated shuttle buses could be used to provide on-demand door-to-station or door-to-door (taxi) services, but with the current technology and pre-defined routes, such applications are not possible.

Cities and public transport operators who want to benefit from automated shuttle buses, are well advised to choose pilots as a starting point. Involvement of all stakeholders of the public transport system is crucial when planning pilots and commercial implementations. Automated shuttle buses will not solve all problems related to challenges in public transport, and planners and decision-makers should have realistic expectations when setting goals for automated shuttle bus applications.

I. User Requirements

"What are the requirements of cities and operators for automated shuttle buses?"

"What are the end user requirements and how is the current user acceptance?"

1. Criteria of implementation

Disruptive technologies have throughout history shaped the society in a myriad of ways only few expected – positive as well as negative. While predicting implications of a certain technology comprehensively is near impossible, it does not make the effort less vital. By examining alternative future scenarios, it is possible to divert from certain unwanted paths. The ways the technology will be utilized are not fixed and should not be treated as an inevitability, but rather as a conscious decision made by decision-makers. This thought pattern allows us to steer the development – to set the goals to be achieved and the criteria that must be met.

Criteria are standards to be met for the services to become viable. They help in the planning process and can be used to guide implementation of the technology. Certain criteria, such as resource efficiency, safety, reliability, transport system effects, user experience, and environmental impact, can be identified from the current state of practice of transport planning. However, it is reasonable to question whether the current guidelines are sufficient for steering the implementation of a technology whose implications are not fully understood.

Criteria are often complex entities that may be difficult to comprehend completely, and even more challenging to include in planning. For example, safety in public transport is not only the number of traffic accidents but also the social dimensions of safety as well as the perceived experience of safety. The importance of the latter two is likely to increase with the automation of transport, as removing the driver changes the dynamics of traveling on public transport. Moreover, the criteria may be interconnected and placing emphasis on one criterion may have a positive or negative effect on another. For example, developing accessibility solutions for driverless services may enhance the overall user experience but simultaneously increase capital costs. Therefore, planners should have a clear understanding of the priorities when designing these services.

It is intuitive to associate the criteria for the implementation with the operation of a service, but this is incomplete. The broader societal implications may not be distinctly visible in the every-day operation, but they must be considered in the planning regardless. For example, where the services take place is a question of social equity. Unlike most current collective transport services, early implementations of automated shuttle bus services will likely serve only one neighbourhood or postal code area at a time. Therefore, all capital and operative investments towards the use of automated transport, are made into that area. Considering that areas differ in terms of income and other socio-demographic factors, capital-heavy investments benefitting only few people could be seen as unjust. This problem requires consideration, especially in the early stages of automation when the technology is still expensive compared to conventional public transport vehicles.

In a broader context, the same question of equitable distribution of benefits and burdens can be extended beyond the spatial dimension. Currently, the most widely acknowledged downside of automated public transport is the risk of worsening accessibility for people with physical disabilities. As a service person is displaced from the vehicle, it is apparent that even equipping a shuttle bus with a wheelchair ramp, braille inscriptions, and audio-visual notifications does not render the service as accessible as the current services with an operator on board. Additionally, automated services may introduce new barriers that exclude other social groups, regardless of their physical abilities. These barriers may relate to fear, mistrust, cost, technological accessibility, or a variety of other factors.

These speculations illustrate how the conventional criteria of transport service evaluation, and their relative importance, might be deemed insufficient as they are examined in contrast to the anticipated implications of transport automation. The question is then: what are the right criteria? Scientific research offers insight on the matter, and it is of highest importance, that the cities, public authorities, and developers identify these criteria and incorporate them into the planning of the services. Pilots offer a great platform for this criteria identification process. However, most pilots, so far, have concentrated on collecting user-data on site. Although surveying user feedback is of vital importance, it is also a very limited way of developing the services. Hence, it would be beneficial to include stakeholders, special interest groups, experts, and the public into the planning of future pilots, and eventually the services, from the very start.

2. Pilot site survey

As part of the Sohjoa Baltic project, a survey was conducted aiming to study city officials' wishes regarding automated public transport. The survey was completed before the pilots began and received seven answers: one from each pilot city and two from the Zemgale region.

The respondents were able to identify the priority of various goals on a scale of 1 (lowest) to 5 (highest). Improved flexibility and responsivity to demand changes was the number 1 goal, closely followed by reduced operational costs. Increasing capacity of feeding lines, trunk lines or increasing capacity at peak hours received lowest priorities. A more detailed overview of the scores the various suggested improvements received is shown in Figure 1.

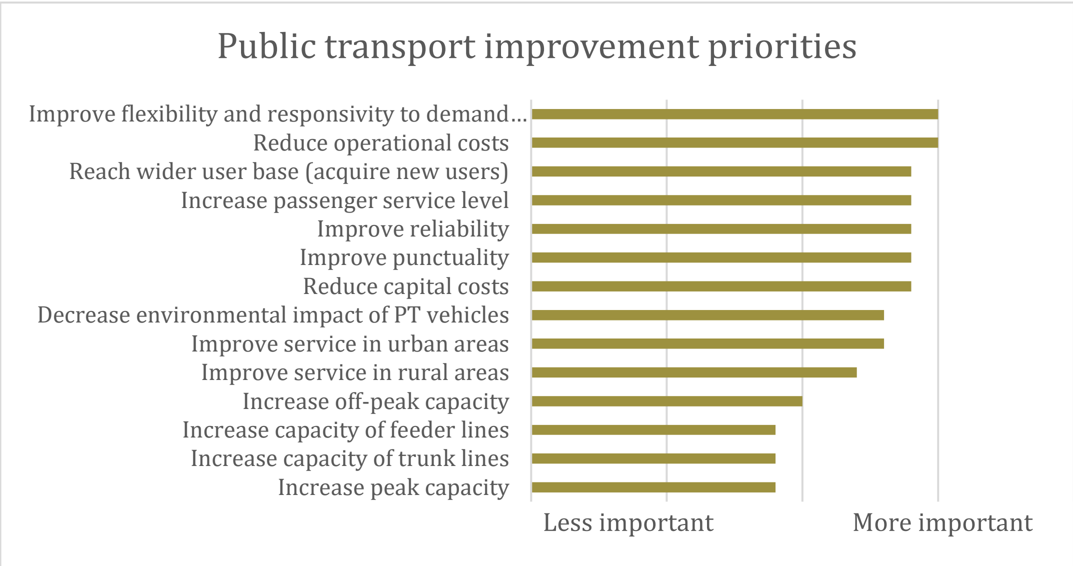


Figure 1. Importance of various possible improvements to the public transport system.

Automated electric shuttle busses are expected to result in cost savings compared to the current vehicle fleet in the long term. The savings are predicted to arise from reduced personnel costs by removing the driver from every vehicle and by reduced energy costs though the transition to electric vehicles. Impact on maintenance and other costs are still unrevealed. The large number of sensors and other vital equipment of automated vehicles combined with smaller vehicles and larger fleet size can be expected to increase maintenance cost.

Survey participants were asked to estimate the distribution of operating costs of current public transport in four categories: energy, personnel, maintenance, and other. According to the survey results, personnel costs represent the largest individual cost category on average but with considerable differences between the responses. Personnel costs were estimated to range from 25-60 % of all operating costs. Vehicle size has a significant influence on personnel costs, where smaller vehicles generate higher personnel costs to achieve the same capacity. For this reason, services currently provided by small shuttles cause higher than average personnel costs and may benefit from automation more than other modes. The division of operational costs as surveyed in shown in Figure 2.

