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Deliverable due date: M50 – January 2021

D4.15 AUTONOMOUS LAST MILE PILOTS IN OPERATIONS

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

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Abbreviations and Acronyms

Acronym	Description
ADS	Automated Driving System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMU	Metropolia University of Applied Sciences
HSL	Helsinki Region Transport
KPI	Key Performance Indicator
LiDAR	Light Detection and Ranging
Metropolia	Metropolia University of Applied Sciences
MMS	Mobile Mapping System
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
NTRIP	Networked Transport of RTCM via Internet Protocol
ODD	Operational Design Domain
Robot bus	Automated electric last mile small bus
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
SAE	Society of Automotive Engineers
Trafi	Finnish Transport safety Agency
Traficom	Finnish Transport and Communications Agency (former Trafi)
TRL	Technology Readiness Level
VRS	Virtual Reference Station
3G/4G	3rd and 4th generation of broadband cellular network technology

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0. Executive Summary

This deliverable describes the level of technological maturity of autonomous electric last mile small buses (robot bus) on the market, suitable route environments for testing autonomous buses and what is needed to be done to get an autonomous bus driving on public roads in Finland. The deliverable also takes a stand on the role of robot buses in the traffic system and use as part of sustainable public transport.

The content of this deliverable is based on the results of two separate 6-month pilot periods implemented as part of mySMARTLife project where a robot bus was operated in road traffic among other road users during the years 2018 and 2019. The Pilot routes were located in Helsinki, in the Kivikko and Kalasatama districts. These pilots were the first long-term pilots in Finland where a robot bus was operating with fixed schedules as part of public transport with established official bus line numbers, 94R and 26R. Anyone could get on board in the bus free of charge in the purpose of collecting user feedback and introducing self-driving technology to the potential users. The pilots were strongly linked with the Helsinki RobobusLine project financed by The City of Helsinki Innovation Fund in which the procurement of the bus used in the pilots was made. Prior experience of smart mobility projects which Metropolia University of Applied Sciences (Metropolia) has been involved in, such as the autonomous bus project SOHJOA [Sohjoa Robot Bus Experiment 2017], is also used to further understand and explain the nature of these special types of vehicles used in the pilots.

First, the deliverable introduces robot buses generally and how they are related to autonomous driving. The focus is on two different suppliers' buses (Easymile and Navya), which could be said to be the most commonly-featured buses on the market. These robot buses are able to provide autonomous last mile public transport solution as part of the travel chain in specific surroundings and conditions. Features (such as localization and obstacle detection technology) are further explained to better understand the special requirements and properties of suitable robot bus routes and operating environments. The analysis continues with explaining how autonomous vehicles in general as well as robot buses can be tested in road traffic in Finland.

By analysing the results of the two separate 6-month pilot periods, the role of the robot buses in the transport system is finally assessed. Robot buses are yet not applicable in year-round use in harsh weather conditions, and do not manage in a variety of traffic environments, but they are able to operate in road traffic in low-speed areas within specific conditions, and they do not necessarily need any special traffic arrangements or changes to the infrastructure. However, a responsible person on board is still needed in various situations because of the lack of technological capability as well as unfinished legislation and liability issues related to autonomous driving. The technology of robot buses is currently setting too many restrictions on cost-effective operation as part of sustainable public transport solutions. The service level and reliability of the vehicles as well as related services, such as remote control centres, are still not at the

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point where they would be sensible to procure as part of public transport. As robot buses are still prototypes and under development, the lack of on-site technological know-how often also limits the response time when different problems occur.

When robot buses are used as the first/last mile service, where the noted demand is, should be taken into account how the buses would increase the modal share of public transport while reducing journeys made by private cars. Replacing walking and cycling with a complementary public transport solution and serving people who are already using public transport is not necessarily a sustainable way of deploying autonomous buses, since electrical vehicles produce CO_2 emissions as well. Due to current technological constraints, it is difficult to carry out real use cases within the pilots as robot buses can rarely replace the existing public transport fleet and must be deployed and operated on routes which are technically possible to implement, not necessarily where they could offer the best value and meet the demand. Novelty value of the buses attracts many people who come just to test the bus and not necessarily use it as part of the actual travel chain, which is also a question of finding a viable route. The required presence of the on-board operator/safety driver can prevent from getting into genuine use cases and does not give the real impression of a driverless, remotely supervised vehicle.

The focus in the further pilots and research should mainly be on the technological development of the vehicles and the background related services (such as remote control centre and on field actions that require human intervention on site). Special attention should also be paid on the field of energy consumption of the vehicles. The potential benefits of robot buses will be refined as experiments progress, technology advances and legislation allow the full uptake of the autonomous solutions. Currently robot buses cannot offer a viable complementary option for public transport, and thus, they do not present a reckoned near future solution for lowering CO_2 emissions.

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1. Introduction

1.1 Purpose and target group

Robot buses have the potential to address the challenge of transition from private cars to public transport by introducing attractive, energy efficient and improved service. Robot buses as part of public transport can be a dynamo in developing a sustainable multimodal mobility system. Innovative mobility solutions, e.g. robot buses, could be a valuable starting point for firms and policy makers to create new business models and services.

mySMARTLife introduces a last mile public transport autonomous bus experiment, focusing in particular on more sustainable and smarter mobility as well as long-term usability implemented in the Helsinki Lighthouse demonstration city. The experiment is divided into two 6-month pilot periods, where a robot bus is operated in road traffic among other road users. The purpose of this deliverable is to analyse and report the experiences of the two separate pilot periods which were implemented during the years 2018 and 2019.

The deliverable is targeted at city public transport planners, area development specialists, public transport agencies and operators, traffic safety agencies as well as users of public transport and companies providing technology and services related to autonomous means of transport. This deliverable serves as a basis for introducing autonomous public transport for these target groups.

1.2 Contributions of partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of partners

Participant short name	Contributions
HMU	Overall content of the deliverable

1.3 Relation to other activities in the project

The following Table 2 illustrates the main relationship of this deliverable to other activities (or deliverables) developed in the mySMARTLife project and they should be considered along with this document for further understanding of its contents.

Table 2: Relation to other activities in the project

Deliverable Number	Contributions
D4.1	This deliverable provides the overall description of the mySMARTLife project and the specific KPIs and baseline values. Deliverable also provides

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	a comprehensive overview of Helsinki on various aspects and the actions carried out in the project including action 23: Autonomous Electric bus pilot to address Urban last mile mobility issues
D4.15 M12	Description of automated buses generally and the work done as well as achievements during mySMARTLife months M1-M12 in relation to Action 23: Autonomous Electric bus pilot to address Urban last mile mobility issues; as well as subtask 7.7.2: Last mile delivery strategies based on EV deployment. Autonomous last mile pilots in operations will be deployed and monitored through the project.
D4.15 M32	Analysing results of the first autonomous bus pilot period implemented in Helsinki Kivikko in 2018.

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2. Robot bus

2.1 Robot buses generally

Robot bus is an established word for a small electric automated bus with a capacity of 10-15 passengers. Nothing would actually prevent the word being used also to describe bigger full-size public transport buses with automated capabilities. However, the trials that have been carried out all around the world in the past few years with automated buses have been made mainly with just such smaller vehicles. This can be explained by the fact that automated technology on rubber wheels is still under development and cannot operate reliably in a variety of traffic situations and environments nor provide the same level of service and reliability around the year as traditional buses currently can. On the other hand, the development of autonomous technology on open roads among other vehicles has been easier to start from areas where speeds are low (under 40 km/h) and traffic is light. In these kind of areas, traditional full-size buses are probably not at their best and the need for subsidization increases especially in sparsely populated regions.

For shorter distances the term “first/last mile” is used, which often refers to the first or last 200-2000 m of the travel chain – trip from the nearest public transport station to home door for instance. This part of the travel chain is usually expensive to implement by traditional means due to the driver’s wages; hence, the solution has been sought from autonomous means of transport. As the functionality of the entire travel chain has been seen reducing (or increasing) the threshold for using public transport, it is also evident that this part of the travel chain is implemented well. These could be the use cases where robot buses could improve public transport service while making it more cost-effective and attractive already in the near future. That is to say, at least, for the time being, the purpose of robot buses has not been to replace traditional large public transport buses, but to supplement and improve the existing service.

In this context, it is also worth talking about the words automated and autonomous which have previously appeared in the text. An automated vehicle does not necessarily need any kind of human intervention as long as it stays within the defined Operational Design Domain (ODD). In an ODD, different operating domains are described where the certain Automated Driving System (ADS) of the vehicle is designed to function. These domains can be related for example to geographic, roadway, weather and speed limitations. An autonomous vehicle can operate and make decisions in any dynamic driving situation under all conditions without human intervention. As an autonomous vehicle does not yet exist in any vehicle category, henceforth the word automated instead of autonomous is used in this report from now on to describe the vehicles that have been used as part of the pilots. Words “shuttle” and “robot bus” mean the same automated vehicles here as well.

The point of having automated buses as part of public transport leads from the assumption that one person could control and supervise several vehicles remotely. This is how it could be possible to save costs that result from drivers’ wages, which are causing the majority of the personnel costs related to operating public

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transport buses. In total around 50% of the costs of bus transport comes exclusively from personnel costs. Remote operating of several vehicles is a prerequisite for cost-effective automated public transport. If even remotely still one person is needed to monitor every single vehicle, there would not be any cost savings in this respect compared to traditional means of transport where the driver is located on board in the vehicle. However, the trials made with automated vehicles on open roads have not yet been unmanned. A reliable remote supervision and particularly a system capable of controlling fleets of automated buses has not yet been developed. Generally, at the moment a safety driver must still be inside the vehicle to control that everything works as it should and in case of an unusual situation or upon request of the ADS, take over the vehicle. Even if the remote control technology would be ready, according to the law in several countries a human must still be physically inside the vehicle. In many countries, however, laws are being amended but the questions of liability especially in accident situations remain open. In some countries, it would be possible to remove the driver out from the vehicle, but still there would have to be a person in charge of the vehicle remotely.

2.2 Features

Currently, there are not many commercialized robot bus products on the market but new businesses and companies are emerging at a great pace. The most commonly featured robot bus suppliers whose products are trialled all around the world are now French companies Navya and Easymile. Their buses, Autonom Shuttle (former ARMA) (Figure 1) and EZ10 (Figure 2) use similar technologies for the vehicle to position itself and detect obstacles on the route. Similar properties can also be generalized to be in other robot buses on the market or in buses that are in the process of development. The details described in this Deliverable are based on practical experience gained in various smart mobility related projects that Metropolia has been involved in and which have been dealing with robot buses. One of the above-mentioned robot buses, Autonom Shuttle, was piloted as part of mySMARTLife which is discussed also in more detail from chapter six forward in this Deliverable.

Figure 1: Navya Autonom Shuttle robot bus [Rutanen 2018]

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Figure 2: Easymile EZ10 robot bus [Lehmusjärvi 2016].

Society of Automotive Engineers (SAE) international standard J3016 describes levels of automation for on-road vehicles [Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles 2018]. The six levels of automation from level zero "no automation" to level five "full vehicle automation" are described in Figure 3. Basically, in levels 0-2 human is always the main component for carrying out the different driving tasks. In levels 3-4, the main component is the vehicle but the automation is conditional, the vehicle is capable of driving autonomously only if certain conditions are met. In level 3, human only performs tasks upon need or request by the vehicle and level 4 does not require presence of a human nor request for intervention but the certain pre-defined conditions have to be met. At level 5, vehicle does not need any human intervention in any conditions for driving tasks. Thus, this kind of vehicle does not need any control devices for driving (such as steering wheel or pedals). According to the SAE standard, Autonom Shuttle and EZ10 can be defined at max as fourth level automated vehicles in very limited occasions, currently in practice only in closed areas. Generally, at this point, the robot buses can be categorized as level 3 vehicles but this applies only if certain ODD's are fulfilled that can be related for example to road characteristics and weather.

Robot buses are designed to operate on specific predetermined routes. On these predetermined routes they are able to operate automatically at a high level and human intervention to the driving has been attempted to be minimized as much as possible. Robot buses do not have control devices typical of normal vehicles, such as steering wheel or pedals and immediate intervention for driving is limited in that sense. The specific ADS of the shuttles covers all the dynamic driving task areas such as longitudinal and transverse control. They can steer, accelerate and brake independently but, in some cases, human has to take control over the vehicle. These are typically situations where some obstacles are on the path of the vehicle and the operator has to manually overtake it. In contrast to a normal vehicle, this overtaking happens by using a joystick located inside the bus.

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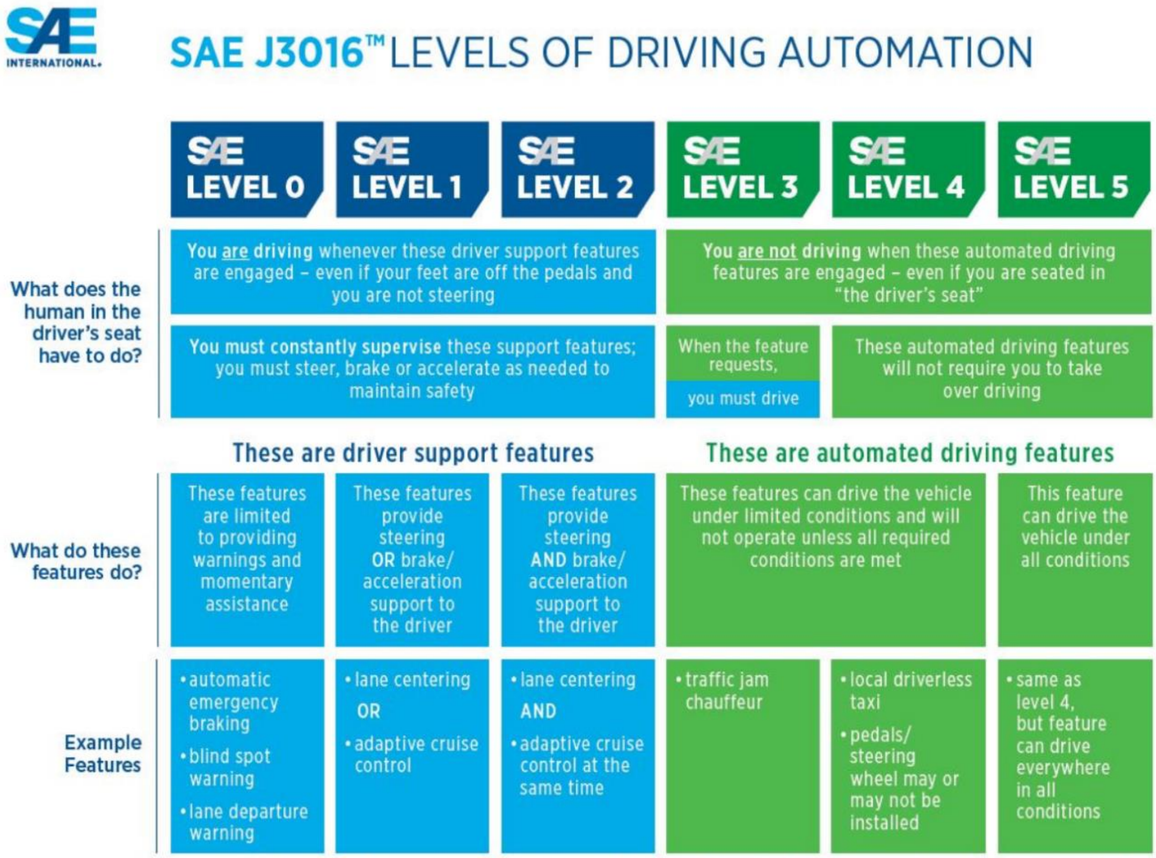

Figure 3: Six levels of driving automation for on-road vehicles [Shuttleworth 2019].

Robot buses do not make self-governing decisions of getting from point A to B. The buses are following a pre-programmed route and can be compared to a tram that follows a virtual trajectory instead of rails. In some situations, robot buses have been called as horizontal elevators. The trajectory for automated operating of the bus is made by driving the wanted route manually with the joystick. During this manual run, data from the surrounding infrastructure is gathered with multi-layer optical Light Detection and Ranging (LiDAR) radars located usually on the roof of the buses. Alternatively, this high precision spatial data can be obtained around the route with a Mobile Mapping System (MMS) installed on the roof of a normal car. This gathered data is then processed to produce a map. To get a high-quality map, there should not be a lot of traffic during the recording run as other traffic, such as vehicles may disturb the quality of the data. When driving in automated mode, data gathered in real-time from the LiDAR radars is compared to the produced map. Together with the LiDAR data and satellite positioning data received through a Global Navigation Satellite System (GNSS) antenna on the shuttle, the bus can position itself with few centimetres accuracy on the map and remain within the predetermined route. In contrast, for instance, to passenger cars on the market that have some sort of lane assistant system to keep the vehicle automatically between the lanes, shuttles seen so far do not use lane markings for the navigation at all.

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Location information from the satellites is not usable as it is, while the positioning accuracy of for example the Global Positioning System (GPS) can be several meters at its worst. To reach a few centimetres of positioning accuracy, Real Time Kinematic (RTK) differential GNSS technique is used to enhance the precision of position data. Precise position data is received through radio frequencies or via 3G/4G network from a fixed GNSS RTK reference station that has been installed near the operating site. Alternatively, a system called Networked Transport of RTCM (Radio Technical Commission for Maritime Services) via Internet Protocol (NTRIP) can be used. By using NTRIP, differential GNSS data can be sent via 3G/4G network to the bus from a Virtual Reference Station (VRS) instead of a fixed GNSS RTK reference station. Robot buses can navigate on the path just by using GNSS. This works if ODD related to environmental conditions are met, for example when there are not trees, big buildings or bridges blocking the connection to the satellites.

Robot buses use LiDAR radars also to detect obstacles on the path, which rationally placed and combined can see 360 degrees around the vehicle. In first models of the EZ10 shuttle used in project SOHJOA [Sohjoa Robot Bus Experiment 2016-2018] obstacle detection LiDAR radars were located in each corner of the vehicle around 30 cm above the ground. These radars detected obstacles in one layer and obstacles higher or lower from 30 cm was not detected. This resulted in the ADS failing to react for example to an open tailgate of a truck or a tail swing of a large bus on the path where the shuttle would most likely have hit without human intervention. In order to the vehicle to be able to safely operate in automated mode, it is vital that obstacles can be detected in several layers all around the vehicle. Newer EZ10 models (Figure 4) were later fitted with multi-layer LiDAR radars located in the front mask at both ends of the shuttle.

To detect obstacles, Autonom Shuttle (Figure 5) uses two (in total four) one-layer LiDAR radars located vertically in the front mask at both ends of the bus as well as two one-layer LiDAR radars on both sides of the vehicle. In addition, the shuttle uses two multi-layer LiDAR radars for obstacle detection located on the roof of the vehicle. These multi-layer radars are also used for the shuttle's positioning.

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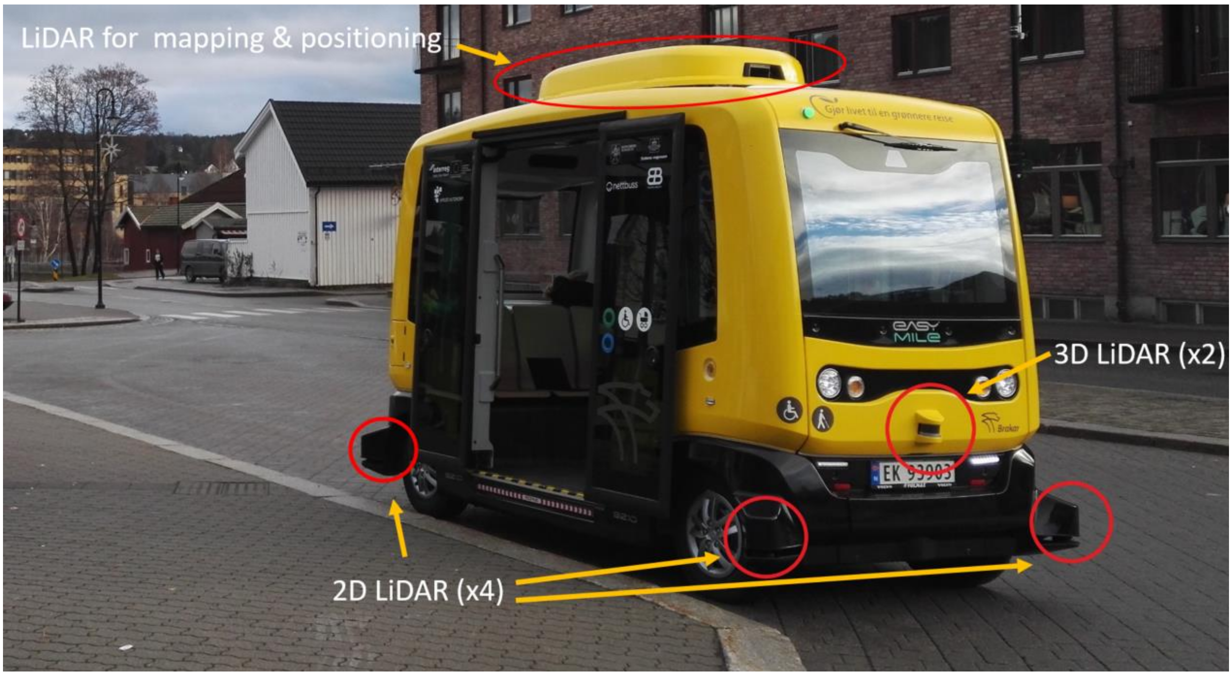

Figure 4: Easymile EZ10 Gen2 automated shuttle LiDAR radars [Ismailogullari 2018].

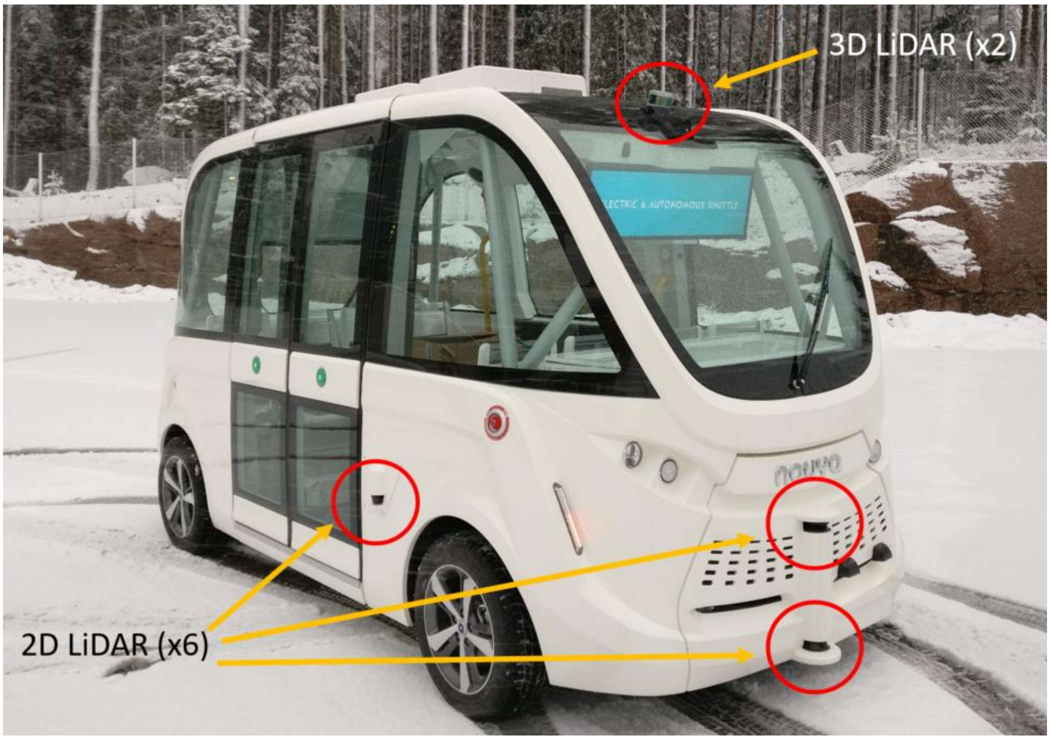

Figure 5: Navya Autonom shuttle LiDAR radars [Rutanen 2018].

When a robot bus sees an obstacle near or on the trajectory, it slows down and eventually stops if the obstacle is close enough. This applies both on stationary and moving obstacles on the path. The software of the shuttles is very responsive and safety-oriented so even a small object (e.g. flying leaves, birds and

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dust) may trigger a strong braking or emergency stop. If it is raining hard enough or snowing it can be impossible to operate with the bus completely as these particles are seen as obstacles. Due to passenger comfort and safety, the speed of the buses in automated mode has been comparatively slow. In the pilots led by Metropolia, the speed of 13 km/h with EZ10 (pilots in 2016-2018) and 18 km/h at tops with Autonom Shuttle (pilots in 2018-2019) has been achieved. Even in these speeds, braking can feel very rough which is why passengers should not stand during the drive - the use of seatbelts is also recommended while seated.

Robot buses are of the same size as large passenger cars except for their height, which is around 3 meters. However, on streets, in the width direction, they may require more space due to the ADS, which rely only on LiDARs. With LiDARs, it is difficult for an automated vehicle to specify obstacles on the path. Sometimes shuttles may stop or, at least, slow down with no apparent reason, because a branch or a blade of grass bends in the right way near the shuttle due to wind or when a vehicle is parked on the roadside a few centimetres outside of the assumed area. Generally, there should be at least around a half meter of clear space on both sides of the programmed path to avoid these kinds of situations. These safety limits can be reduced by slowing down the operation speed. On two-way roads robot buses are therefore programmed often to drive more on the left side of the road (in right-hand traffic) which is why it can be problematic to drive on narrow streets and places.

Robot buses follows a predetermined route and, currently, they are not able to overtake an obstacle on the path by themselves on open roads. By default, the route must be clear for the buses, otherwise the operator inside the bus must manually overtake the possible obstacle. Most common and trouble causing obstacle along the routes has been incorrectly (or sometimes also correctly) parked vehicles or vehicles that stop for a short time on the shuttles' path. The buses are identical from back and front and can move similarly forward and backward. However, the doors are located only at one side in the same way as in traditional buses. When the doors are to the right of the driving direction, this is generally regarded as the front of the bus. As driving right-hand traffic on open roads, the doors must be always on the right side so that the passengers can safely exit the vehicle to the sidewalk. This must be considered when planning routes for the buses.

At the moment robot buses do not understand or know traffic rules. To ensure the traffic flow and safety of both passengers and other road users robot buses may need priority in intersections or the intersections must be handled manually by the operator. Priority is done with traffic arrangements – with traffic lights, traffic signs or other relevant arrangements. This is how the intersections in first open road pilots was handled in the past. Later, it was possible to program the shuttle to stop automatically at a junction after which the operator would validate a safe passage by pressing a button. For passing intersections, traffic arrangements, programmed stop or manual driving can be still necessary if the ODD of an intersection is not fulfilled, that it to say the intersection is too difficult for the shuttle to handle autonomously.

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Currently, different intersections can be programmed beforehand so that the shuttle can handle them autonomously. A so-called priority zone can be programmed and adjusted at the junction areas, which will make it possible for the shuttle to manage for example T-junctions and roundabouts automatically. LiDAR radars of the shuttle detect that a vehicle is on the priority zone and reacts upon it by breaking or stopping. When the object has moved off from the zone, the shuttle will continue its trip. This way, also zebra crossings, can be programmed on the path so that the shuttle stops if a pedestrian is on the priority zone near the zebra crossing and is about to cross the street. Priority zones will work only if certain ODD's are met, for instance if the speed limit in the area is low and other vehicles are not driving fast or traffic is otherwise not heavy. Robot buses can also manage junctions led by traffic lights if the buses and the traffic lights are configured with certain communicating modules.

Route planning has an important role in finding a suitable area where the shuttle's automated actions and safety will be maximized while minimizing the actions done by humans. This emphasises the importance of understanding the features and limitations of robot buses. The following chapter below describes some general observations of suitable operating environments for robot buses noted in different pilots including the ones in mySMARTLife.

2.3 Suitable operating environments

Since a fully autonomous vehicle does not yet exist, robot buses as well as any other automated vehicles are dependent on having a route and conditions that match with the specified ODDs. Areas that meet the requirements and are suitable for robot buses cannot be unequivocally specified. In many cases, on open road conditions most of the route can be driven easily automatically while, for example, one single crossing can make the whole route impossible to execute in automated mode without special arrangements or without operator's intervention, if at all. Some route can be seen feasible but after a practical experiment on site or after the vehicle is programmed to drive on the route, the situation may change in unfavourable direction when something is noticed that could not be seen beforehand. Weather is the clearest single factor that limits the ability of an automated vehicle to operate as it is dependent on the ADS's capabilities, and it cannot be mitigated with route design. Taking all the possible variables into account and reacting upon them is very difficult for the ADS of an automated vehicle.

Robot buses have been tested in Finland both in road traffic among other vehicles as well as on ways for light traffic among pedestrians and bicycles. If velocity were used as the only parameter, robot buses would currently be best suited to move among pedestrians and bicycles. However, the ways for light traffic are often so narrow, that the bus will fill the whole street leaving very little room for other road users. Pedestrians are moving considerably slower (typically max 6.5 km/h) than the bus and the bus will automatically adjust the speed according to the objects in front of it. This may cause unpleasant situations while pedestrians are forced to give room for the bus to ensure unobstructed operation of the bus. On the other hand, cyclists may move significantly faster than the bus in which case cyclists are hindered by the bus. Also, according to the

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Finnish legislation, driving a motor vehicle on a way for light traffic is not allowed if it is not a temporary special use case. In order for the bus to be driven on a way for light traffic, the way could be changed for example to a yard street, but this allows also any normal motor vehicle to use the road. Not any special permissions have been given so far for robot buses in Finland for driving on roads that are not meant for motor vehicles. It should also be considered whether this kind of special exemptions would be necessary for large scale uptake of robot buses in the future and would the buses bring significant added value to the transport system through these use cases.

Robot buses are best suited to operate in road traffic among other vehicles even though their operational speed is not high, maximum of 18 km/h in mySMARTLife pilot. Though speeds of the buses have been constantly increasing and lately in spring/summer 2020 it was demonstrated the speeds of 28 km/h in Helsinki Pasila pilot as part of Horizon 2020 FABULOS project [Helsinki pilot 2020]. Because of the velocity, for now, it is not recommended to operate in an area where speed limit is over 30 km/h. There should not be much traffic or heavy vehicles driving in the areas. Basis for a suitable area is an urban environment with many fixed structures such as buildings with clear shapes. Fixed structures are used by the vehicles mapping LiDARs and are needed for precise positioning of the vehicle. The shapes should be somewhat varied and not completely monotonous, not just a big straight wall, for example. Large windows also degrade the positioning capabilities of the LiDARs.

At the moment, robot buses are sensitive to changes in the environment and driving for example on a construction site where new buildings are built and where surroundings are often changing can be tricky. If the exact path where the robot bus is operating has to be changed for example due to construction site, it has to be programmed again or drive manually this part of the route. In addition, it can be impossible to operate in an environment where trees are in the immediate proximity of the route. In SOHJOA project, an attempt was made to program an Easymile EZ10 to operate in an environment as shown in Figure 6. There was even an attempt to build structures in several spots along the route to help LiDAR positioning but this did not work out. Trees and leaves are constantly moving which prevents LiDAR positioning to work properly while they can also block connection to satellites. Other vegetation such as grass and bushes next to the path can cause problems while the bus can see them as obstacles and brake unnecessarily.

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Figure 6: Unsuitable operating environment for a robot bus [Rutanen 2017].

Because robot buses cannot currently overtake obstacles automatically, roadside parking spots should be clearly marked or roadside parking should be completely prohibited in intended operating areas. The lane where the bus operates should not be too narrow so that it can operate smoothly and will not pointlessly slow down for example because of parked vehicles or vegetation next to the street. Figure 7 from Kalasatama and Figure 8 from the Aurinkolahti area in Helsinki represent relatively well-suited urban environments and infrastructures for a robot bus. In both areas the speed limit is 30 km/h and vehicles should park in dedicated areas on the driveway or outside of it.

Intersections may lower the robot buses' ability to work in automated mode, and if traffic lights on the path cannot communicate with the bus, the operation is impossible or these sections of the route have to be driven manually. The problems and challenges in different environments can be circumvented as well as the amount of possible operational environments increased by implementing different arrangements and accepting that the operator intervenes more in the operation. There is a threshold of accepted environmental changes and frequency of operator intervention, which varies from deployment to deployment. In cases where the number and magnitude of arrangements as well as frequency of intervention increases too high, the feasibility and viability of the deployment needs to be critically reconsidered. Overall, when operating on open roads with robot buses safety level to be maintained should be considered, as well preparing for interference with other traffic, as robot buses are not able to keep up with the traffic flow in the majority of

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areas where they could be useful. Currently the best results of operation are obtained in closed areas, but as the development has to be pushed forward, open road trials in real traffic conditions are crucial.

Figure 7: A well-suited urban environment and infrastructure for a robot bus in Helsinki Kalasatama [Rutanen 2017].

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Figure 8: A well-suited urban environment and infrastructure for a robot bus in Helsinki Aurinkolahti [Arffman V. 2018].

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3. Testing automated vehicles in Finland

Testing of automated vehicles (SAE levels 0-5) is possible in road traffic in Finland. Finnish legislation does not require or does not mention that the driver should have hands on the steering wheel or be physically inside the vehicle during driving. Based on these findings the first automated bus trials in road traffic in Finland were carried out in the SOHJOA project [Sohjoa Robot Bus Experiment 2017] in 2016-2018, followed by the pilots in mySMARTLife in 2018 and 2019.

While testing automated vehicles on public roads, the vehicle must still have a dedicated driver either inside or outside the vehicle. The driver is responsible for the vehicle and makes decisions on the movement of the vehicle. This responsible person must be able, for example, to stop the vehicle remotely, if necessary. One person can be in principle the driver of more than one vehicle at the same time but this still needs some clarification. Even before a vehicle reaches the fifth level of automation (full vehicle automation) and is capable of theoretically fully independent driving in every situation as well as environment and conditions, the responsibility for the vehicle may and should be shifted to the vehicle supplier or some other entity. It is unlikely that any individual human supervising one or a fleet of vehicles would like to take responsibility in the future of vehicles that are operated by a computer. Currently, when the operator has been inside the vehicle the question of liability has been clearer as this person is directly seen as the person in charge and can quickly intervene in the functioning of the bus.