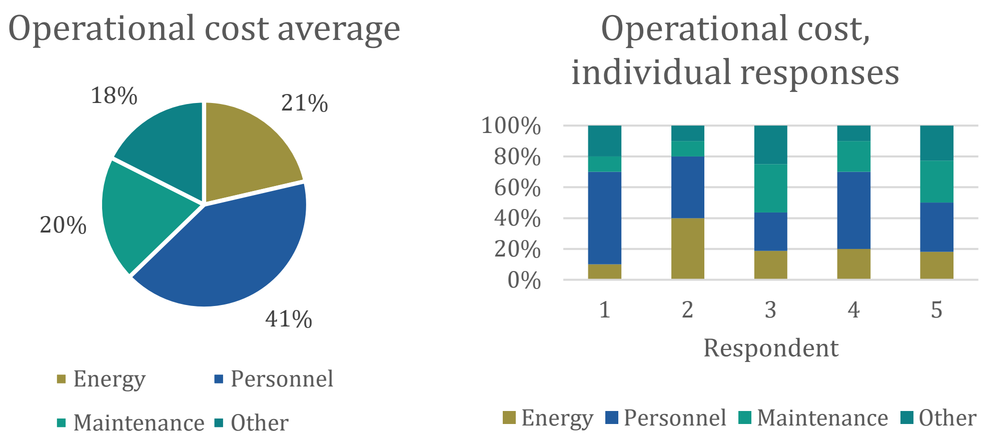


Figure 2. Division of operational costs as estimated by the respondents to the pilot site survey. The personnel cost is the largest individual cost component, but with significant variation between pilot sites.

Reliability is an essential requirement for functioning public transport. Delayed and missed departures negatively impact passenger experience and if repeated frequently, render public transport a less attractive option compared to other modes. Lack of reliability may increase the service providers' expenses due to extra fees charged for missed departures by the public transport authorities. Automation is expected to impact the reliability of the service. Enhanced complexity of the vehicles and numerous safety critical components in the system may increases the probability of equipment failures. On the other hand, reduced dependency on personnel and high repeatability of driving can improve other aspects of reliability. A more detailed breakdown of reasons for disruptions as reported by the respondents is shown in Figure 3.

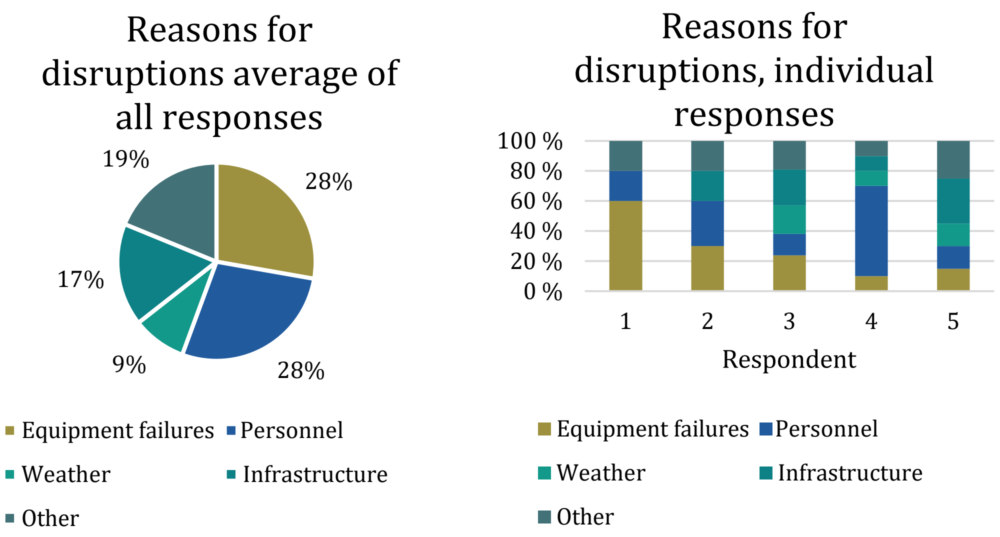


Figure 3. Reasons for disruptions in the public transport service as reported by the respondents to the pilot site survey.

3. Passenger Experience and Acceptance

A socially and economically feasible transport system must be attractive to users, and therefore better than the available alternatives in terms of passenger comfort, accessibility, safety, cost, area coverage, and travel times.

a) Passenger experience survey

Several distinct aspects of user experience and public acceptance in automated transportation were studied during the Sohjoa Baltic project. User experience surveys were conducted in the pilot cities Gdansk, Helsinki, Kongsberg, and Tallinn and 837 responses were collected. The overall experience in all cities was very positive, as seen in Figure 4. In all cities, score 5 (maximum) was given most frequently while lowest scores were rare.

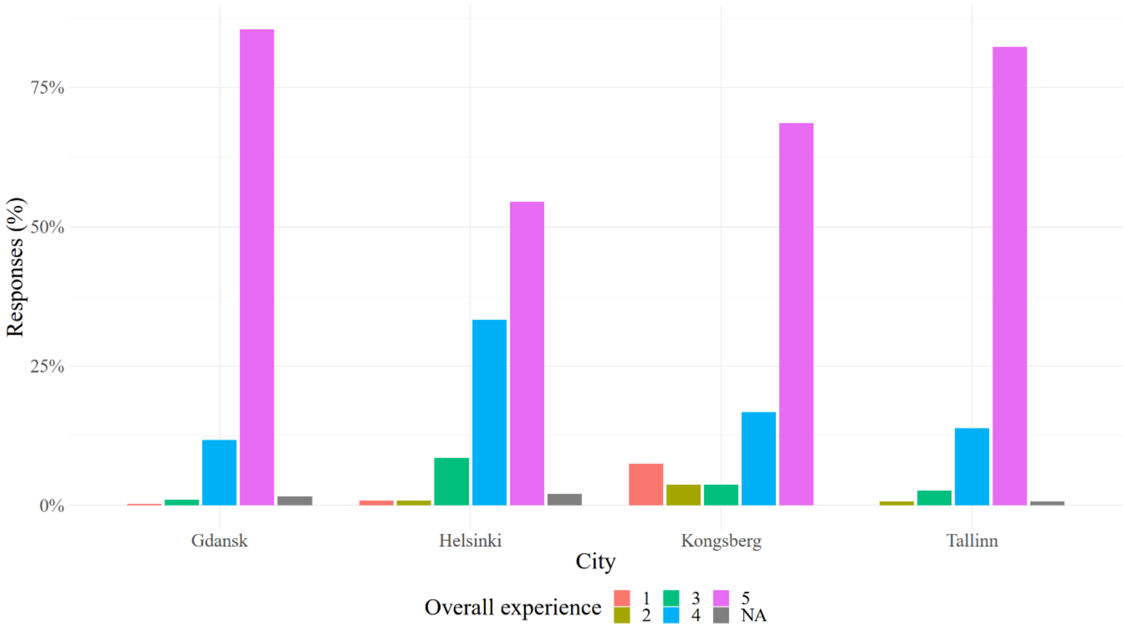


Figure 4. Distribution of overall experience rating in four pilot cities.

A key aspect of user experience is the smoothness of the ride. In Sohjoa Baltic pilots, participants commented that shuttle bus speeds should be higher. The average speed in many pilot sites was around 10 to 15 km/h between stops (Torabi et al. 2020). Even in urban settings, the average speed was quite low, which reduced the appeal of the automated shuttle bus over other modes of transportation. When users choose an automated shuttle bus, they expect their journey to progress faster. Thus, the average speed of the automated shuttle buses should be improved in order to reach wider acceptance as part of the public transport system.