As reliable remote supervision and not particularly a system capable of controlling fleets of automated buses is not yet available to be used in open road conditions, an operator was onboard in the vehicle during the automated bus pilots in the mySMARTLife project.

3.1 Acquiring a test plate certificate

Anyone wishing to test automated vehicles in mixed traffic must apply for a special permit to do so. A test plate certificate must be applied for and issued together with the yellow test plates seen in Figure 9 by the Finnish Transport and Communication Agency (Traficom), former Finnish Transport Safety Agency (Trafi). Traficom describes the following about the test plate certificate process:

> *An enterprise, agency or other organisation engaged in research and development of automated vehicles may apply to Trafi for a test plate certificate. The certificate entitles the bearer to drive test vehicles, to a limited extent and on a temporary basis, both in road traffic and off-road. For testing in road traffic, Trafi will issue test plates.* [Testing automated vehicles in Finland 2016: 1.]

For example, Metropolia has applied for test plates for automated vehicles that are used for smart mobility projects. Automated vehicle experiments aim at clarifying the compatibility of autonomous mobility

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technologies to Finnish conditions, their technological maturity level and development targets for the more intelligent mobility infrastructure.

Figure 9: Yellow Traficom test plate for the robot bus [Åman 2018].

During mySMARTLife in 2017, Metropolia successfully applied for the test plate certificate and Traficom issued the test certificate as well as the plates that were used on the Navya Autonom Shuttle during the automated bus pilots. The test plate certificate is valid for one year from the date of issue, and it is automatically renewed annually. A separate application must be filed in for each set of test plates. The application form must be included in the application (Figure 10) and as appendices a Trade register extract from the company's country of incorporation as well as a trial plan which should include the following information:

1. A General description of the trials
    a. What, where and when
    b. How many vehicles
    c. What time period
    d. At what time
    e. Who will be operating
    f. Driver information
2. Research plan

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   a. What is being studied
   b. A description of the final report
3. Technical specification of the test vehicle
   a. Basic vehicle information
   b. Differences to type-approved vehicle
4. Information of the road area
   a. Maps of the area
   b. Is there a need for infrastructure changes?
   c. Has there been discussion with the city
5. Description of how road safety will be ensured
   a. How to ensure risk-free operations
   b. Risk assessment
   c. How does the vehicle observe the environment?
   d. How to respond to the risks involved
   e. Data collection and sharing
   f. Privacy policy
   g. Cyber safety
   h. Are there any hindrances to the operations (e.g. environment and weather conditions)?
   i. How the drivers (operators) are trained.
6. Proof of insurance cover for third party liability. [Testing automated vehicles in Finland 2016: 2; Pilli-Sihvola 2017.]

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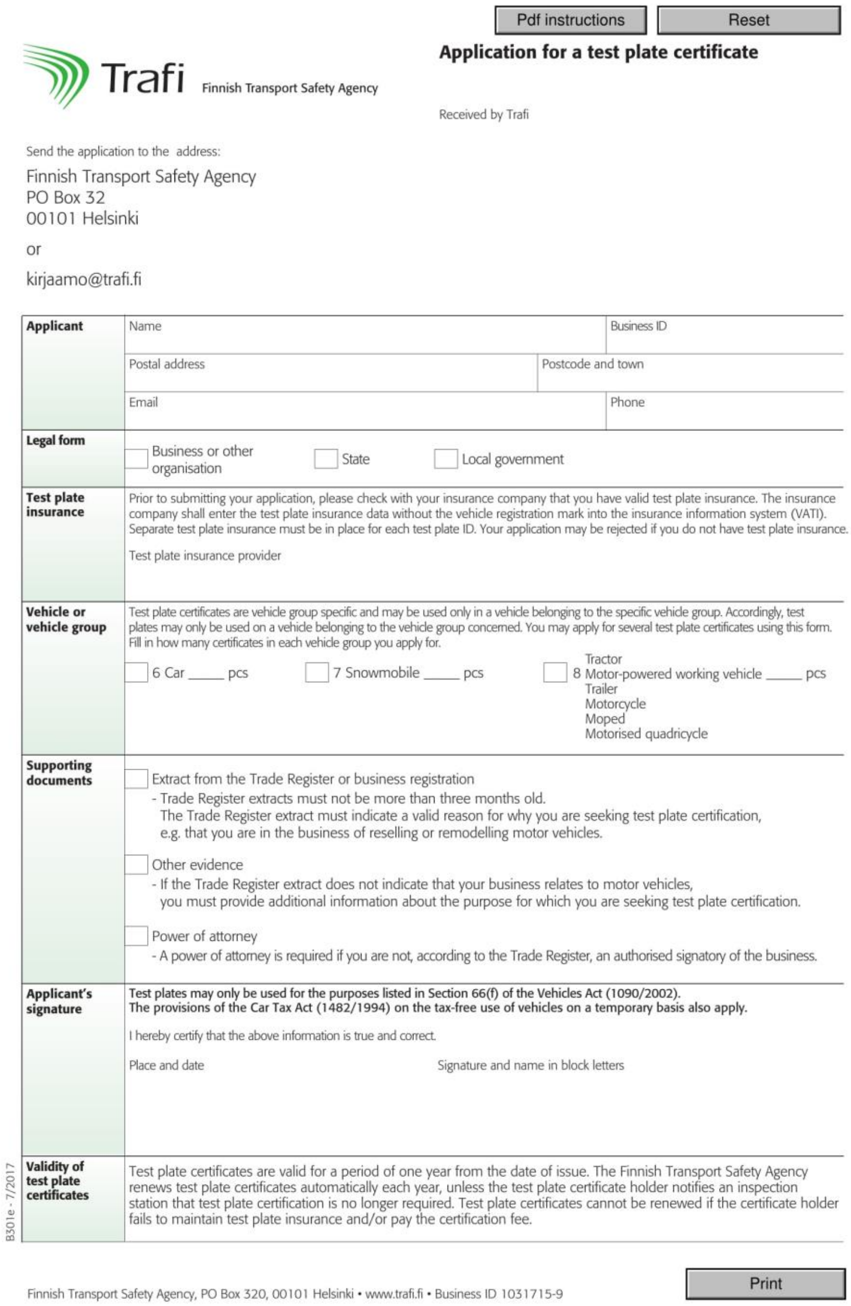

Pdf instructions | Reset

Trafi Finnish Transport Safety Agency

Application for a test plate certificate

Received by Trafi

Send the application to the address:
Finnish Transport Safety Agency
PO Box 32
00101 Helsinki
or
kirjaamo@trafi.fi

Applicant	Name / Business ID / Postal address / Postcode and town / Email / Phone
Legal form	Business or other organisation / State / Local government
Test plate insurance	Prior to submitting your application, please check with your insurance company that you have valid test plate insurance. The insurance company shall enter the test plate insurance data without the vehicle registration mark into the insurance information system (VATI). Separate test plate insurance must be in place for each test plate ID. Your application may be rejected if you do not have test plate insurance. Test plate insurance provider
Vehicle or vehicle group	Test plate certificates are vehicle group specific and may be used only in a vehicle belonging to the specific vehicle group. Accordingly, test plates may only be used on a vehicle belonging to the vehicle group concerned. You may apply for several test plate certificates using this form. Fill in how many certificates in each vehicle group you apply for. 6 Car _____ pcs 7 Snowmobile _____ pcs 8 Tractor, Motor-powered working vehicle, Trailer, Motorcycle, Moped, Motorised quadricycle _____ pcs
Supporting documents	Extract from the Trade Register or business registration - Trade Register extracts must not be more than three months old. The Trade Register extract must indicate a valid reason for why you are seeking test plate certification, e.g. that you are in the business of reselling or remodelling motor vehicles. Other evidence - If the Trade Register extract does not indicate that your business relates to motor vehicles, you must provide additional information about the purpose for which you are seeking test plate certification. Power of attorney - A power of attorney is required if you are not, according to the Trade Register, an authorised signatory of the business.
Applicant's signature	**Test plates may only be used for the purposes listed in Section 66(f) of the Vehicles Act (1090/2002). The provisions of the Car Tax Act (1482/1994) on the tax-free use of vehicles on a temporary basis also apply.** I hereby certify that the above information is true and correct. Place and date / Signature and name in block letters
Validity of test plate certificates	Test plate certificates are valid for a period of one year from the date of issue. The Finnish Transport Safety Agency renews test plate certificates automatically each year, unless the test plate certificate holder notifies an inspection station that test plate certification is no longer required. Test plate certificates cannot be renewed if the certificate holder fails to maintain test plate insurance and/or pay the certification fee.

B301e - 7/2017

Finnish Transport Safety Agency, PO Box 320, 00101 Helsinki • www.trafi.fi • Business ID 1031715-9

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Figure 10: Application for a test plate certificate [Application for a test plate certificate 2017].

After the trials have been completed, the test plate certificate holder must submit a report to Traficom of the trial results. The report should describe, for example, how the trial plan was implemented and how the experiments deviated from the plan. If there will be changes in the testing area, Traficom should be informed about this but no separate new application is required. The certificate is not fixed to one certain automated vehicle and can thus be used in other vehicles as well, as long as the trial plan stays the same. The agency's main interest lies in knowing where and when the trials are being conducted.

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4. Automated last mile pilots in operation

mySMARTLife included two separate 6- month pilot periods during the years 2018 and 2019 where a Navya Autonom Shuttle robot bus was operated and monitored on two different routes in the Helsinki lighthouse demonstration city, in Kivikko and Kalasatama. In Kivikko, the bus was operated completely by Metropolia and, in Kalasatama, the operation was arranged in cooperation of Metropolia and Rolan Oy. In case of both pilots, the operation of the robot bus was supported by the bus supplier who also took care of the deployment of the shuttle on the routes. The pilot routes as well as deployment and the operation of the bus is described and analysed in the following chapters.

The original plan was to pilot the automated bus in two locations in Helsinki, in Kalasatama district and in the urban port at West Harbour the Helsinki Jätkäsaari area. The route in Kalasatama was realized in 2019 but the idea of operating the bus over a pedestrian bridge (Isoisänsilta) to the Korkeasaari Zoo area did not materialize, as it did not receive permission to drive the bus over the bridge. The route was, therefore, shortened serving only the Kalasatama district. The second pilot planned to the West Harbour area faced adversity as the environment had heavy traffic and ongoing constructions which were deemed too challenging for the bus in use. An alternative route had to be found that would fit the goals of mySMARTLife while demonstrating how automated public transport could bring added value to the current public transport service. The task was further complicated by the capabilities of the available technology and since the Helsinki area is under heavy development where new residential areas are being built and the old ones are widely renovated. In addition, the supply of public transport is very comprehensive in the Helsinki area which makes it difficult to find places where public transit is not already operating to some extent. However, a potential route was found from east of Helsinki at Kivikko district where the pilot was conducted in 2018.

4.1.1 Kivikko

The robot bus pilot period of 2018 was implemented in the East of Helsinki, in the Kivikko district. The route described with orange colour in Figure 11 was approximately 1 km long in one direction (circa 2 km round trip). The idea of the route was to demonstrate how automated public transport could work as complementary service in an area where public transport services are not provided with dense intervals and where it is necessarily not reasonable to operate with conventional means of transport. People mainly arrive in the area by private cars. Therefore, the impact of the robot bus service on the use of private cars was investigated.

The route was covered by two bus stops, of which the other was a stop of a regular Helsinki region public transit authority Helsinki Region Transport (HSL) bus line 94B (described in blue colour in Figure 11) on Kivikonlaita road. HSL bus line 94B was operating on its route four times in a day. The bus stop, called "Kivikontie", was near a larger ring road (Kehä 1) along which HSL bus trunk lines were running. Kivikontie worked as a stop that connected the trunk line buses to the robot bus line. The stop at the other end of the

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robot bus line on Savikiekontie road, approximately one kilometre away from Kivikontie, was located in a local sports park and was called “Kivikon liikuntapuisto” (Kivikko sports park). The robot bus worked as the last or first mile service as part of peoples’ travel chain between these two stops.

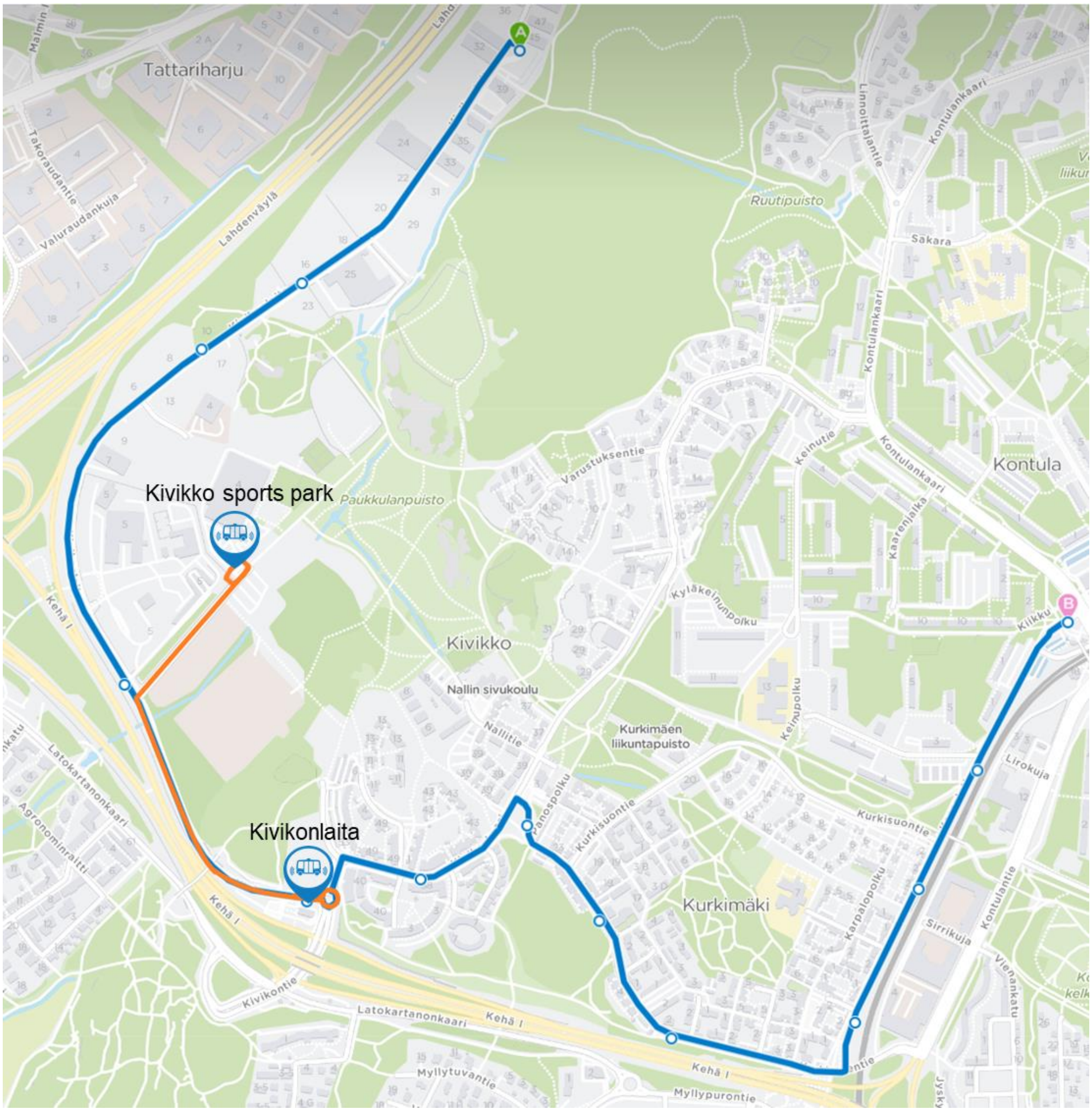

Figure 11: Kivikko robot bus route map [Arffman V. 2019]. (Map data: Reittiopas 2019a).

The robot bus route was integrated to HSL Journey Planner (Reittiopas) with the line number 94R (Figure 12) and the line description “Kivikon liikuntapuisto” “Kivikko idrotsspark”. The letter R was introduced for the first time in HSL‘s history and was describing the word robot bus. The bus was operating from 9 am to 3 pm on weekdays and the route was run three times per hour on regular 20 minutes intervals. The daily operation was started from the Kivikon liikuntapuisto robot bus stop. Because of the Finnish climate that was inapplicable for the used technology, the bus was operated only focusing on the warmer season of the year.

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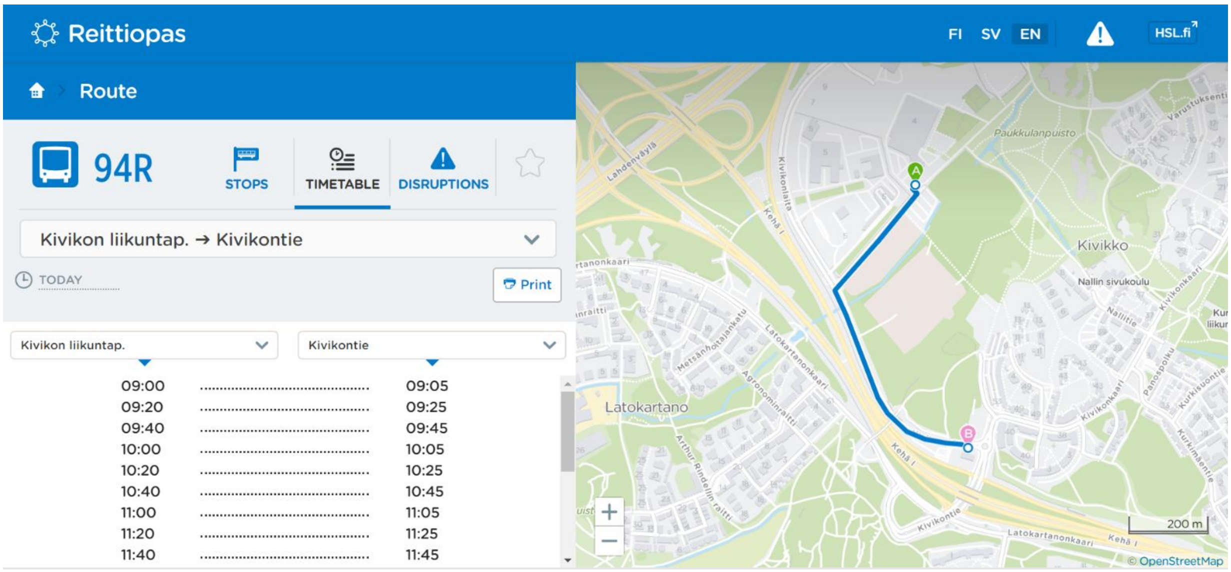

Figure 12: Robot bus route 94R as shown in Reittiopas, HSL's journey planner [Reittiopas 2018].

Even though the other end of the shuttle's route was on a stop that were used by HSL buses, separate bus stop signs to describe the pilot was used on the stops as shown in Figure 13. The signs described among other things the station name, route and departure times. One side of the sign was written in English and the other in Finnish.

The route had two intersections, one roundabout (Figure 14) and one T-junction (Figure 15). A bridge crossed the route on Kivikonlaita near the Kivikontie stop, which increased the difficulty of the route setup and reduced operational certainty. Speed limit in the area was 50 km/h which was lowered to 40 km/h during the pilot on the shuttle's path so that the speed difference between other road users and the bus would not had grown too high. Traffic density in the area seemed to be quite low but a garbage sorting area near the sports park and industrial estate after Savikiekontie road increased especially the number of heavy vehicles (trucks, etc.) driving in the area.

Environment by the Kivikko route was mainly lacking structures that could be used by the LiDAR radars which is why positioning of the shuttle was mostly done by using satellites (GNSS). There were a lot of vegetation and trees that created challenges in sense of changing environment and the LiDAR map that was created in the beginning of the shuttle's deployment. Road side parking was prohibited completely along the route except on Kivikonlaita road where there were a few marked parking places for buses and trucks. However, these parking lots were out of the main road so there was plenty of room to operate with the shuttle.

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Figure 13: Robot bus stop sign at Kivikonlaita road [Rutanen 2018].

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Figure 14: Roundabout at Kivikonlaita stop [Rutanen 2018].

Figure 15: T-junction at Kivikonlaita [Ismailogullari 2018].

4.1.2 Kalasatama

The second robot bus pilot period was implemented in 2019 in the Kalasatama district. The route depicted with orange line in Figure 16 was approximately 900 m long and was operated only in one direction. The main idea of the route was initially to increase the users of public transport arriving in the Korkeasaari Zoo by deploying the robot bus to operate between the Kalasatama metro station and the zoo while improving the public transport connection. But, as already described previously, it was not allowed to use the Isoisänsilta Bridge that unites Kalasatama and the rest of the potential route. If the robot bus would have had the permission to pass the bridge, other vehicles could have done it as well, as no special exemptions

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have been given nor exist for robot buses in road traffic in Finland. The robot bus was thus operating only in the Kalasatama area while serving mainly people visiting and living in the district.

First, it was planned to have four bus stops and a bit longer route described with the orange dashed line in Figure 16. This extension would have passed a settlement apartment as well as enabled having a bus stop closer to the Redi shopping mall and the Kalasatama metro station. After discussing with the city, it turned out that there was going to be built a kindergarten next to Arielinkatu street during the summer and some temporary traffic arrangements would be implemented on the streets due to this project. This would have most likely required programming of the changes in the path of the shuttle or increased the amount of manual driving. Therefore, the route was shortened, and, finally, it was covered by three bus stops, all of which were specifically arranged for the robot bus to be used during the pilot. The names of these bus stops were Redi, Polariksenkatu and Isoisänsilta; Redi being the closest stop to the Kalasatama metro station and Isoisänsilta the stop at the other end closest to the bridge leading to the zoo. The route was operated in counterclockwise. HSL bus lines 50 and 59, described in blue colour in Figure 16, were operating partly on the same route in the opposite direction and the robot bus sometimes confronted these buses on Junonkatu street where one of their official bus stops was (named as Polariksenkatu as well) and in the crossing of Junonkatu-Parrulaituri streets.

Figure 16: Kalasatama robot bus route map [Arffman V. 2020]. (Map data: Reittiopas 2020).

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The route of the robot bus was integrated to the HSL Journey Planner with the line number 26R and line description “Isosiänsilta”/“Farfarsbron”. The bus was operating from 9 am to 3 pm on weekdays and the route was run three times per hour on regular 20 minutes intervals as seen in Figure 17. The daily operation was started from the Redi robot bus stop and also ended there.

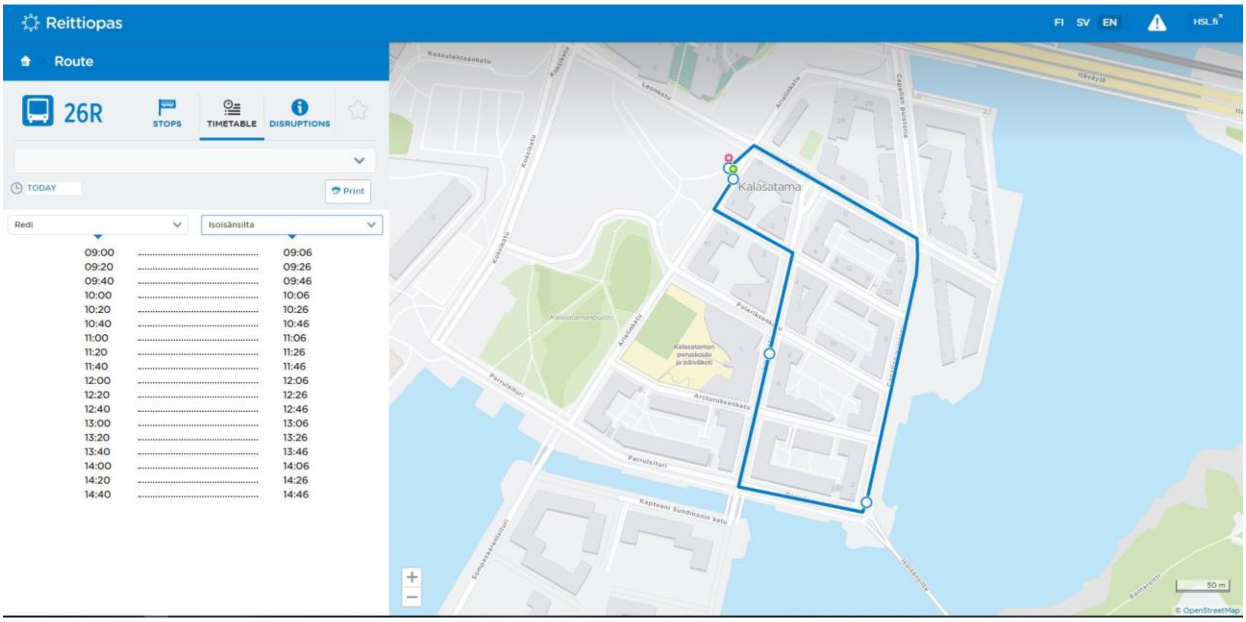

Figure 17: Robot bus route 26R as shown in Reittiopas, HSL’s journey planner [Reittiopas 2019b].

All of the robot bus’s bus stops were established only for the purpose of the pilot and were not existing before, thus it required that passengers’ information was arranged by the stops. Same kind of bus stops signs were used as in Kivikko describing among other things the station name, route and departure times. In Figure 18, it is depicted the bus stop sign on Polariksenkatu street which was in the middle of the other two bus stops when driving south in the direction of the Isoisänsilta bridge.

All of the 10 intersections by the route were uncontrolled T-junctions (or similar to these without any traffic lights nor signs indicating the right of way) but in total 6 of them were such where the robot bus did not have right of way. At these 6 intersections the bus had to give way for the vehicles coming from the right according to the rule of the road. Figure 19 depicts a typical intersection and the overall looks of the environment in the Kalasatama area as well as by the route of the robot bus. Speed limit in the area was 30 km/h and traffic density was quite low but the HSL bus lines operated within around 10 minutes intervals which was much tighter compared to Kivikko. Also, some construction trucks occasionally drove on the same streets where the robot bus operated even though instructed to use other ways when driving to the near built new neighbourhood at Sompasaari. Of course, other road users such as passenger cars, bicycles and pedestrians were also present.

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Figure 18: Bus stop sign at the Polariksenkatu robot bus stop in Kalasatama [Rutanen 2019].

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Figure 19: Typical intersection and environment by the route of the robot bus in Kalasatama [Rutanen 2019].

Overall, the environment by the Kalasatama route was completely different than in Kivikko, as it represented an urban district with buildings near on both sides of the streets. The positioning of the shuttle could be thus done mainly by using the LiDAR radars. There was no vegetation next to the roadside either. On one hand, the area was still somewhat under construction and there was roadside parking nearly by the whole route, though only in clearly marked places as seen also previously in Figure 7. The streets in Kalasatama were between 6-7 m wide (3-3,5 m per lane to one direction), much narrower than in Kivikko, and around 2 m wide area was reserved in addition for parking next to the driving lanes and the roadside.

4.1.3 Route setup

Automated buses cannot be directly deployed and operated on a route. Usually a thorough planning and analysis is needed to first see, if the bus could be theoretically able to operate on the desired route after which the actual arrangements and actions are carried out on site, if seen feasible. In the case of the myMARTLife pilots the process was approximately as follows:

1. A potential route was found and tentatively planned (e.g. place for bus stops, charging and storage place for the bus) by the assigner (Metropolia in this case) together with the city (landowner).
2. The route was presented to the bus supplier (Navya) by showing videos and pictures of the route as well as describing the characteristics generally.
3. The route was tentatively found feasible by Navya after which a representative from Navya made an onsite visit to see the route in practice.
4. After the onsite visit the route was seen feasible and Navya made a site analysis report which listed comprehensively all the specifications and arrangements that were needed prior to the deployment to ensure secure operation of the shuttle. All the requirements could not be

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implemented necessarily according to the analysis, which was discussed afterwards in order to achieve a sufficient level of safety and operation of the shuttle. In addition, everything could not be stated before the actual deployment of the shuttle and new things and issues occurred during the deployment of the shuttle and operation which had to be reacted as required.

5. Based on the site analysis report, necessary arrangements were added on the site before Navya's deployment engineer came to deploy (mapping and programming of the route) the shuttle on the route. The report was also used as a general guide for Navya's deployment engineer on how the shuttle should be deployed on the route. The implemented arrangements were not based only on the supplier's site analysis and demands but also on arrangements that were deemed otherwise necessary by the assigner, such as warning signs.
6. Simultaneously during the deployment of the shuttle, the operators were trained to operate the shuttle on the route. Manual driving had been trained already before the deployment.
7. After the successful deployment, the actual operating could be started and it was possible to take passengers on board in the shuttle. The vehicle´s deployment together with the assigner took around 10 days in Kivikko and 13 days in Kalasatama.

Arrangements on the route that had to be done for succeeding with the operation of the shuttle can be related to:

- traffic arrangements which affects the other traffic driving in the area (e.g. installing warning signs and changing the right of way in some intersections);
- additional arrangements that are needed to make the bus operate on the route (e.g. building up additional structures to improve the navigation of the bus);
- bus stops of the shuttle;
- fixing the GNSS RTK reference station to a roof of a building near the route.

The general process of deploying and implementing a pilot is described comprehensively for instance in The Roadmap to Automated Electric Shuttles in Public Transport Publications Volume 3. Starting Your Own Pilot of the Sohjoa Baltic project [Müür et al. 2020]. In case of Kivikko and Kalasatama in mySMARTLife the route setup and deployment of the robot bus on the routes is described in more detail in the following chapters.

4.1.3.1 Kivikko

The most laborious arrangements on the site were related to the bridge on the Kivikonlaita road. When the robot bus drove under the bridge it lost connection to satellites. Solid objects such as the pylon of the bridge and rock around the bridge was found to be inadequate for the bus to locate itself using only LiDAR radars. Additional stationary reference points for localization were deemed necessary, which is why wooden

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constructs were installed near the bridge. In total ten sets of wooden panels were installed, nine of them around the frames of growing trees (Figure 20) and one around a lamppost (Figure 21). After the bridge was passed, it took around 20 seconds for the bus to gain connection again to the satellites. Because of this, the constructs had to be installed on a longer distance, not only under the bridge or its immediate vicinity.

Figure 20: Installation of wooden constructs to frames of growing trees near the bridge at the Kivikonlaita road [Rutanen 2018].

Figure 21: Wooden construct around a lamppost near the bridge at Kivikonlaita road [Rutanen 2018].

In the robot bus experiments in Finland, traffic signs have been previously used to warn other road users of the ongoing trials in the area. Creating a safer test environment has also required lowering the speed limit,

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if it has not been low enough as such. The same practice was followed in Kivikko and different traffic signs were installed along the robot bus route. Generally, the placement of the signs can be seen in Figure 22. Other traffic arrangements except different types of signs were not needed nor done. The traffic signs consisted of test zone sign attached with area speed limit sign (Figure 23) which were placed in the roundabout area where road users entered the trial zone. Warning signs (Figure 24) were installed mainly at intersections and next to zebra crossings. Signs indicating the ending of the area speed limit were installed in places where the test zone ended. Bus stop signs on the shuttle's two bus stops were added as well but only after the shuttle was deployed to be sure what kind of schedule could be applied and written in the sign.

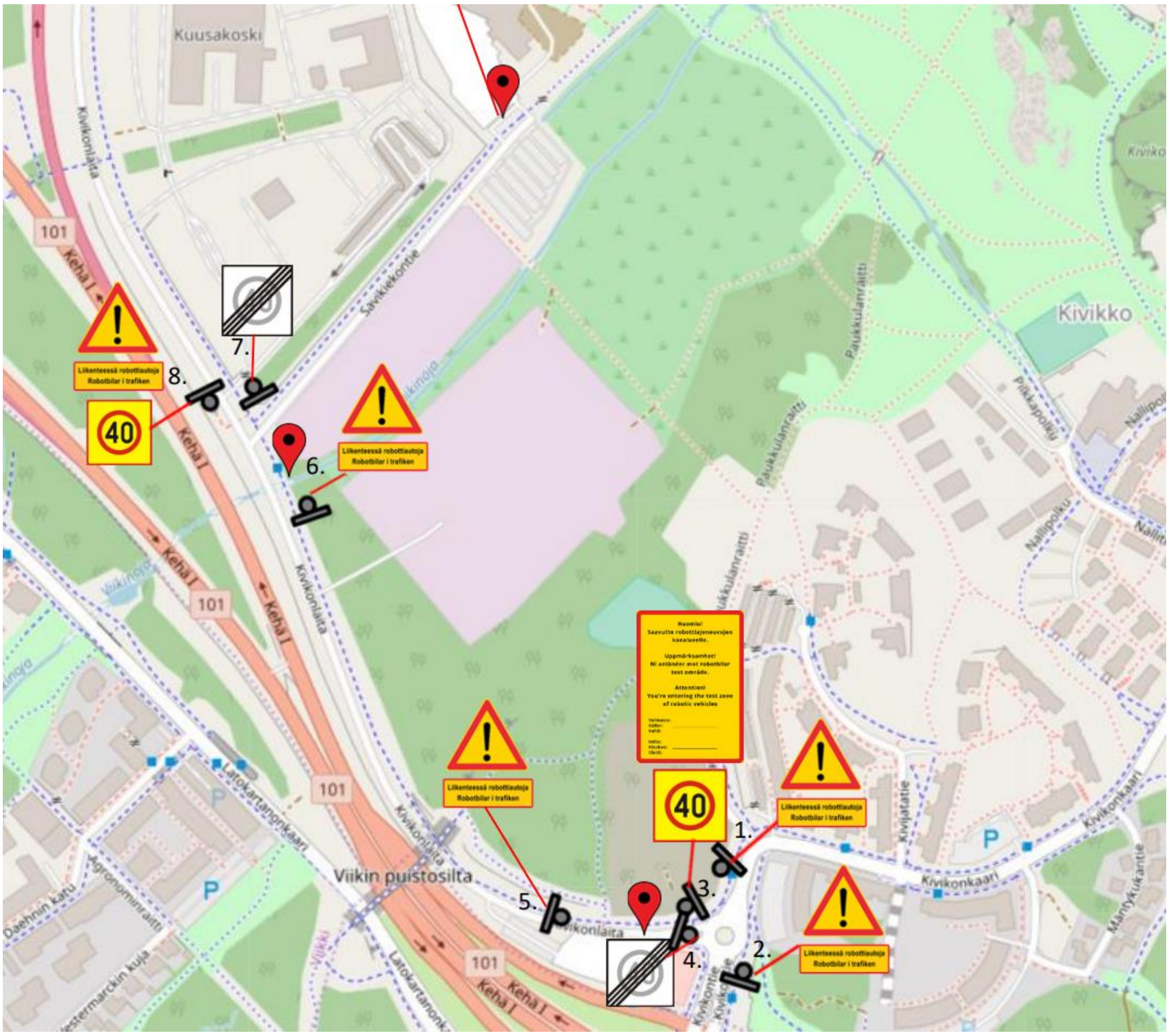

Figure 22: Disposition of traffic signs for the robot bus route in Kivikko [Arffman V. 2018]. (Map data: © OpenStreetMap contributors)

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Figure 23: Robot bus test zone sign and 40 km/h area speed sign at Kivikonlaita road [Rutanen 2018].