Increasing the speed however does raise another issue. Several passengers commented that braking maneuvers of the automated shuttle bus were perceived as unpleasant. Firstly, the bus reacted too aggressively to minor objects in its field of view, such as falling leaves, thus reducing smoothness of the ride and lowering average speed. Secondly, the automated shuttle bus showed aggressive braking behavior, leading to an unpleasant experience for the passengers inside the vehicle. Various passengers even expressed that seat belts are a must have, in contrast to many other public transport vehicles where seat belts are not provided. The large open space in the automated shuttle bus did not provide passengers with support to hold on to in case of breaking. Still, most survey respondents rated the perceived personal security and traffic safety high in the pilots, as seen in Figure 5 and Figure 6, despite the highlighted drawbacks with speed and braking behavior.

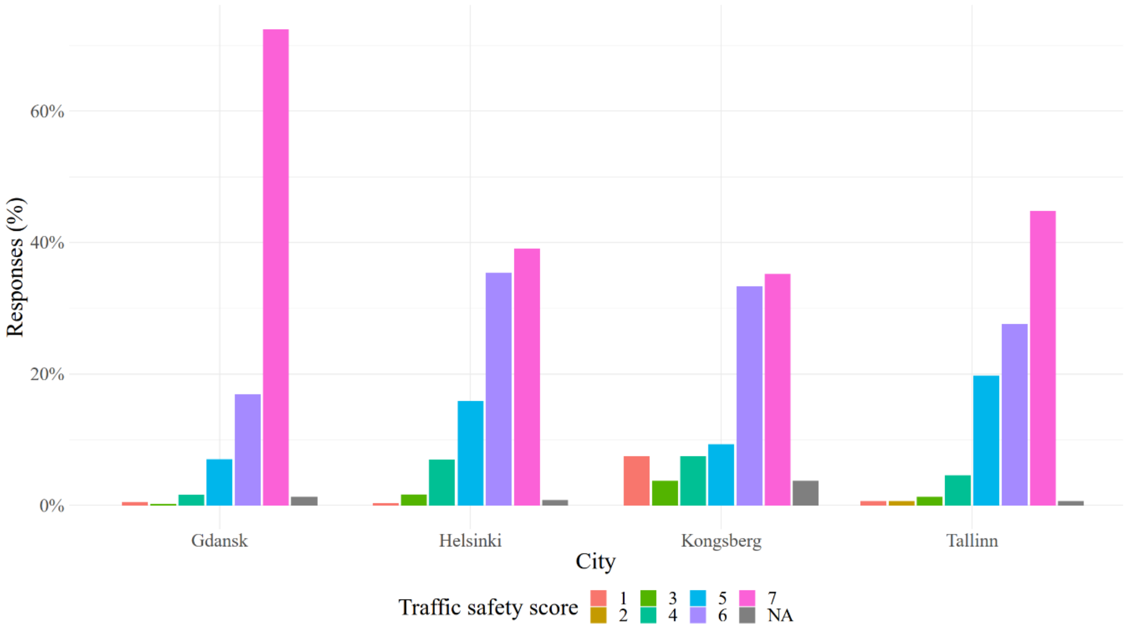


Figure 5. Distribution of traffic safety scores in four pilot cities.

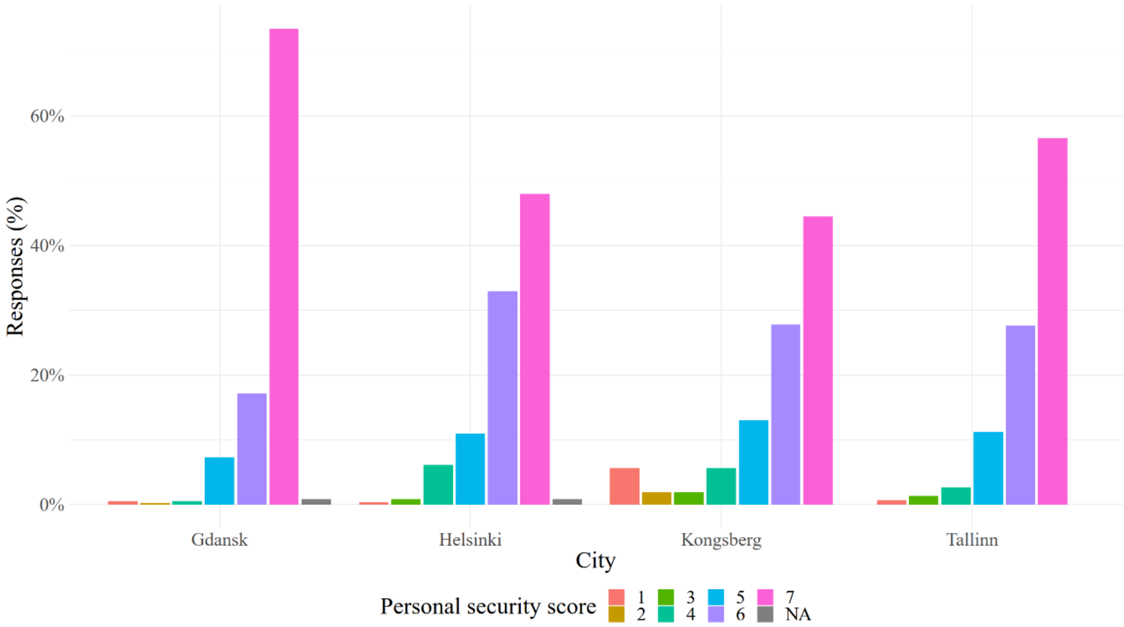


Figure 6. Distribution of personal security scores in four pilot cities.

Passengers also commented on the size of the automated shuttle bus in the pilot, expressing the wish for the vehicle to be larger and provide more seats and room in general. More passengers per vehicle could improve the feeling of personal safety. As there is no driver or operator on board, personal security may be lower than in other modes of public transport. Most respondents of the Sohjoa Baltic user experience survey expressed, that they would likely use a bus without an operator (there was an operator on board the pilot vehicle due to legal requirements), but some are hesitant as seen in Figure 7.

According the study, passenger acceptance of automated shuttle buses seems high, even though the technology is not fully mature. Perception of personal security may change, for example when services are provided during the night without an operator on board. This remains to be seen when automated public transport is used more widely.

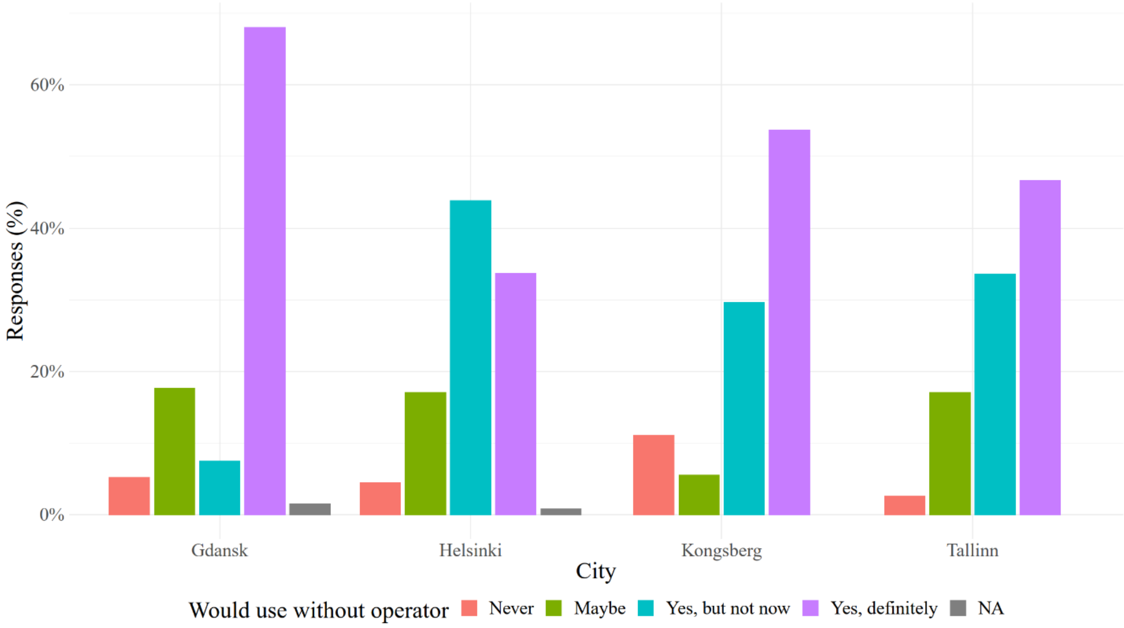


Figure 7. Distribution of answers whether passengers would use the automated shuttle without an operator in four pilot cities.