Figure 24: Robot bus warning sign and zebra crossing on the path at Kivikonlaita road [Rutanen 2018].

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Deployment (including mapping and programming of the route) of the shuttle took 10 days starting on 2nd of May and ending on 14th of May which was the day when passengers could hop on in the shuttle. Just before the actual route programming a GNSS RTK reference station was installed on the roof of a skiing hall located at the other end of the route by the Kivikko sports park stop as shown in Figure 25. Installation was made together with Navya and Metropolia, and this was basically the first task of the deployment in which the bus supplier was involved in practice on site. For proper satellite connection and communication between the shuttle and the station, the station had to be installed in a high and open space near the route. It had to be also secured that the antenna, the yellow mast seen in Figure 25, did not move during the pilot. Because the reference station was placed at the other end of the route, connection with radio frequencies did not work on the whole route and connection was usually lost around the Kivikontie stop. However, the communication between the shuttle and the reference station could be also handled through 3G/4G which covered the connection loss at this point.

Figure 25: Fixed RTK GNSS reference station installation on the roof of the Kivikko Skiing hall [Rutanen 2018].

After the reference station was installed and connection established between the shuttle and the station, the actual route mapping and programming could be started. The route was driven manually and slowly roughly on the spot where the actual trajectory (virtual rails) of the shuttle would like to be had. There was so much

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traffic (overtaking vehicles) during the day that eventually the mapping had to be done during night time to be able to have a good quality LiDAR map.

When the mapping was completed, modifications and programming for different traffic situations was started:

- Driving lines and other minor adjustments were made to the baseline map.
- Velocity of the shuttle was increased little by little to make sure that everything worked as it should until the maximum speed, 18 km/h, was reached.
- Priority zones were programmed at zebra crossings on the route, at the roundabout and in the bus stop areas where the shuttle should have avoided vehicles already on the road (coming from behind) when leaving from the bus stops.

Priority zones had to be adjusted precisely so that the shuttle would run smoothly and would not stop in vain. If the zones would have been programmed incorrectly, the shuttle could have stopped while thinking that the object on the zone should be avoided, even though it would have been only a solid object in its place or a pedestrian walking parallel with the bus over a priority zone for instance at a zebra crossing. Priority zones could not be programmed at the T-junction in the intersection of Savikiekontie and Kivikonlaita roads because other road users were driving too fast, where the shuttle could not react quickly enough to be able to work automatically – the shuttle's LiDAR radars did not see far enough to detect the vehicles driving on the road from a longer distance. At this point the shuttle was programmed to stop just before the junction and the operator had to manually press "GO" button from the control panel inside the shuttle to make it to continue the ride.

The initial plan was to have three bus stops on the route. The third one would have been just before turning right to Savikiekontie where one of the HSL bus line 94B stops was also located. This bus stop would have worked only in one direction when driving the route from Kivikontie towards the Kivikko sports park as there was no place for stopping the shuttle on the other side of the road on the planned path. Eventually it was not sensible to include this bus stop while the shuttle would have needed to stop there even though no one would have entered the shuttle or no one would have got out from it. It was not possible to choose this bus stop and stop there upon request from inside or outside the shuttle after the shuttle was sent on its trip towards the Kivikko sports Park.

4.1.3.2 Kalasatama

Compared to Kivikko, the preparatory arrangements on site in Kalasatama were limited only to traffic arrangements including same kind of warning and informative traffic signs as well as the bus stop signs that were used in Kivikko. The general disposition of these signs can be seen in Figure 26. Position of the concrete bases of the signs had to be adjusted to some extent (around few meters at max) during the programming of the shuttle as the original locations at the bus stops were not suitable. They were seen as

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obstacles by the shuttle. The relocation of the concrete bases was not simple as they weighed around 200 kg.

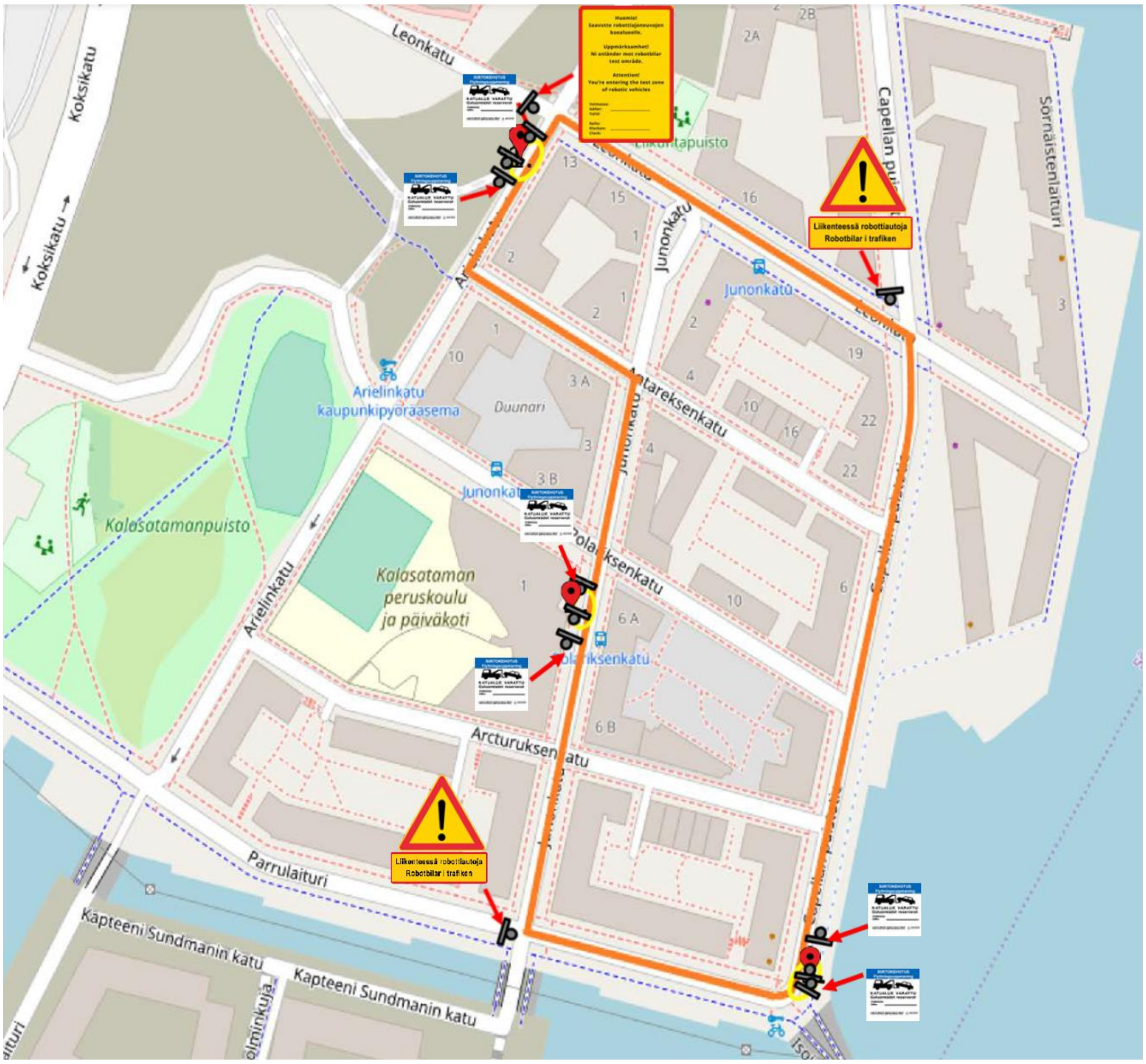

Figure 26: Disposition of traffic signs for the robot bus route in Kalasatama [Arffman V. 2019]. (Map data: © OpenStreetMap contributors)

Unlike in Kivikko, road side parking spaces were reserved to be used as the shuttle's three bus stops. The reservation was made by using specific signs that are used to reserve a street area in the city as seen also seen in Figure 27 in case of the Isoisänsilta robot bus stop. If other road users would have parked on the reserved spots, the parked vehicle could have been towed away. Though this arrangement did not seem to be clear enough as vehicles were parking on these reserved spots, nevertheless, complicating the deployment process and operation of the shuttle. As vehicles were parked at the shuttle's bus stops they were hindering the complete route programming and adjusting of the shuttle's trajectory when driving to the stop. Additional work had to be done to get the vehicles off the spot, and sometimes that work took a longer time.

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Figure 27: Isoisänsilta shuttle bus stop and specific signs to reserve the area [Arffman V. 2019].

In Kalasatama, it was not necessary to find a place for the GNSS RTK reference station and fix it in place before starting the shuttle's deployment. NTRIP was used to send differential GNSS data via 3G/4G network to the shuttle from a Virtual Reference Station (VRS) – a Trimnet VRS RTK service provided by Geotrim Oy [Trimnet VRS RTK 2020]. This was seen as a much easier way of arranging the necessary satellite connections for the shuttle's localization and can be recommended if such service is available to be used in the area where a robot bus pilot is implemented.

Deployment of the shuttle started on 8th of May and was finished on 20th of May lasting up to 13 days. On 21st of May passengers could hop on in the shuttle. The deployment proceeded similarly as in Kivikko, but the mapping of the route was done by different means: high precision spatial data were gathered around the route with a Mobile Mapping System (MMS) installed on the roof of a normal passenger car as seen in Figure 28. The mapping was done directly during night time to have as little other traffic as possible in the area. After the mapping was completed, the data were then transferred to the shuttle and route programming was started. The route in Kalasatama had several zebra crossings and uncontrolled intersections, so it was necessary to program many priority zones which made the deployment more complicated than in Kivikko. Unlike in Kivikko, the speed of the shuttle was programmed at max to 14 km/h because of the urban narrow

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and short streets with many intersections and zebra crossings as well as parked vehicles on the road side. The safety distance and the distance of the shuttle itself to objects near the shuttle (e.g. parked vehicles on the roadside) should have been longer if the velocity would have been higher, which was not possible. At Capellan Puistotie street, the velocity was programmed to be even slower than 14 km/h due to the narrow street and roadside parking, at around 8 km/h.

Figure 28: Installing Mobile Mapping System (MMS) on the roof of a passenger car [Rutanen 2019].

As the traffic by the route was not dense and other vehicles were not driving fast, the shuttle could be programmed to automatically handle the intersections. However, it was not possible to program the shuttle to automatically take pedestrians into account who were about to cross the zebra crossings to the left of the direction of travel of the shuttle. If the left side had been programmed as well, it could have led into a situation where a pedestrian or a vehicle that were only crossing the priority zone parallel to the shuttle could have forced the shuttle to stop. Though later during the pilot the shuttle received an update which improved this functionality and the priority zones could be programmed to the left side of the route as well. During the programming, the priority zones were tested by having someone (from the project staff) walking on the pedestrian zones and at intersections to see that they were correctly programmed and adjusted.

4.2 Analysis of the operation

During the pilot periods in Kivikko and Kalasatama the operation of the shuttle was analysed in contrast to situations that required intervention of the operator, deviations in the timetable, passengers, operator's

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conditions and tasks as well as storage, energy consumption and CO_2 emissions. These aspects are processed separately in case of both pilot periods in the following chapters.

4.2.1 General experiences and operator's intervention

During the pilots, special attention was paid to how the robot bus generally behaved on the road, among other road users and in different situations. The operator inside the bus observed individual situations that required intervention and listed them out whenever possible. The pre-intervention event was mostly related to the shuttle's stopping for some reason or a preventive measure done by the operator. These stops and measures were of the following nature:

- Soft stop (calm braking and stopping) made by the shuttle itself.
- Hard stop (lock braking and stopping) made by the shuttle itself.
- A stop by pressing the stop button from the control panel inside the shuttle or manual overtaking (or stopping) made by the operator with the on-board remote controller (an Xbox controller).

The emergency braking buttons inside the shuttle, which were also usable for the passengers, were not used once during the pilots, except for in Kivikko, when a passenger accidentally pressed one of the buttons, but the shuttle had already stopped (staying still) before that. Reasons for intervening in the operation were specified to incidents caused by the environment, technical issues and unidentified issues. An automatic and systematic way of collecting information about the situations and the number of interventions was not possible to implement (nor was it possible to measure the overall time spent and percentage in automated and manual mode during the operation). Hence, it was the responsibility of the operator to collect and report this information manually in a questionnaire on a tablet. Due to all kinds of hassle in the vehicle among other things with passengers asking questions while resolving the situation, it is clear that not all of the situations could be listed out. The purpose of this breakdown is to describe what the most common issues in the operation were and how they were dealt with.

4.2.1.1 Kivikko

In Kivikko, both the environmental and technical incidents appeared in the same proportion causing around 50% each of the listed 91 incidents. Incorrectly parked vehicles on the route were the most common issue during the pilot causing approximately 70% of the listed environmental issues. Usually vehicles were parked at the Kivikontie stop which prevented the shuttle for being able to stop at the bus stop and continuing back to the Kivikko sports park (Figure 29). Vehicles could also be parked at the regular bus stop near the Savikiekontie road or on the Kivikonlaita road on the allowed street parking area slightly too much outside of the dedicated area in which the case operator had to manually overtake them or position manually the shuttle at the bus stop. Environmental issues could be related to vegetation next to the roadside as well to prevailing weather conditions, for example to heavy rain. In case of rain the shuttle could start to brake vaguely after which the operator usually made decision whether it was safe to continue the operation.

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Figure 29: Incorrectly parked vehicle at Kivikontie bus stop [Ismailogullari 2018].

Technical issues could be related for example to loss of localization or some unidentified bug in the software. However, it was often difficult to state whether the incident was caused only just by an issue in the software or whether it was, for example some swinging hay (environmental issue) on the roadside that made the ADS to react by stopping the shuttle. General experience of the operators was that not a single day passed without the need of interfering in the functioning of the shuttle during automated driving mode. It is clear that not all of the incidents were listed out because of various distractions that the operators encountered while monitoring the drive and serving the passengers. A decision was made that the following incidents were not registered:

- **Programmed stop at the T-junction where a safe passage had to be validated by the operator by pressing the "GO" button from the control panel inside the shuttle**. This action had to be done once during each driven round trip and was a normal action according to programming of the shuttle on the route.
- **Unclear action of the shuttle when leaving the Kivikontie bus stop.** The shuttle automatically monitored the priority zone and decided whether to watch out for vehicles already on the road (coming from behind). Quite often other road users were driving over the permitted speed limit before entering the priority zone in which case the shuttle could leave from the bus stop in front of them dangerously while not being able to react to the situation as required. Sometimes other road

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users did not know, if they should yield for the shuttle or not, when the shuttle was blinking to exit the stop. In this case some road users stopped and waited for the shuttle, ending up in a situation where either one of the vehicles moved while the object (vehicle) was on the shuttle's programmed priority zone. This situation had to be resolved by the operator by pressing the "GO" button after which the shuttle left from the bus stop ignoring the priority zone.

- **Launching the shuttle for its trip from a bus stop**. While operating the shuttle in so-called bus mode and by following a fixed schedule, it had to be sent for the trip by choosing separately the next bus stop – a normal practice according to programming. After this the operator pressed the "GO" button and the shuttle left from the bus stop automatically and safely, except in situations mentioned above where the operator had to stop the shuttle manually or where "GO" had to be pressed once more to override the priority zone.
- **Shuttle's hesitating behaviour by the roundabout**. The shuttle generally behaved quite well at the roundabout and was able to dodge automatically other road users that were driving at the roundabout. However, after the shuttle had stopped by the roundabout when seeing a vehicle on the priority zone, it took a couple of seconds for it to start moving again after detecting that the route was clear. While the shuttle started to move also quite slowly, this resulted sometimes in situations that the next vehicle had time to reach the priority zone either stopping the shuttle before it could move or after it had moved a few meters ahead following up an unpleasant stop. The shuttle could not also understand whether the road user was going to turn off the roundabout in which case it could wait in vain while being an obstacle for other road users. These situations were prevented and overridden by pressing the "GO" button.