In Sohjoa Baltic pilots, passengers were asked whether the automated shuttle bus would be suitable as a school bus. While the responses show variation, as seen in Figure 8, most consider it suitable at least if children are attended and many (40-60% of responses) would allow children to use the automated shuttle bus alone for trips to and from school.

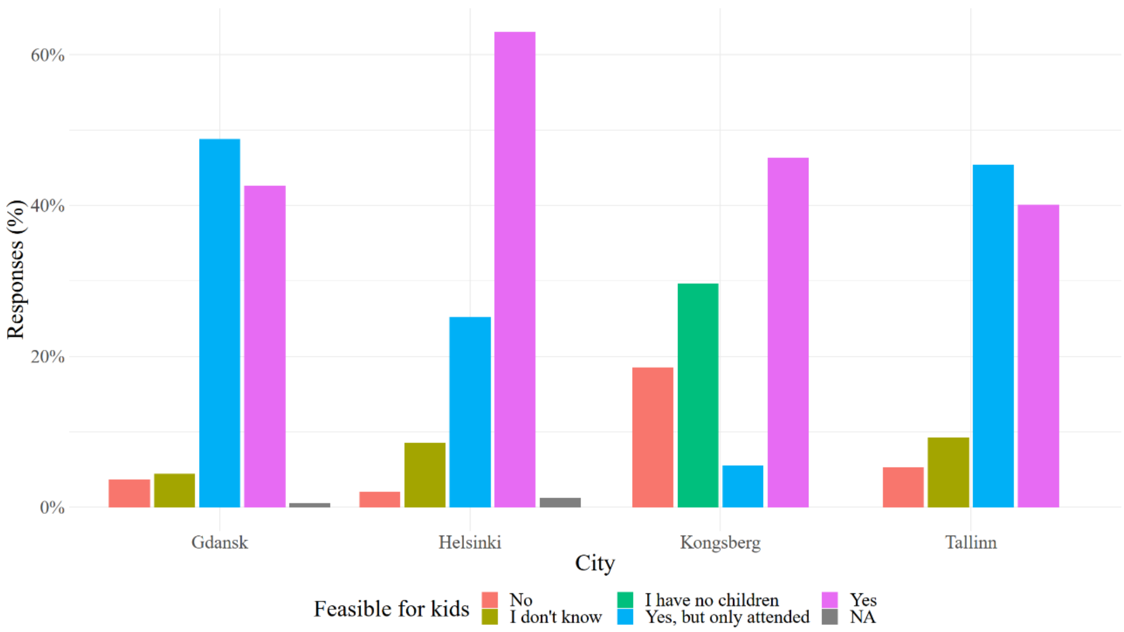


Figure 8. Share of responses for suitability of automated shuttle bus for school bus application in four pilot cities.

Passengers were given a multiple-choice question; in which cases they would be willing to use the automated shuttle bus. In each city, the responses were almost equally distributed between the given choices. In Helsinki, passengers were slightly less inclined to commute by automated shuttle, while in Kongsberg bad weather was seen to increase the foreseen usage of the automated vehicle, as shown in Figure 9. Naturally, the area and route where the bus operates affects the preference over other transport modes, such as walking.

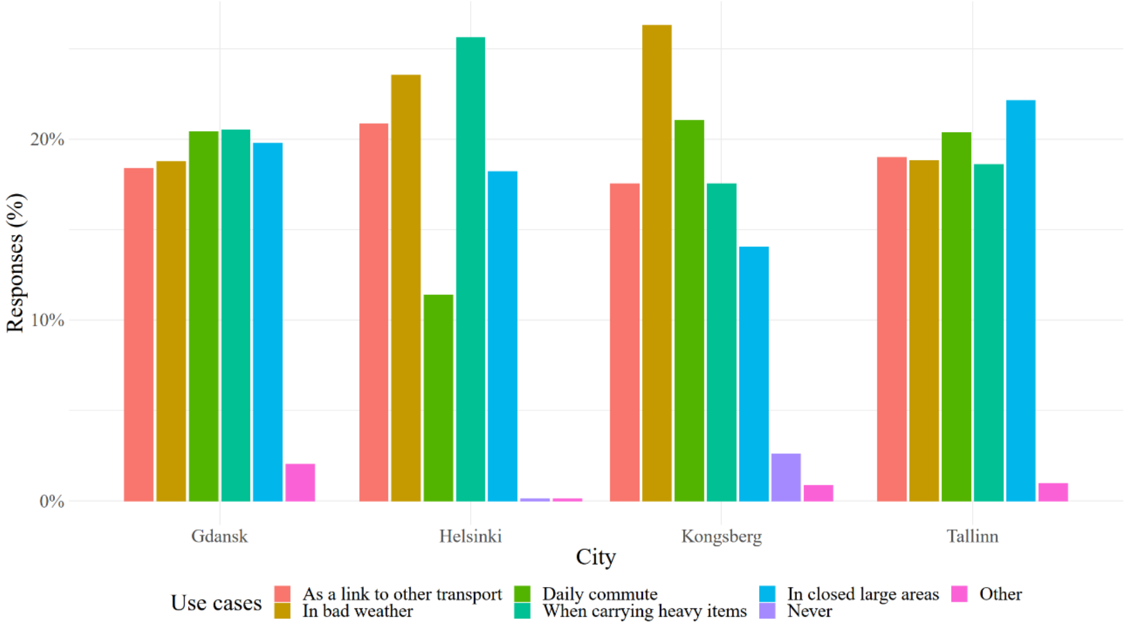


Figure 9. Distribution of responses for question regarding potential use cases in four pilot cities.

Key User Concerns

- Attractiveness
    - Passengers only choose automated shuttle buses over other modes of transportation if doing so increases comfort, shortens travel time, reduces monetary cost, or grants other tangible benefits. Automated shuttle buses need to be at least as comfortable as other alternatives to be chosen by passengers. Both passengers and operators expect the automated shuttle buses to be safe to use and reliable.

- Accessibility
    - Automated shuttle buses need to provide at least equal accessibility for vulnerable passenger groups, such as the elderly, people with disabilities, or children, compared to other modes of public transport. In an optimal scenario, automated shuttle buses enable service extensions to new user groups or new geographic areas.

- Better service coverage
    - Servicing more routes and more frequently is of interest for both operators and passengers. The hope is for automated shuttle buses to provide a cost-efficient way to serve both high-demand and low-demand areas.

- Cost-efficiency
    - Cities and public transport operators are hoping to find savings in both capital and operating expenses. Reducing the cost of public transport was ranked as one of the highest goals of using automated shuttles.