In addition to the above-mentioned incidents, the time spent in automated mode heavily decreased because of overtaking situations. Even though the speed limit was lowered from 50 km/h to 40 km/h, the speed difference between the shuttle and other road users grew high. Specifically, the Kivikonlaita road was wide, straight and had good visibility, which is why the velocity among other road users easily increased even to over 50 km/h. As there was plenty of room for other road users to overtake the shuttle on Kivikonlaita, it was thought that overtaking would not be a problem and the route would be suitable for the shuttle. However, every time overtaking happened the shuttle braked when the vehicles returned to the same lane in front of it. The shuttle braked because it thought that the overtaking vehicle was an obstacle and the ADS reacted upon this too roughly even though the vehicle returned in front of the shuttle on a longer distance. The shuttle could not distinguish that the vehicles were moving away from it. In this case, the action could be considered as a "false positive" issue where the shuttle braked needlessly under normal driving circumstances to maintain certain safety level. On this kind of route such overcautious behaviour was only more dangerous and the risk of rear-end collision increased. When other road users were overtaking the shuttle, they did it also sometimes on quite dangerous places ignoring traffic rules, for example by the bridge

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on a curve, which increased the risk for them to collide with incoming vehicles. Overtaking was not made easier by the fact that the shuttle was programmed to drive more on the left side of the lane to watch out for vegetation next to the roadside as seen in Figure 30. To avoid unnecessary and dangerous braking, the shuttle was driven manually on the fly when vehicles were overtaking it, which happened several times almost on every departure. Safety parameters related to the overtaking issue were attempted to change for less responsive but without success.

Figure 30: Overtaking truck on the Kivikonlaita road [Arffman J. 2018].

Vegetation by the shuttle's route was the reason for several false positive issues. The vegetation caused some unwanted braking or even caused the shuttle to stop completely which required the operator's intervention for the shuttle to continue operating. An effort was made to prevent this situation by cutting grass and bushes regularly (Figure 31). ADS of the shuttle seemed to be particularly sensitive for vegetation especially near the zebra crossings and intersections where the priority zones had been programmed.

The shuttle could also be disturbed by any solid objective staying on its priority zones by the route. For example, as seen in Figure 32, some construction materials had been laid partly on the driveway where vehicles exit from a parking lot by the Kivikko sports park stop. A priority zone had been programmed in this exit area to give way for vehicles coming from the right. These materials were laying on the priority zone and the shuttle thought that there was a vehicle coming. The shuttle stopped and waited until the object had gone away, which, of course, in this case was not going to happen soon. The situation was solved and the priority zone bypassed by the operator inside the shuttle by pressing "GO" from the on-board control panel.

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Figure 31: Project worker cutting grass from the roadside on Savikiekontie [Arffman V. 2018].

Figure 32: Construction material on the shuttle's priority zone by the Kivikko sports park bus stop [Rutanen 2018].

Altogether, it became clear that the route in Kivikko did not remain within the specified ODDs regarding the road characteristics and especially the speed limit, which is why the shuttle could not operate in the best possible way and the need for the operator's intervention heavily increased. The route proved why it is not recommended to operate with a shuttle in an area where the speed limitation is over 30 km/h and the road characteristics do not also otherwise encourage slow driving. Other road users were attempted to warn of the ongoing trial with warning signs, and in addition, with an attention logo located in the backwards facing screen of the shuttle seen in Figure 33. A leaflet with info about the trial and the robot bus was also distributed to local companies in the start of the pilot. However, this seemed to have nearly no effect on how most of the road users drove in the trial area, making both dangerous overtaking as well as driving close behind the shuttle.

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Figure 33: Info text on the backwards facing screen of the robot bus [Lehmusjärvi 2018].

4.2.1.2 Kalasatama

Compared with the Kivikko route, the route in Kalasatama was seemingly more suitable for the shuttle in use. The speed limit was only 30 km/h and the environment did not encourage driving fast due to the several zebra crossings and uncontrolled intersections. The number of vehicles in traffic in the area was also lower. However, in total 489 incidents were listed where the operator's intervention was needed. The difference between the number of incidents in Kivikko (n=91) is explained at least with the high number of roadside parking and narrow streets. Environmental incidents were classified to cause 82% of all the incidents 67% (n=402) of which were ensued because of parked vehicles. In this number it is not taken into account that, in several cases, the vehicle was parked on the same spot for a longer period of time, in whose case this obstacle had to be overtaken manually during each departure as long as the vehicle stayed on the spot. Typical situations where these vehicles were parked at some of the shuttle's bus stops as for example seen in Figure 34 in case of the Redi robot bus stop. These situations were listed to cause around 20 % of the incidents related to parked vehicles. For improving the information exchange of the ongoing pilot with a view to reducing incorrect parking, leaflets were distributed on the windshield of the parked vehicles such as depicted in Figure 35.

Figure 34: Vehicles parked at the Redi robot bus stop in Kalasatama [Rutanen 2019].

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Dear recipient,

A self-driving electric minibus (robot bus) is being piloted in the Kalasatama area from the middle of May to the end of November. The bus is operating on the route mainly on weekdays between 9 AM and 3 PM. The pilot is related to the Helsinki RobobusLine project (https://www.helsinkirobobusline.fi/in-english/) coordinated by Metropolia University of Applied Sciences and is part of EU wide mySMARTLife project which is contributing to sustainable city life, housing and mobility.

Your vehicle has been parked on an area that has been reserved for the robot bus and is used by the bus as a stop. Parking your vehicle at this location will cause significant harm to the bus service and your vehicle could be towed away. Please be aware of the ongoing pilot and restrictions on parking in the Kalasatama area as shown below.

Figure 35: Leaflet distributed on the windshields of incorrectly parked vehicles on the shuttle's route in Kalasatama [Rutanen 2019].

Around 50 % of the incidents related to parked vehicles were merged to be caused of situations where a vehicle or some part of it came a bit too much outside of the allowed roadside parking area, as seen in Figure 35 for instance. In Figure 36 at least the van's mirror is coming outside of the allowed parking area on Capellan Puistotie street. In some situations a vehicle did not even seem to come outside of the allowed parking area, but the shuttle still stopped even though it would have had space to continue the ride on the programmed trajectory. This happened because the conditions for the required safety distance was not met – the trajectory of the shuttle was programmed perhaps a bit too close for the allowed roadside parking area at some points of the route. On the other hand, the reserved area for parking in Kalasatama was around 2

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meters wide which seemed not be enough on every occasion for the parked vehicles to completely fit inside the dedicated parking area and maintain a sufficient distance to the driving road, if thinking of the impact on the operation of the shuttle. The width of the road by the route was otherwise quite narrow, varying between 6-7 meters, which prevented programming of the trajectory more on the left side of the lane as there would not have been enough space left for oncoming vehicles driving in the opposite direction to the shuttle.

Figure 36: A parked van on the roadside on Capellan Puistotie street prevents the shuttle from moving [Rutanen 2019].

Encountering other vehicles on the route, especially the HSL bus lines 50 and 59 in the intersection of Junonkatu and Parrulaituri streets were causing around 17% (n= 402) of the listed environmental incidents. In these cases, the operator manually stopped the shuttle at a longer distance before the intersection to give space for the HSL bus to turn or made some manual manoeuvring if the shuttle had already reached the intersection. Sometimes the HSL buses allowed the shuttle to go first in the intersection, even though the HSL was coming from the right and had the right of way. In these cases, the operator had to override the priority zone for allowing the shuttle to continue the ride. Around 9% (n=402) of the listed environmental incidents were caused due to some construction equipment and material or street work as seen in Figure 37 near the Redi robot bus stop. The equipment on the road had to be passed by driving the shuttle manually as they were located partly on the shuttle’s trajectory.

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Figure 37: Street work on the shuttle’s route near the Redi robot bus stop in Kalasatama required manual driving [Rutanen 2019].

The remaining 18% of all the listed incidents (n=489) was categorized to be caused by technical or unidentified reasons. These issues were mainly identified to result from loss of localization of the shuttle or some software issue after which the bus stopped and some measures had to be taken. If considering the measures that were taken by the operator in case of all of the incidents (n=489), in 62% of the incidents an obstacle was overtaken and the ride was continued in automated mode. In 18% of the cases the shuttle stopped and the ride was continued by pressing the “GO” button from the control panel of the shuttle. In 15% of the cases the shuttle was driven manually for a longer distance to a safe spot or to the next bus stop where the ride was continued when possible.

In Kalasatama, there were not any specific incidents that were left unregistered on purpose. Due to the several zebra crossings by the route a noted deficiency in the shuttle’s operation was the inability to take pedestrians into account that were about to cross the zebra crossings to the left of the direction of travel of the shuttle. Though these situations were not registered to a large extent but required extra caution from the operator. Towards the end of the pilot in October 2019 the shuttle received an update which improved this functionality and the priority zones could be programmed to the left side of the route as well. This update also improved the shuttle’s functioning in situations where other vehicles were overtaking the shuttle and returned in front of it by resulting in not as harsh braking as in Kivikko. However, it was not possible to get a very clear picture of this improvement as the overall velocity of the shuttle in Kalasatama was slower than in Kivikko (not necessary to brake as harshly for being able to maintain a sufficient safety distance) and

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overtaking was not happening very often. In the update, a feature that ignores stationary objects on the priority zones was also included. This meant that when an object stood still around 3 seconds, the shuttle ignored the priority zone and continued the ride automatically. If the object had moved within the 3-second time frame, the shuttle would have stopped again until reaching the outside of the sphere of the influence of the priority zone. This kind of functionality would have been particularly useful for instance in Kivikko in the situation described previously in Figure 32.

In the same way as in Kivikko, the pilot route in Kalasatama did not either remain within the specified ODDs which did not allow the shuttle to work fully automatically without the intervention of the operator. If considering the operational environment in Kalasatama, the narrow streets combined with roadside parking were the main reasons which made the environment unsuitable for the shuttle. In addition, the temporary arrangements for organizing the shuttle´s bus stops were not clear for other road users and additional actions had to be taken by the operator because of others not obeying traffic rules and parking their vehicles in these restricted areas. On the other hand, both in Kivikko and in Kalasatama the most significant shortcoming of the shuttle was the inability to automatically overtake obstacles or the possibility to deviate otherwise from the programmed trajectory. This ability would have solved the majority of the cases and reduced significantly the amount of operator's intervention. Taken into account that on open streets in road traffic unexpected situations can happen, it is vital that the shuttle can solve these problems in the future automatically or with the assistance of a remote operator.

The clearest incidents in which intervention was needed, were situations where the shuttle stopped by itself and the ride had to be continued by pressing some button or using the remote controller to overtake something. However, it is not possible to unambiguously say whether in case of all confronted incidents in Kivikko and in Kalasatama it was always necessary to intervene in the functioning of the shuttle, excluding normal practices and actions according to the programming. Subjective experience of the operator also influenced the way in which different situations were handled. Anyhow, the way the bus was behaving in several cases was not fluent when considering normal practices and rules in road traffic. According to the operators, it was necessary to intervene in the operation of the shuttle within several departures during the operational day. Especially since the bus and passengers inside was on the responsibility of the operators, they rather preferred to rest assured, than took unnecessary risks.

4.2.2 Deviations in the operation

For the pilots in Kivikko and Kalasatama, fixed schedules were stablished and, according to them, the shuttle was operating on the route. On both routes, the shuttle was planned to operate on weekdays for six hours between 9 AM and 3 PM including 18 departures per day during the six months´ pilot periods. Departure intervals were 20 minutes from a bus stop of the route and the shuttle waited for around 5 minutes at the bus stops before continuing its ride to the next stop (except in case of Polariksenkatu bus stop in Kalasatama which was in the middle of the route). The routes were seen as loops having only one direction of travel.

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The accuracy of measuring the timetables was not exact: a departure was considered as undriven when a departure was not started before the next departure. A day was counted as operational, if even one of the days planned departures materialized. The operator on board in the shuttle was responsible for keeping track of the realized and undriven operation through filling manually an Excel sheet on a tablet. The following separate chapters explain and analyse how the planned schedule was realized and what the reasons for deviations in case of both of the pilots were based on the observations made by the operators, followed by a summary of the deviations.

4.2.2.1 Kivikko

The pilot period in Kivikko took place between 14th of May and 14th of November 2018. Table 3 represents the realization of the operating days, the departures and the hours during the planned operating schedule of the pilot period.

Table 3: Realization of the planned operation of the shuttle in Kivikko.

14.5-14.11.2018	Operating days	Departures	Hours
Planned	130	2310	770
Realized	97	1564	516
Deviation (n)	33	746	254
Deviation (%)	25	32	33
14.5.-31.8.2018	Operating days	Departures	Hours
Planned	77	1370	465
Realized	75	1248	411
Deviation (n)	2	122	45
Deviation (%)	3	9	10

Table 3 has been divided into two separate periods of which the upper one (14.5-14.11.2018) is representing the realization of the whole planned operating period and the lower one (14.5-31.8.2018) which can be considered as the summer period. In total, 25 % of the planned operating days (n=130), 32% of the planned departures (n=1370) and 33% of the planned operating hours (n=465) were undriven. The reasons for undriven departures were studied and general reasons for deviations throughout the pilot period can be listed as follows:

- **Connection issues between the robot bus and fixed RTK base**. Approximately every two weeks the connection between the shuttle and RTK base at the roof of the skiing hall was interrupted. In this case, the base had to be rebooted. As the base was behind a closed door and the project workers (operators) did not receive a key for the task, the skiing hall staff had to be called to give

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access to the roof. Sometimes there were no staff nearby and it could take several hours or even the entire day before the base could be rebooted.

- **Heavy rain.** When it was raining hard enough and the bus started to brake vaguely because of that the operator on board decided usually to stop the operation.
- **Sorting out abnormal behaviour observed in the robot bus operation**. If something abnormal was found out in the operation of the shuttle, an effort to solve the problem was made as soon as it was noticed. This could delay the operation while the issue had to be often filmed and some logs might be needed to be retrieved from the shuttle's computer.
- **Work machines or building supplies on the robot bus route**. On the nearby sorting station, a construction work started and as a result of it some supplies were laid on the bus's path. However, the situation, depicted in Figure 38, could be solved quite quickly by contacting the construction operator.
- **Vehicles parked on the route**, for example at the robot bus stop. If a vehicle was parked at the bus stop it was not safe to continue the operation until the vehicle was removed. The bus would have needed to be driven manually on the path after which it could have taken time to restart it in automated mode while staying idle on the driveway.
- **Abnormal traffic arrangements on the path**. In October a charter bus began to burn on Kivikonlaita road and was parked at the roadside (Figure 39). The traffic going pass the burning bus was stopped. Afterwards police guided the traffic on an alternative route passing a nearby gas station until the situation was settled. This alternative route had to be driven manually with the shuttle and a decision was made to stop the operation until the situation was cleared. Also training of a rescue department was arranged in Kivikonlaita during the pilot on one day. The traffic was guided through a detour but this did not affect the shuttle's operating schedule (was not counted as deviation) as the shuttle was driven manually through these arrangements.

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Figure 38: Construction supplies on the robot bus's path in Kivikko [Rutanen 2018].

Figure 39: Burning charter bus on Kivikonlaita road [Ismailogullari 2018].

If studying specifically the reasons for deviations during the summer period (14.5-31.8) the reasons can be listed as follows:

- **Hot weather**, which is why the air conditioning had to be on for several hours during the day. Therefore, the 80V battery of the shuttle (33 kWh) did not last whole days operation and a couple of departures from the end of the day had to be cancelled.

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- **Installation of watering bags because of dry and hot weather**. The wooden constructs around the frames of growing trees used to improve the shuttle's localization under the bridge, needed to be cut at the bottom for fitting watering bags inside them (Figure 40). After cutting partly the constructs, the functionality needed to be tested but the action did not seem to affect the behaviour of the shuttle.

Figure 40: Watering bag between frames of growing trees (no wooden constructs on the nearest tree) [Rutanen 2018].

Reasons for deviations during the autumn period (1.9-14.11.2018):

- **Software update**. On 11th of September the shuttle's software was updated which was not suitable for the shuttle and route in Kivikko. Update brought a feature in which the safety zones were used also in manual driving mode, which is why it was not possible to operate on the route, while the shuttle braked when vehicles overtook it even it was driven manually. It took 6 days to solve the issue (no operation during this time) and eventually a decision was made to use the old software version.
- **80V battery charging issue probably caused by cold weather**. The shuttle was stored outside throughout the whole pilot period. During the first weekend of October (6-7 October, 2018), the temperature was below 0C° which most likely caused an issue with the shuttle's 80 V battery after starting the operation on Monday. The shuttle was over-speeding (driving over the normal programmed speed of 18 km/h) on a downhill on the route which indicated also that the regenerative

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braking system did not work properly. Finally, after 14 departures and 4 hours of driving, the shuttle stopped next to the Kivikko sports park bus stop and did not move anymore. After trying to solve the issue, the shuttle was towed to its charging place and it was found out that the shuttle does not receive power. The shuttle was later transported by trailer to Metropolia's garage where the 80V battery was replaced (Figure 41). The operation was started again on 22nd of October but after a few days of operation the same over-speeding issue occurred and a decision was made to stop the operation until further notice by the supplier. Eventually the shuttle was not operational after 25th of October and the final 14 days of planned operation were not realized. In total 23 days and 414 departures were left undriven because of the issue related with the shuttle's battery.