II. Technological Requirements

"How mature is the current automated shuttle bus technology?"

"What are the technological requirements for operating automated shuttle buses?"

1. Current State

Most automated buses currently rely on the global navigation satellite system (GNSS), lidars and high definition maps to navigate. Numerous sensors enable localizing the vehicle on a preprogrammed route, while steering input is continuously calculated to keep it moving forward on this route. The sensors also provide information about the vehicle's environment and other traffic, enabling the vehicle to avoid obstacles and follow traffic rules. Generally, the technology does not scale outside the programmed routes and the vehicle must be manually steered back on route if diverting too far for any reason. As such, the current approach is not easily applied to the more challenging on-demand and door-to-door services.

Other methods of self-driving technology are in development, offering a more scalable approach. These systems are mainly deploying cameras and computer vision to identify the drivable road surface, obstacles, road markings, traffic signs, traffic lights etc. This approach is more challenging compared to the system relying on preprogrammed routes.

As the technology is still strongly under development and production volumes are low, the cost of the vehicles is currently high. The cost of an automated shuttle is presently around 250 000 EUR for a 6-month lease (Rogers 2017). This may be a limiting factor for some use cases, as human-driven vehicles may be cheaper to operate. The cost is expected to drop significantly when the technology matures, and production volumes of various subcomponents as well as whole vehicles increase. Technology and regulations currently require a safety operator on-board the vehicles, largely negating the possible cost savings of driverless vehicles.

2. Technical Requirements

Probably the number one factor determining the general acceptance of automated public transport is safety. The vehicles must be safe for passengers and other road users alike in order to be generally accepted. The safety standards for emerging technologies are higher than for existing public transport vehicles. Any accident or injury involving automated public transport would entail a serious negative impact on the acceptance, even if the total accident rate is lower than for human driven vehicles. For that reason, public transport authorities or vehicle manufacturers are reluctant to take any risks regarding safety.

Aiming for superior safety standards does not come without cost. As discussed in Section I.3, passengers reported sudden braking maneuvers of the bus to render the ride feel unpleasant. The abrupt braking mainly has two causes: unreliable sensor data and the aggressive braking algorithm that avoids collisions with the environment at all cost. Today, even small objects, such as falling leaves trigger the sensors and thus the breaks of the automated shuttle bus.

In many cases, the automated shuttle buses operate in an open environment among other modes of transport: cars, buses, pedestrians, and cyclists. The low speed of the automated shuttle bus improves passenger safety, especially considering the open layout of the buses and aggressive braking behavior. This also helps pedestrians, as they gain more time to predict the movements of the vehicle. On the other hand, with the low average and top speeds seen in Sohjoa Baltic pilots, both cars and bicycles tend to drive faster than the automated vehicle, leading to overtakes. A cyclist overtaking the shuttle bus and immediately returning into the lane in front of the bus may potentially cause it to brake, leading to even lower average speeds by the bus and reducing its appeal even further.

Integration of the automated shuttle bus alongside other road users poses major technical requirements. As mentioned before, travel speed of the bus is one important aspect. The vehicle must be able to match the speed of the surrounding traffic flows. The movements of the buses need to be predictable to other road users. Integration with other modes of public transport is also important. The schedules and routes of automated shuttle buses should be designed such that other transport operations are not disrupted, especially when travel speeds and reliability of the shuttle bus may be initially lower. Integration does not end with the physical environment; the automated shuttle buses also need to integrate with public transport information systems and communicate wirelessly with other vehicles. When automated shuttle buses are being introduced to pilots or commercial applications, ensuring integration is vital.

Further, the technology of automated shuttle buses needs to develop further towards higher level of autonomy. Currently, automated vehicles follow preprogrammed virtual tracks and new routes must be implemented manually. Even minor changes and obstacles require human input before the bus can continue its route. For many applications, operation would need to adapt to rapidly changing environments to be feasibly integrated into existing systems. A solution could either be the use of remote control of the vehicle or a more advanced and sophisticated technology to handle possible events arising on the road.

Remote monitoring and operation of the vehicles is required to intervene if any issues rise with the vehicles or passengers. The passengers should also be provided with an easy and fast method of contacting a human operator any time needed. For a remote operator, the vehicle must provide high quality low latency video feed in- and outside of the vehicle, and two-way communication with the passengers. The number of required remote operators for a given size fleet is highly dependent on the reliability and level of automation of the vehicles. To be feasible, the vehicles must be able to automatically solve any issues in everyday traffic. The remaining cases should be virtually all be solvable using remote control and requiring physical presence only in very rare occurrences. The expected types of issues impact the required number of remote operators. The most critical factors being influence of external conditions e.g. adverse weather. A high number of stand-by operators is necessary if a likely change in an external factor could cause multiple vehicles to require assistance at the same time. If the causes of disruption are connected to a single vehicle or its immediate surroundings alone, the probability of multiple vehicles requiring simultaneous human intervention is greatly reduced and the number of operators can be lowered.

3. Future

The expectations for automated vehicles are incredibly high; stemming from the promises of tech-developers with financial interests in the industry, these expectations are further inflated by enthusiasts and activists alike. While significant improvements to the transport system are achievable with this technology in the long term, the short-term implementations will most likely play only a minor role in the transport system. Although the Sohjoa Baltic pilots have operated in relatively central city districts, it is unlikely that these will be the first actual areas of implementation. Achieving a sufficient level of safety, service, and cost efficiency at the early stages is challenging, and hence the first implementations will likely be realised in more isolated areas such as campuses of universities or companies, which can be served with a fleet of one or two vehicles.

A medium-term goal of operation could be to enhance connectivity of certain neighbourhoods to public transport. For this to become possible, the technology must advance significantly, and the operating costs must decrease.

When integrating automated shuttle buses into existing public transport, we encourage planners and decision-makers to thoroughly consider all technical requirements, some of which are listed below. The technical requirements depend heavily on the use case of automated shuttle buses, platforms used and systems the buses need to be integrated with and are as such of too complex nature to be listed exhaustively in this volume.

Key technological concerns

- Safety
    - The vehicles must be safe for the passengers and other road users. As a new mode, the safety requirements exceed those of the existing modes and any incidents involving automated shuttles can be expected to have large negative impact on the acceptance.
- Speed
    - Passengers generally select the route and mode based on the travel time. With insufficient average speed the automated shuttles are unable to provide competitive service and will at most replace use of active modes like walking and cycling. Speed is also limiting the length of a route that can be operated with the given number of vehicles and headway.
- Reliability
    - Reliability of the vehicles is crucial for operational public transport. Failures and missed departures will both negatively affect the passenger experience and increase the production cost of the service. Low reliability of the fleet will also increase the need of maintenance personnel and remote operators.
- Independency
    - Automated vehicles are expected to be more expensive to acquire than traditional vehicles in the foreseeable future. The fewer human operators are needed, the more the automated shuttle buses can reduce operational costs. Remote operators monitoring simultaneously multiple automated vehicles could be first step before autonomous driving technology matures more.

III. Implementation of Automated Public Transport

"What are the use cases for automated shuttle buses?"

"How do automated shuttle buses change public transport?"

1. Various Types of Public Transport

a) First/Last mile

The first and the last kilometer of a trip are the most challenging to serve by public transport. Especially in residential areas, the demand for first and last mile transport is distributed over a large area, while the density of the trips is too low to be efficiently served with the existing public transport vehicles. The challenge is lower in densely populated urban areas but increases in suburban areas with individual housing.