Figure 41: Towing robot bus on a trailer after facing technical issues in Kivikko [Ismailogullari 2018].

Issues with the shuttle's software update and battery in October and November were clearly causing most of the noted issues and increased the number of deviations disproportionately high. 29 days were left undriven because of these issues causing in total 88 % of the noted deviations with the operational days (n=33). Likewise, 522 departures did not materialize due to these issues causing in total 70% of the noted deviations in case of the departures (n=746). If excluding the deviations caused by the software update and battery from the overall realization of planned operation during the whole pilot period, the share of deviations would have been around 3 % (4 undriven days) in case of the planned operational days (n=130) and 10% (224 undriven departures) in case of the planned departures (n=2310).

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4.2.2.2 Kalasatama

The pilot period in Kalasatama took place between 21st of May and 22nd of November 2019. Table 4 represents the realization of the operating days, the departures and the hours during the planned operating schedule of the pilot period.

Table 4: Realization of the planned operation of the shuttle in Kalasatama

21.5 - 22.11.2019	Operating days	Departures	Hours
Planned	123	2178	714
Realized	84	1424	463
Deviation (n)	39	754	251
Deviation (%)	32	35	35

In total 35% of the planned operating days (n=123), 35% of the planned departures (n=2178) and 35% of the planned operating hours (n=714) did not materialize. The reasons for undriven departures were somewhat different than in Kivikko. The reasons were studied and general reasons for deviations throughout the pilot period can be listed as follows:

- **Sorting out abnormal behaviour observed in the robot bus operation**. If something abnormal was found out in the operation of the shuttle, it was solved as soon as it was noticed. This could delay the operation while the issue had to be often filmed, and some logs might have needed to be retrieved from the shuttle's computer.
- **Uploading of small software upgrade packages to the shuttle by the shuttle's supplier** after which the functioning of the shuttle had to be tested without passengers on board.
- **Door issue**. Due to a faulty micro switch of the shuttle's door, the shuttle did not work in automated mode as it thought that the doors were not closed. It took 2 days to find and fix the issue with remote assistance of the supplier and the shuttle was not operational at that time.
- **Repetitive localization issue by the Redi robot bus stop and its vicinity**, because of which the shuttle was crossing partly the curb between the pedestrian street and the driveway and did not remain exactly on the programmed trajectory as seen in Figure 42. The issue was noticed for the first time in June after which some logs were sent to the shuttle's supplier. It was found that it was not safe to continue the operation and the shuttle was out of operation (not taking passengers on board) between 14th of June and 16th of July. During this period the shuttle was every now and then tested and logs were collected according to the supplier's instructions. After some updates the issue was fixed but on 28th of August the issue was again noted and the shuttle was not operational until 18th of September. After a map update the operation could be continued, but vague behaviour

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still occurred to some extent. On 8th of October a supplier's deployment engineer came to program the route again and updated the shuttle's software. The shuttle was not operational at the time of these actions between 8th and 11th of October. In total 36 days and 648 departures did not realize due to this issue.

- **Shuttle's broken outside facing info screen**. The screen was replaced with a new one (within few hours) by the shuttle's supplier during the operational hours of the shuttle.
- **Snowfall**. On 7th of November it was snowing and the shuttle's LiDAR radars saw the snowflakes as obstacles because of which the shuttle did not move at all or the operation was very discontinuous.
- **Fog**. On 18th of November there was thick fog in the morning as depicted in Figure 43. The shuttle saw the fog as an obstacle and did not move in automated mode.
- **Interference in the mobile network of Telia telecommunications service provider**. The shuttle was using mobile network connections (3G/4G) from Telia to communicate with the supplier's remote supervision and Trimnet VRS RTK service for GNSS localization. As the connection was lost due to the interference, the shuttle did not work in automated mode. However, the shuttle was driven manually at the time and no deviations were counted due to this issue.

Figure 42: The shuttle crossing the curb between the pedestrian street and the driveway in Kalasatama [Rutanen 2019].

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Figure 43: Fog on the shuttle's route in Kalasatama [Bremer 2019].

Localization issue was clearly the most significant cause of deviations due to which 36 days in total and 648 departures did not realize in Kalasatama. This issue covered 92% of the noted deviations within the operational days (n=39) and 86% of the noted deviations within the departures (n=1424). If excluding the deviations caused by the localization issue from the overall realization of the planned operation during the pilot period, the share of deviations would have been around 2% (3 undriven days) in case of the planned operational days (n=123) and 5% (106 undriven departures) in case of the planned departures (n=2178).

4.2.2.3 Summary of the deviations

When considering the overall deviations on the pilot routes of both Kivikko and Kalasatama, it must be noted that not all of the deviations were caused due to issues with the shuttle. Also, Metropolia and Rolan, as an "operator company", did not have the resources of an official public transport operator company nor more than one bus to be used for the pilots (no spare vehicles available). In Kivikko, the problem with the fixed RTK reference station could have been solved quite easily just by receiving a key to have access to the roof

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where the base had been mounted. The issue with warm weather during summer was because the operating schedule during the day (6 hours) was too long for one shuttle to manage and no charging possibility was possible by the bus stops. On the other hand, when the air conditioning (or heating) could be turned off, the shuttle could run over two days (12 hours) before it had to be charged, while driving according to the fixed schedules during the pilot. Some of the issues could have been settled, if other road users would have adhered to traffic rules, for instance not parking a vehicle at an official bus stop which was used in Kivikko.

Nevertheless, when driving in real traffic conditions and taking into account that all kinds of situations can happen, it is necessary that the vehicle can operate in the future in the required conditions year-round and handle different situations independently or with the assistance of a remote operator. For a normal bus driven by a human, none of these encountered issues would have caused deviations in the operating schedule, excluding technical breakdowns which can occur also in case of human driven vehicles. For instance, annual basis the share of uncovered departures of all HSL's bus traffic is around 0.15-0.17% [Kyllönen 2019a]. Referring to the realization of the planned operation in Kivikko and Kalasatama, especially the reliability of one shuttle is still quite far away from achieving this. However, the realization of the planned schedule in Kivikko and Kalasatama describes the experimental operation of one vehicle – rather than an operational service – in a certain area with certain type of operation, and the results may not be generalized in all environments and conditions. In any case, same kind of issues could be expected on any open road conditions, especially with adverse weather.

The pilot-like nature of the shuttle's operation and passengers brought its own challenges in meeting the exact set schedule of the operation and calculation of the number of passengers during the operational time. Sometimes large groups of visitors specifically came to test the shuttle filling the whole capacity of the shuttle for several rounds/departures. In this kind of situations, a decision was made to leave from a bus stop as soon as the shuttle was full. However, these situations were not counted as deviations.

Deviations to the operating timetable which occurred during the pilots were informed about through dedicated channels. Departures could be cancelled through a HSL's system which further exported the information to the Journey Planner where the timetable and covered or uncovered departures could be seen. Metropolia as an operator was responsible for delivering the information of deviations to HSL. In addition to this a Twitter account (@HRLpoikkeusinfo) and its feed were used on the pilot's website as seen in Figure 44. Links for this Twitter account and website could also be seen in the bus stop signs at the pilot sites.

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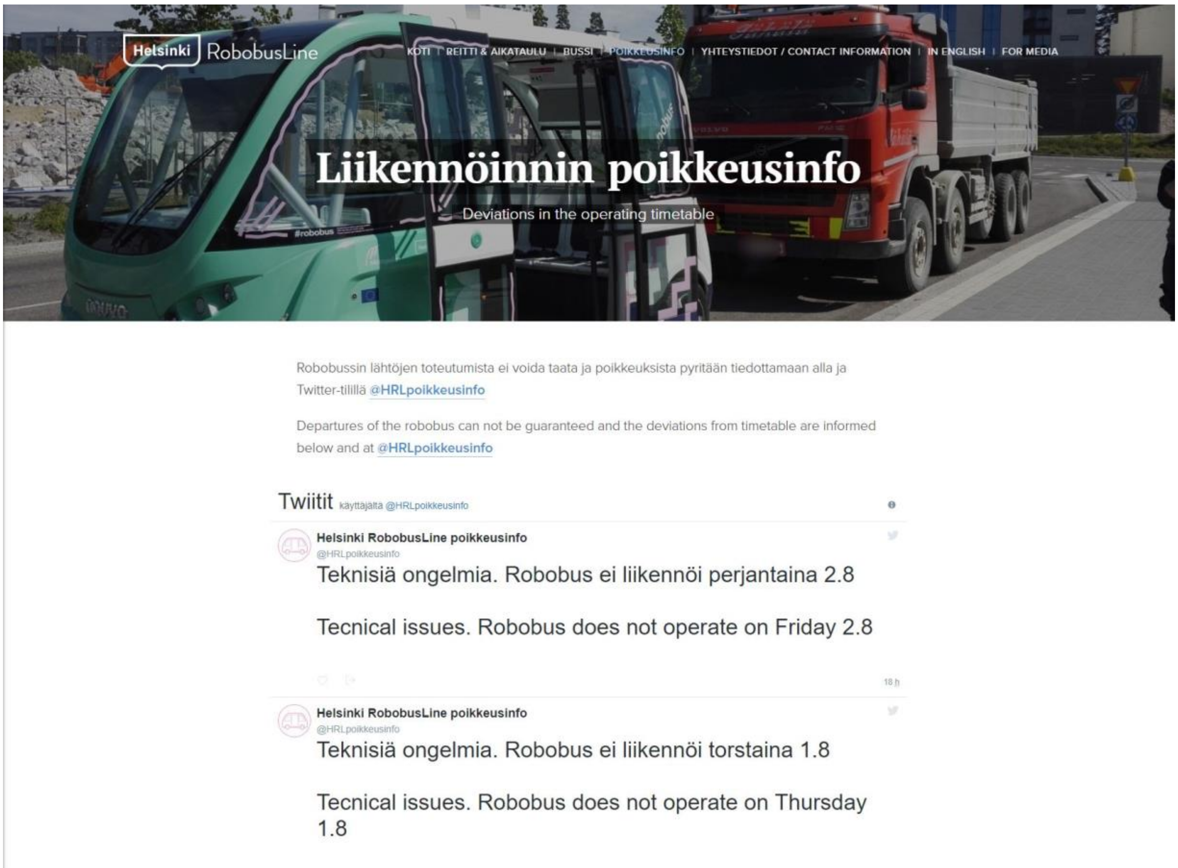

Figure 44: Twitter feed on pilot's website [Helsinki RobobusLine 2019].

4.2.3 Passengers

During the pilot periods in Kivikko and Kalasatama, passengers were welcome to enter the shuttle free of charge during the operational hours. The shuttle could take on board at max 8 passengers plus the operator at the time, so the maximum capacity was 9 persons in total. If the operator would have had a D class driver's licence, the shuttles theoretical maximum capacity of 15 passengers could have been filled. However, as the shuttle was registered with test plates as a passenger car, the maximum capacity was, therefore, limited to 9. Basically, it was also required that all the seats (in total 11 in the shuttle) where passengers were sitting had seatbelts. Standing passengers were not allowed during the pilots.

The on-board operator was responsible for limiting the number of allowed passengers who could enter the shuttle at a time and counted manually the total number of passengers during the pilots. Simultaneously, when counting the number of passengers, the operator tried to find out answers to the following questions:

- How did the passenger arrive to the robot bus?
- Was the robot bus a part of the passenger's travel chain?
- If the passenger came by car, was the reason for the trip to specifically see the robot bus?
- Did the robot bus service affect the passenger's decision to use public transport?

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In addition, the passengers were invited to answer a more comprehensive survey of experience of travelling in a driverless shuttle and give their views about mobility solutions in the future. More specifically the survey dealt with questions about the following four categories:

- Comparing experience of travelling in a robot bus to travelling in a conventional bus.
- Estimation of changes that will happen in the responder's mobility routines and habits by 2030.
- The Responder's vision about privately-owned cars in the future (by 2030).
- How important the responder considers different factors (such as environmental friendliness, health benefits, costs, etc.) when deciding how to move from one place to another.

The passengers answered the survey using a tablet by filling in the survey during or after the trip on the robot bus. The questions were mainly answered on Likert scale from 1 to 7 where for instance 1 represented "much worse" and 7 "much better". These surveys and general views of the passengers are analysed separately in case of the pilots in the following chapters.

4.2.3.1 Kivikko

During the pilot period in 2018, 1294 passengers travelled by the robot bus in Kivikko. Table 5 presents the number of passengers per month and shows their relation to the operational hours, departures and operational days of the robot bus. The summer vacation months June, July and August were clearly the most popular months for travelling in the robot bus. On the other hand, especially the effect of the software update and battery issue towards the end of the pilot period was directly affecting the amount of operational time of the bus, and thus, the number of passengers.

Table 5: The number of passengers per month in Kivikko pilot.

Month	Passengers	Operational hours	Departures	Operational days
May	144	56	186	12
June	360	112	334	20
July	322	119	358	21
August	287	123	370	21
September	136	66	197	13
October	45	40	119	9
November	0	0	0	0
In total	**1294**	**516**	**1564**	**96**
Month	Passengers	Passengers / operational hours	Passengers/departures	Passengers/operational days

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May	144	2,6	0,8	12
June	360	3,2	1,0	18
July	322	2,7	0,9	15,3
August	287	2,3	0,8	13,7
September	136	2,1	0,7	10,5
October	45	1,1	0,4	5
November	0	0	0	0
In total during the pilot period	**1294**	**2,5**	**0,8**	**13,5**

The number of passengers per departure during the pilot period (0.8) indicates that the demand for such mean of transport was not very great in the area, or the shuttle could not fulfil the need in the best possible way. The sparse interval, relatively slow speed, the total length of the route and the timing of the operation of the shuttle most likely also affected the attractiveness of the pilot service. For the passengers who were using a HSL bus as part of their travel chain when arriving to the Kivikontie bus stop, it would have been important to match the departure of the shuttle accordingly to this HSL bus to shorten the layover time in the travel chain towards the Kivikko sports park and increase the number of potential shuttle users. Sometimes the HSL's journey planner could for instance recommend a person to walk to the sports park instead of using the shuttle, as the timetables did not match with each other well enough. This was affected by the relative slow speed of the shuttle compared to walking as well as the short length of the route, which did not either necessarily encourage to use the shuttle as part of the travel chain especially if the weather was favourable and the person was in good health.

If the number of passengers is compared for example to the normal HSL bus line 94B operating partly on the same route where the robot bus was operating, it is possible to get a picture of the activity in the area. Between 14th of May and 14th of November there were 2367 rises on 94B together from each end of the bus line and overall at max 2500 passengers when taken also passengers into account using a mobile ticket[1] [Kyllönen 2019a]. However, it must be considered that the line 94B departed eight times per weekday (four departures from each end of the bus line per weekday) while the robot bus departed 36 times per weekday (18 departures from each end of the line per weekday). Then, again, two of the 94B's departures were driven by a small bus with passenger capacity up to 16 and the rest six departures with a bus with passenger capacity between 32 and 56, while the maximum capacity of the robot bus was 8 passengers plus the operator (as registered as a passenger car).

[1] Mobile tickets are not counted by the ticketing checking system inside a HSL bus, they are only shown for the driver

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Figure 45 shows the modal distribution on how the passengers arrived to the robot bus in Kivikko. Approximately 40% (n=1294) of the passengers came by walking which indicates that they were living nearby and possibly e also used the bus as part of their travel chain when going to or leaving from the sports park. The second largest user group (30%) came by car which indicates the fact that they came specifically to see the robot bus or were just bypassing the area while testing the robot bus along their trip. When the passengers were asked if they used the robot bus as part of their travel chain it could be concluded that approximately 70% of the passengers (n=1202) were just trying out the robot bus (travelled a round trip by the bus back to the starting point) and did not use the bus as part of their travel chain.