If reaching the public transport line poses a barrier, the travelers are likely to use their own car or alternative modes of transport instead. If the first trip of the day is covered by private car, due to interdependencies of individual trips, also the remaining individual trips are covered by the same vehicle. The part of the population unable to use a car or other modes of transportation will suffer reduced access.

Attempting to provide access to public transport services through the current bus fleet in areas with low trip density would either lead to long meandering bus lines with frequent stops and low average speeds, or numerous vehicles providing service to only few passengers. In both cases, such service would be either too slow to be attractive to the passengers or prohibitively too expensive.

b) On-demand

On-demand services promise to solve the first/last mile problem. There are multiple ways of organizing on-demand services utilizing automated shuttle buses.

The automated shuttle bus could be operated on few different routes, while the choice between the routes is based on the current demand. This option would require smart bus stops or other call methods enabling passengers to notify the system to allocate the route to them and smart timetables giving the information about the estimated arrival of the vehicle. Automated shuttle buses could also be on stand-by on one point of the route and wait for passengers to arrive at any of the stops before commencing service.

A door-to-door service (taxi) adds another layer of personalization and is essentially a group taxi service. In Germany, automated shuttles were compared to regular group taxis, with the main observation that the low speed of the automated shuttle bus reduced attractiveness (Wintersberger et al. 2018). Currently, automated shuttle buses are not able to operate outside of a predetermined route, requiring the technology to mature before real door-to-door services become feasible.

An on-demand service creates uncertainties in the public transport system compared to pre-scheduled modes. Waiting time and in-vehicle time may be unpredictable, and it remains a question how passengers react to these uncertainties. Further pilots are needed once the technology has matured.

c) Temporary demand

Automated shuttle buses may create temporary public transport services in new residential areas before enough demand for classic public transport solutions is established. This would improve accessibility and promote the use of public transport instead of private car ownership in such areas. Similarly, exhibitions and other events with short lifespan but high impact on public transport demand could be served with automated shuttle bus fleets.

d) Closed areas

While not directly a part of the public transport service portfolio, one of the more likely applications of automated shuttle buses are closed areas, such as campuses, hospitals, industrial areas, parks and airports. While these areas are frequented by pedestrians, the number of high-speed vehicles is low, thus enabling more straightforward integration of the currently slow-moving automated shuttle buses to the traffic. Environmental changes such as misplaced cars or road work occur less often and people flows are well predictable, thus making it easier to establish point to point services without the need for a dynamic on-demand system. The impact on transport is marginal at best, as the automated shuttle bus replaces mostly walking.

2. Impact of Automated Shuttle Busses

a) What will change, what will remain

The role of the automated shuttle busses will quite likely be complementary to other public transport modes. Capacity restrictions, low speeds and space requirements do not support the use in heavy demand areas or over long distances. The main modes of transport automated shuttle buses could replace are walking, cycling, bus lines in low demand areas and transportation in closed areas. Automated shuttle buses are not likely to replace or reduce the use of private cars dramatically and there are still many areas where a private car provides superior services to most travelers.

b) Replacement of existing services

Currently, automated shuttle buses represent a low capacity, low speed service. However, they can economically provide services to a small number or low density of passengers in relatively short distances. Thus, automated shuttle buses may replace traditional buses only in low demand areas.

When replacing existing services, it is important to consider if the new service can serve all the user groups of the current service. Denying access or increasing the burden for current users is to be avoided. Especially user groups unable to use any other modes or services are in a vulnerable position.

c) Potential for first/last mile services

Automated shuttles can provide improved access to the existing public transport network. If the operational and capital cost of the automated fleet can be kept low, the new services can make public transport an attractive option in wider areas and bring new users to the service. Combining relatively slow-moving feeder services to a high speed and high capacity trunk network enables even longer trips to benefit from the new services.

Passengers generally want to avoid extra boardings and prefer even taking a longer or slower route to minimize the number of boardings. The new feeder services will greatly benefit from any improvements rendering changing the vehicles effortless. These improvements can include for example better synchronization of the lines, or passenger information systems that keep passengers aware of schedules and accurate arrival time of the vehicles.

Figure 10 shows simulation results where passengers would join the existing public transport network in the Helsinki region using either a shuttle service operated at 20 km/h speed and 10 min headway, or by walking. In the dark green areas, average travel time by public transport including boarding and wait times is less than 30 min. Light green areas fulfill the same criteria through introduction of a shuttle service. The population living in the 30 min zone would increase by 36% compared to the current situation. The simulation assumes the service to be available at any starting point of a trip; the scenario therefore does not represent a realistic use case but offers an example of the potential of automated shuttle bus services in different areas.

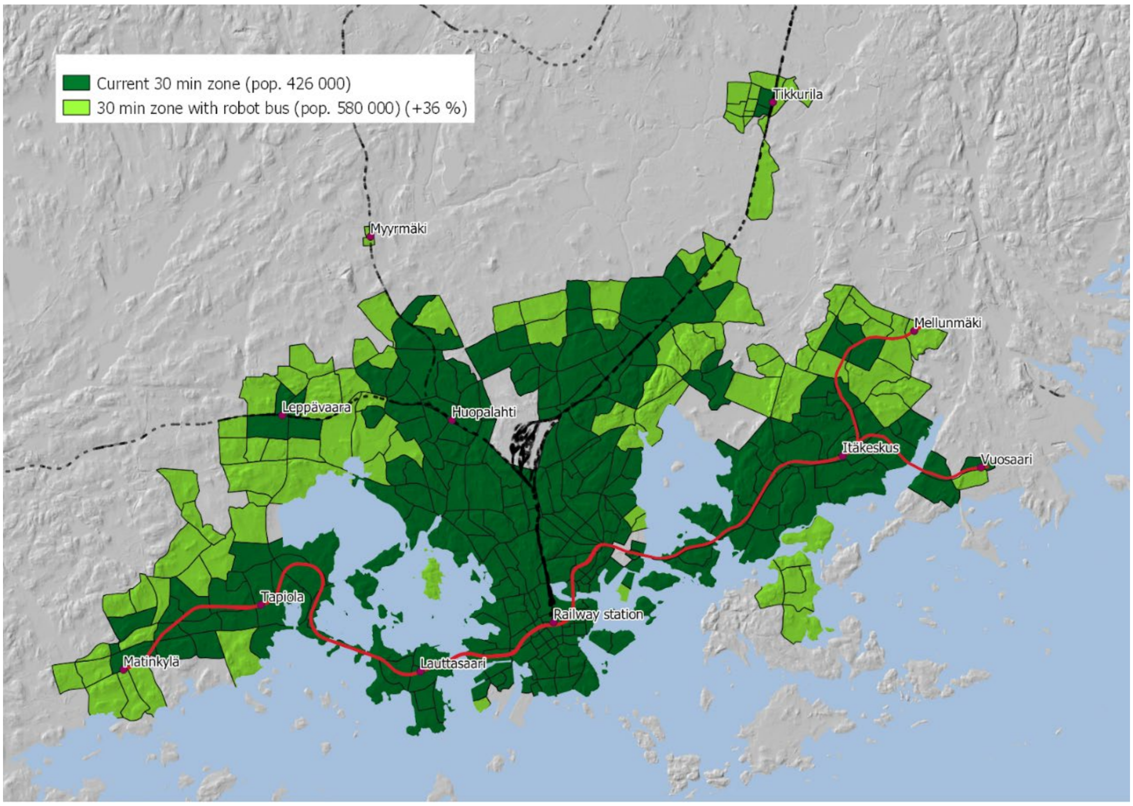


Figure 10. Simulation of service level changes from allowing people to join the existing public transport network wither using fast shuttle services or by walking. The shuttle service is expected to operate at a travel speed of 20 km/h and is operated at 10 min headway. Areas where typical trips in the morning can be currently made in less than 30 min, are marked in dark green. Light green areas represent the extension that can be archived using a shuttle service.

The simulations reveal the travel time saving potential forming a ring around the existing public transport hubs, see Figure 11. In immediate proximity to the stations, the feeder line service cannot compete against walking due to wait times caused by the headway. On long distances, the slow vehicle speed is the limiting factor, and passengers will favor faster public transport lines or use a private car or other modes of transportation instead. Longer feeder service lines also either require longer headway or more vehicles operating in the same area.

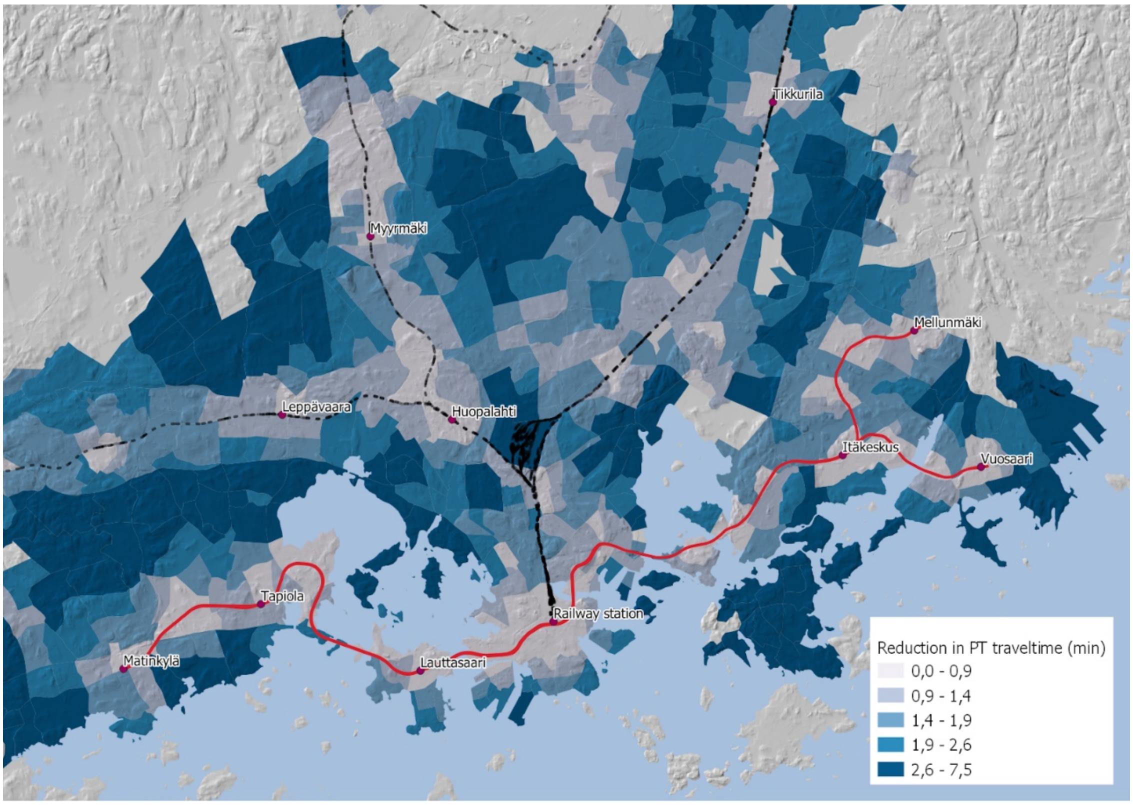
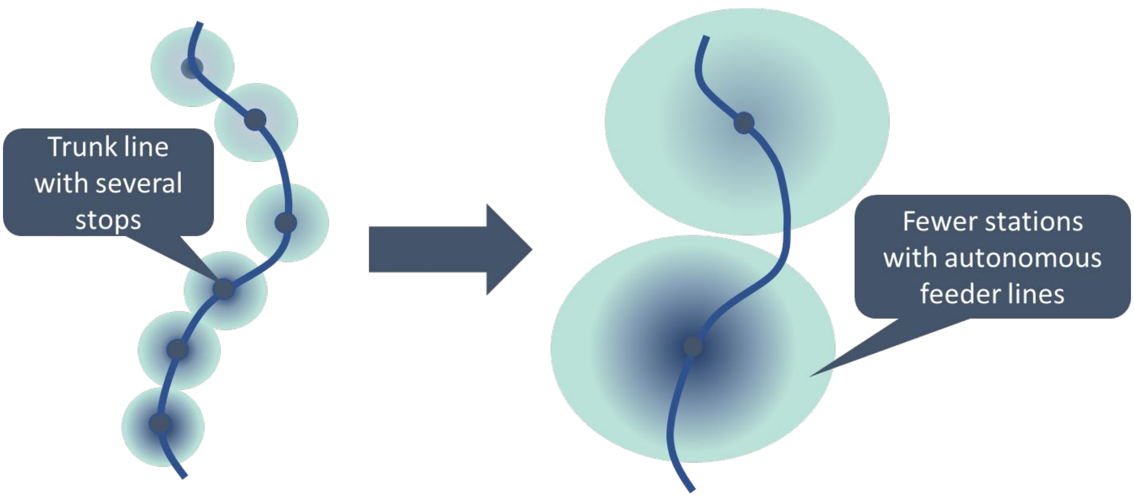


Figure 11. Estimated travel time saving potential of using the feeder service in Helsinki region.

d) Impact on trunk lines

Automated buses may serve as feeder lines for other modes of transport, increasing accessibility of public transport hubs. The introduction of more dedicated feeder lines and thus collecting passengers to fewer stations could lead to the removal of trunk line stops, increasing the average speed of the trunk line, as each stop reduces the average speed. Fewer stations could also reduce the bunching effect, that reduces the capacity and increases the waiting times of the trunk line. Depending on the demand, the service could be either implemented continuously or as on-demand. Figure 12 visualizes the effect on the number of stops and areas served if high-speed automated shuttle service was provided.



e) Capacity / space efficiency

The demand of public transport services varies from one city to another, and between different parts of the same city. Trip density, i.e. how many trips are made per area of land, drives the need for various modes of transportation.

In areas with high trip density, space efficiency, vehicle capacity and speed are the most important factors determining public transport services. When the same infrastructure and vehicles are shared with many users, the cost of the service is a less limiting factor. Outside of city centers the trip density is quickly reducing. Costs will become a limiting factor when the number of users on a transport line is falling. Space is a very limited resource especially in larger cities; approximately 10-27% of a city's surface is reserved for transport, while the percentage is higher in larger cities. (Will 2018)

One of the main goals of an effective public transport system is to minimize the land requirements. Space efficiency is challenging to achieve without wide use of public transport

Figure 12. Average speed of trunk lines (bus or rail) are low due to numerous stops. With automated feeder lines, several stops of the trunk line can be removed, increasing the average speed and throughput times and eventually accessibility.

or active modes like walking and cycling. Electrification and adaptation of self-driving technology in private cars are promising ways to improve the service level of cars while decreasing their environmental impact. However, both technologies offer very little to improve space efficiency. In some cases, widespread need for charging stations for electric vehicles and future vehicles driving without driver or passengers may create further challenges for efficient use of city space.

f) Cost structure

Currently, automated shuttle buses are only at a pilot stage and the final unit cost is uncertain. Nonetheless, automated shuttle buses will likely change the cost structure of public transport. Small vehicles with a high degree of sophisticated hardware and software will remain more expensive than traditional vehicles for quite some time, especially considering the capacity of the vehicles. However, removing the driver from the bus dramatically reduces the operating costs. In Finland for example, personnel costs for the driver constitute half of the cost of public transport mileage. In buses, the number of seats per driver is lower than for example in trains, increasing the effect dramatically. In the broader context of self-driving vehicles, public transport operators are likely the early adaptors of the technology due to the high capital costs of vehicles. Self-driving systems are forecasted to increase the unit price of private cars and taxis with SAE level 4 or 5 system by 40%, whereas marginal impact on price is expected for buses. (Abe 2019, Alku 2019)

An example from the US compares leasing two automated shuttle buses versus leasing two conventional minibuses and hiring 5 drivers for a 16 hour a day operation. If both services are used for six months, the cost of traditional vehicles, including leasing, wages and fuel, only reaches half of the corresponding cost of the automated shuttle bus. If the operation period is extended to twelve months, a gap remains, but to a smaller extent. This highlights the transition from operation expenses to capital expenses when moving towards automated shuttle services, creating an incentive to increase operating hours. (Rogers 2017)

As discussed in Section 5.1.4, automated shuttle buses may change the cost structure by reducing operating expenses and increasing capital expenses with high unit costs. The removal of the driver reduces the mileage cost per seat, thus offering automated shuttle buses as feasible option for several new public transport applications.

Both infrastructure owners and transport operators are ambitious to increase the operating hours of the fleet, which may lead to better off-peak service levels, as working hours by human operators is no longer a restriction. Peak service levels, on the other hand, will remain the same or even decrease, if automated shuttle buses replace vehicles with more capacity. This, however, should be avoided, as the role of the automated shuttle buses is to complement and support the existing transport systems, not to replace it.

IV. Where to start

In this volume, we have seen cities' and passengers' requirements for automated shuttle buses, along with technical requirements and impacts on space use in cities as well as economics of public transport. While making predictions is difficult, especially about the future, some order of implementation seems more feasible than others.

Realization of automated shuttle bus concepts is currently in the stages of early public-road pilots and closed area applications, which are likely the first wide-scale use for automated shuttle buses. Once the technology is mature, automated shuttle buses are likely to serve selected residential areas, either to connect these areas to public transport stations or improve mobility within the area. Feeder systems for trunk lines require high reliability and a large fleet of vehicles, thus maturity of the technology needs to reach such a point that the unit price decreases, and resilience of the systems increases. Once the technology has proven itself on limited route applications and the vehicles are capable of decision making in dynamic environments, on-demand services become possible.

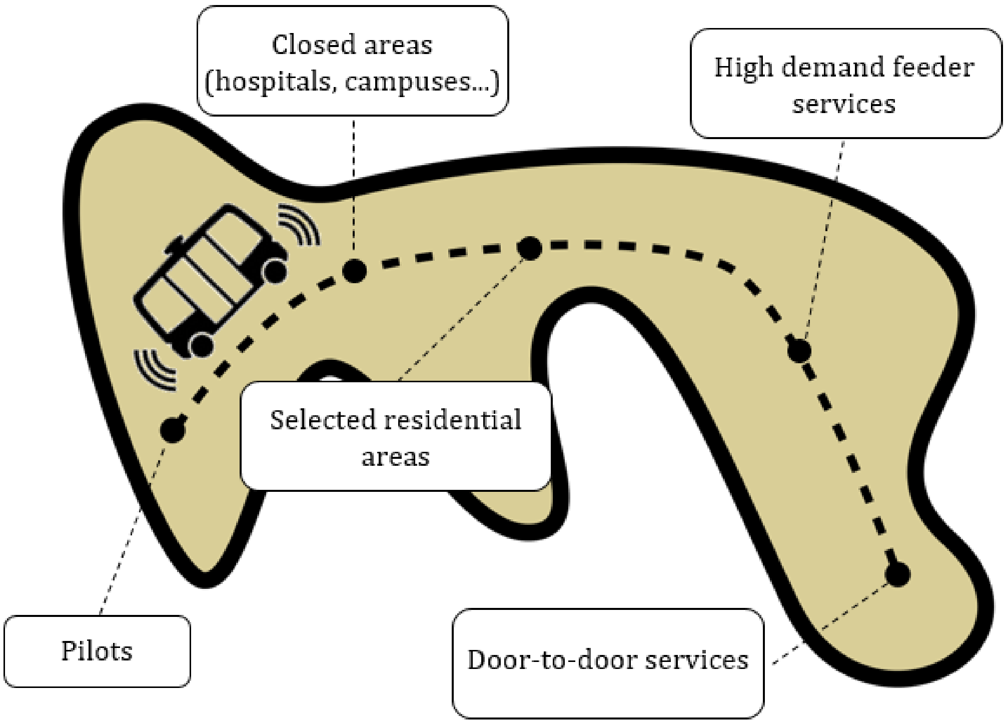


Figure 13 One potential roadmap for introducing automated shuttle buses to public transport system.

Checklist

- Plan before act
    - Early experiences shape the views on the new services and their relation to other modes of transport. Such views have been shown to enter policymaking (Haugland & Skjølsvold 2020).
- Define the needs
    - When planning services using automated shuttle buses, needs must be clearly defined. After this, it is possible to check whether the needs can be served with current automated shuttle bus technology.
- Define implementation criteria
    - What makes the services applicable? Define criteria for example for safety, reliability, transport system impacts, user experience, socio-spatial, and environmental impacts.
- Ensure accessibility
    - Especially when the new service replaces an existing service, extra care should be taken not to deny service to current users including people with disabilities.
- Ensure stakeholder participation
    - Participation of all stakeholders, special interest groups and the general public should be facilitated in the pilots and service planning.
- Organize pilots
    - The pilots should simulate the real service as comprehensively as possible i.e. the routes should be planned according to demand, not to display a vehicle's technical capabilities.
- Analyze the pilots and adjust the plan if needed
    - Analyze and disseminate the feedback from the pilots. Be vary of the limitations of the pilots e.g. their limited scale and possible invisible long-term effects. Adjust the service plans and repeat the previous steps when needed.
- Rollout the service
    - When the identified issues have been addressed properly, the service should be rolled out in stages. Gradual deployment starting from least demanding use cases to most challenging ones gives time to solve possible issues when they arise and change the approach if needed.

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Volumes of The Roadmap to Automated Electric Shuttles in Public Transport

1. The Legal Framework
    - What is the current legal status of automated driving in different European countries of the Baltic Sea Region? Sohjoa Baltic presents the relevant legal information for implementation and provides policy recommendations for the future.
2. Technology and Safety Requirements
    - What are the current relevant technological and safety challenges to be taken into consideration in the implementation of automated shuttle buses? Sohjoa Baltic provides information from Germany, Denmark, Poland, Finland, Sweden, Estonia, and Latvia.
3. Starting Your Own Pilot
    - How to deploy an automated vehicle pilot in a city? Sohjoa Baltic provides a practical toolkit with recommendations based on the practical experiences from automated shuttle bus pilots in Norway, Poland, Finland, Estonia, Latvia and Denmark.
4. Procurement Challenges
    - What are the barriers and enablers of autonomous vehicle procurement in public transportation? The experiences of Sohjoa Baltic's automated shuttle bus pilots in Estonia, Denmark, Finland, Latvia, Norway and Poland describe the complexity.
5. User Experience and Impact on Public Transport
    - How and why should cities prepare to implement automated public transport? What is the role of automated shuttle buses? Sohjoa Baltic provides views based on experiences from pilots in Norway, Poland, Finland and Estonia.