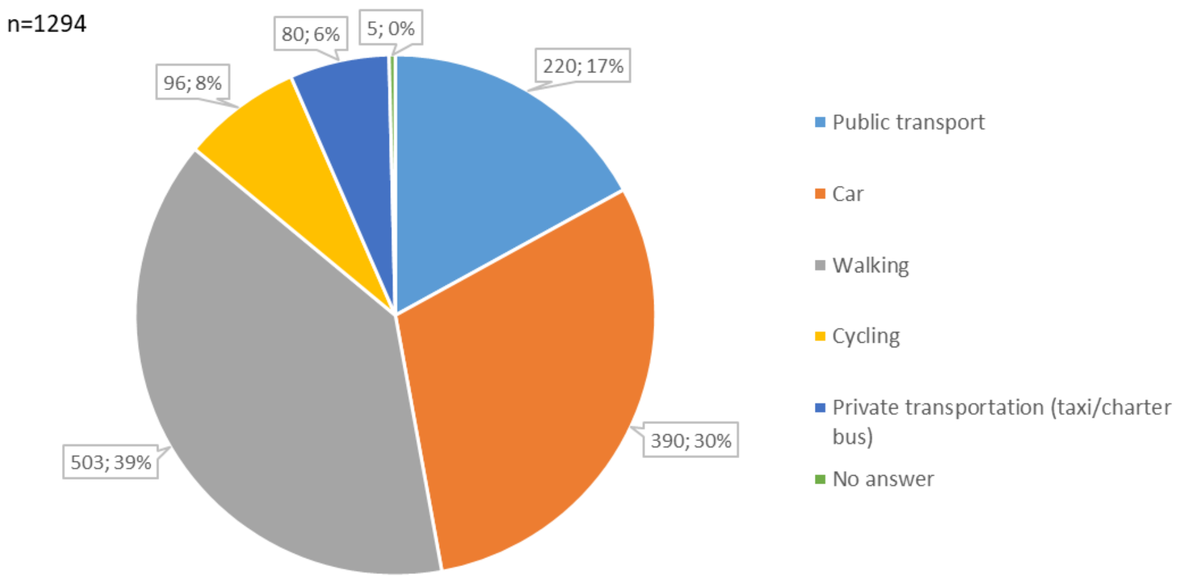

Figure 45: How did the passenger arrive to the robot bus in Kivikko?

When analysing the passengers who came to the robot bus by car (n=374) it was found out that approximately 52% of these passengers came specifically to test the robot bus. The other half of these passengers came to the sports park because of some other reason or were just bypassing the area while testing the robot bus along their trip.

One of the aims of the pilot was to find out if the robot bus service affected the passenger's decision to use public transport when going to or leaving from the sports park. In other words, did the passenger leave his/her car at home and use public transport instead while knowing that the public transport connections to Kivikko sports park had been improved (with automated technology). According to the results, approximately 23% (n=202) of the passengers who arrived at the robot bus by public transport, expressed that the operation of the robot bus affected positively on their decision to use public transport. However, it is not certain whether the passenger would have come to the sports park at all, if the robot bus would not have been operating there.

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141 passengers in Kivikko answered a more comprehensive survey of their experiences of travelling in a driverless shuttle and of their views about mobility solutions in the future (Annex 1). The first section of the survey advised the respondent to compare his/her travelling experience in a robot bus to travelling in a conventional bus. For example, when asked about traffic safety (Figure 46), 85% (n=141) considered it to be on scale 4 or higher (on the same level or better as in conventional buses). The same kind of results occurred with the question of personal security on board (Figure 47), in which 93% (n=141) of the responders thought that it was 4 or higher. According to these results, the passengers generally thought that they felt safer while travelling in the shuttle than in a conventional bus. However, it must be considered that a responsible person was still on board in the shuttle and the atmosphere was happy and conversational between the passengers. Many of the passengers came with groups to try out the bus together, which may also have affected on the way they felt during the trip.

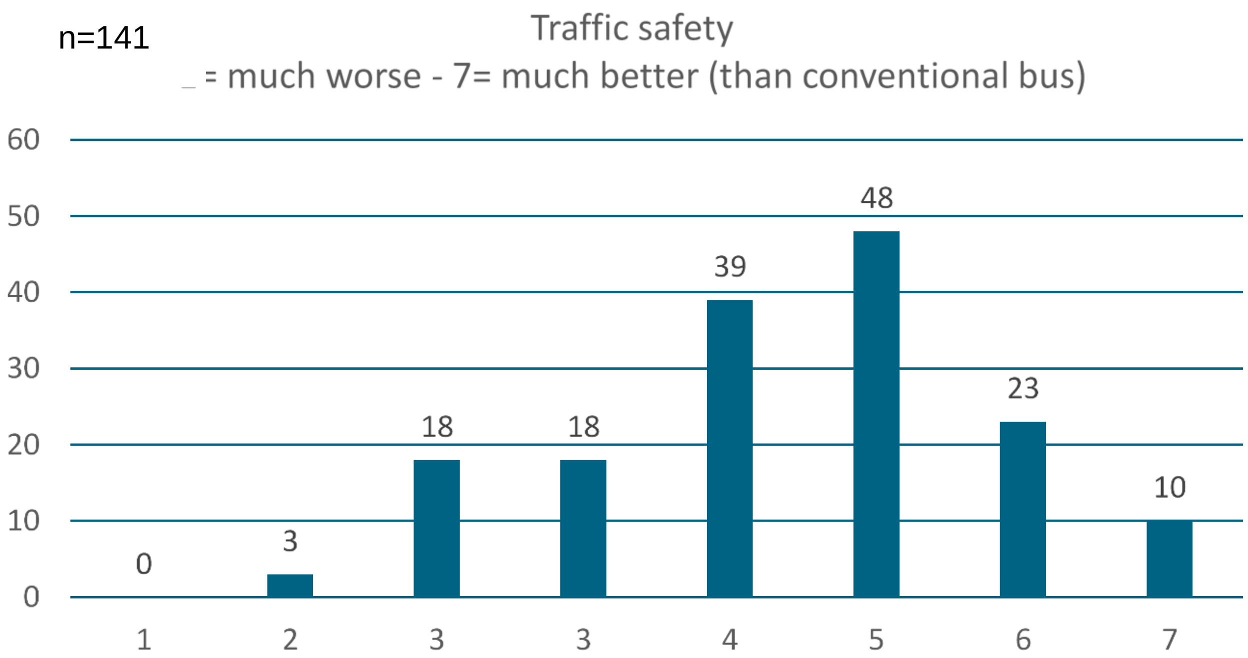

Figure 46: Survey result about considered traffic safety in Kivikko pilot.

Figure 47: Survey result about considered personal security on board in Kivikko pilot.

Travel comfort was considered to be mainly better in the robot bus than in a conventional bus. Approximately 57% of the responders thought that the travel comfort was on scale 5 or higher as shown in Figure 48. As most of the passengers came to test the robot bus rather than to use it for getting from one place to another, they were usually not in a hurry. The passengers seemed to be only more curious and excited when something unusual happened, for example sudden stops, which may have affected on the experience of travel comfort positively.

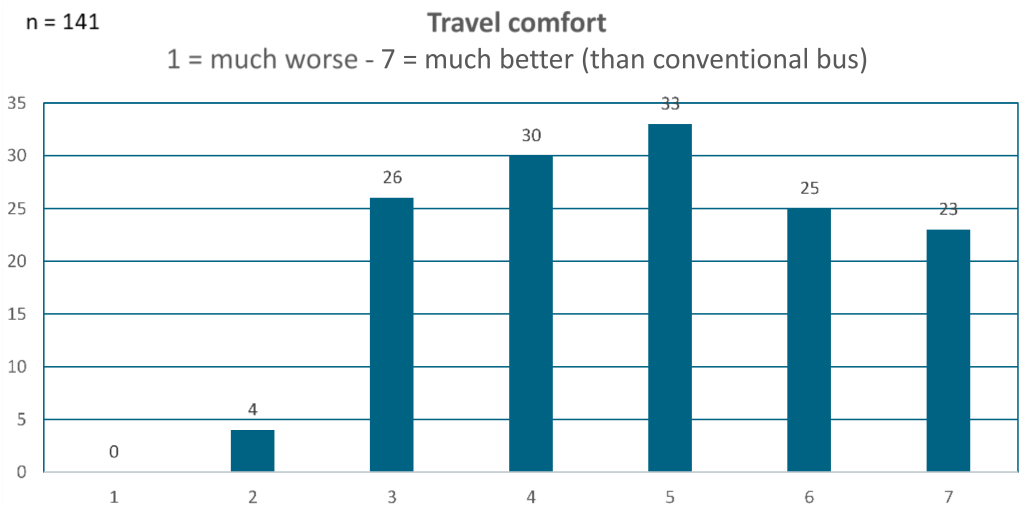

Figure 48: Survey result about travel comfort in robot bus in Kivikko pilot.

4.2.3.2 Kalasatama

During the pilot period in 2019, 3891 passengers travelled by the robot bus in Kalasatama. Table 6 presents the number of passengers per month and what their relation to the operational hours, departures and operational days of the robot bus is. In the same way as in Kivikko, the number of passengers was greatest

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during the summer vacation months June, July and August. Even though there were major deviations in the pilot in Kalasatama and compared to Kivikko even more planned days, hours as well as departures were left uncovered, the total number of the passengers was around three times higher than in Kivikko. With this in mind the route in Kalasatama was more reasonable and offered more value to the passengers. 2.7 passengers were travelling by the robot bus per departure which meant that around third of the bus's capacity was fulfilled in case of each departure. As Kalasatama represented an urban environment near the city center of Helsinki and a lot of people were moving in the area on a daily basis, it was also expected to have more passengers on board compared to Kivikko.

Table 6: The number of passengers per month in Kalasatama pilot.

Month	Passengers	Operational hours	Departures	Operational days
May	307	46,5	142	8
June	530	39,3	120	9
July	869	62	194	11
August	631	75,3	228	14
September	311	40,6	124	8
October	786	106,2	331	18
November	457	93,1	285	16
In total	**3891**	**463**	**1424**	**84**
Month	Passengers	Passengers/operational hours	Passengers/departures	Passengers/operational days
May	307	6,6	2,2	38,4
June	530	13,5	4,4	58,9
July	869	14,0	4,5	79,0
August	631	8,4	2,8	45,1
September	311	7,7	2,5	38,9
October	786	7,4	2,4	43,7
November	457	4,9	1,6	28,6
In total during the pilot period	**3891**	**8,4**	**2,7**	**46,3**

Figure 49 illustrates the modal distribution on how the passengers arrived to the robot bus in Kalasatama. Approximately 69% (n=3891) of the passengers came by walking which could indicate that they lived nearby and possibly also used the bus as part of their travel chain for instance when visiting the close by shopping

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mall Redi. Public transport users represented the second largest user group by 21% (n=3891). 7% (n=3891) of the passengers came by car which indicates the fact that they came specifically to see the robot bus or were just bypassing the area while testing the robot bus along their trip. Approximately 45% of the passengers (n=3890) were just trying out the robot bus, when asked if the robot bus was used as part of the passenger's travel chain or sawn that the passengers were riding a round trip in the bus.

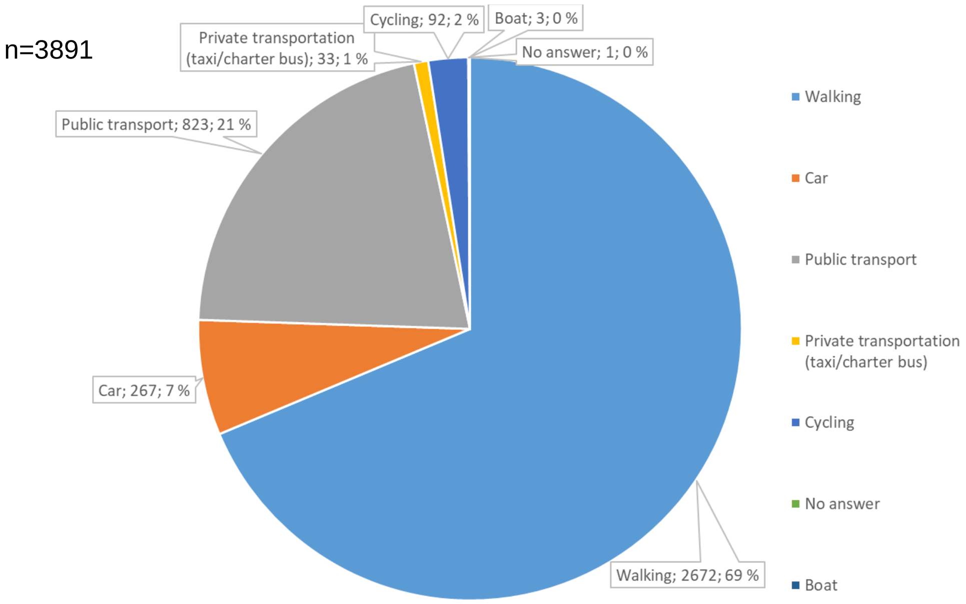

Figure 49: How did the passenger arrive to the robot bus in Kalasatama?

When analysing the passengers who came to the robot bus by car (n=267), it was found out that approximately 52% of these passengers came specifically to test the robot bus, which is almost exactly the same percentage than in Kivikko. Another half of these passengers came to Kalasatama because of some other reason or where just bypassing the area while testing the robot bus along their trip. When asked if the robot bus service affected the passenger's decision to use public transport when moving in the area, around 7% (n=620) stated that the bus affected positively on the decision to use public transport. However, it is not certain whether the passengers would have come to the area at all if the robot bus would not have been operating there.

217 passengers in Kalasatama answered the survey of their experiences of travelling in a driverless shuttle and their views about mobility solutions in the future (Annex 2). The first section of the survey advised the respondent to compare his/her travelling experience in a robot bus to travelling in a conventional bus. For example, when asked about traffic safety (Figure 50), 92% (n=217) considered it to be on scale 4 or higher (on the same level or better as in a conventional buses). In case of personal security on board (Figure 51), where 94% (n=217) of the responders thought that it was 4 or higher. According to these results, the passengers generally thought that they felt safer while travelling in the shuttle than in a conventional bus.

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However, it must be considered that a responsible person was still on board in the shuttle also in the Kalasatama pilot.

Figure 50: Survey result about considered traffic safety in Kalasatama pilot.

Figure 51: Survey result about considered personal security on board in Kalasatama pilot.

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Travel comfort was considered to be mainly better in the robot bus than in a conventional bus. Approximately 65% of the responders thought that the travel comfort was on scale 5 or higher as depicted in Figure 52. In Kalasatama around half of the passengers came just to test the robot bus rather than to use it for getting from one place to another. In the same way as in Kivikko passengers seemed to be only more curious and excited when something unusual happened, for example sudden stops, which may have affected on the experience of travel comfort positively.

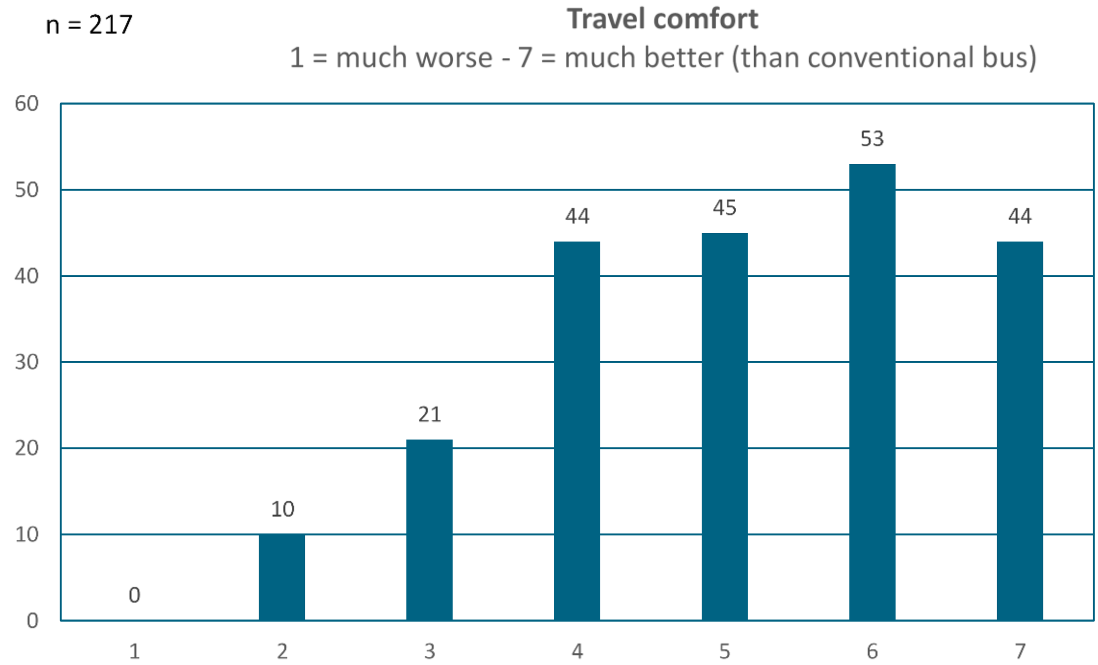

Figure 52: Survey result about travel comfort in robot bus in Kalasatama pilot.

In the survey in Kalasatama it was also possible to answer the question: which mode of transport would the passenger use for this trip (if available) if he/she would not be travelling with the robot bus. These answers can be seen in Figure 53. In total 144 answers were received and according to the survey it seems that the passengers would have mostly walked or used a bicycle for this trip. In addition, the survey also included an open feedback section where the passengers could freely write their thoughts of the ride in the bus. It was noteworthy that several feedbacks addressed issues related to the on-board safety driver. The passengers praised often the safety driver as a competent and welcoming part of the ride which does not give a genuine picture of a driverless vehicle, as the intention is to not have a driver inside the vehicle in the future at all. It could be possible to arrange a remote video connection and talk to the passengers and the remote operator, but depending of the level of autonomy of the shuttle and the desired cost level, a continuous connection is most likely not possible, as the remote operator should be able to monitor several vehicles simultaneously in the future.

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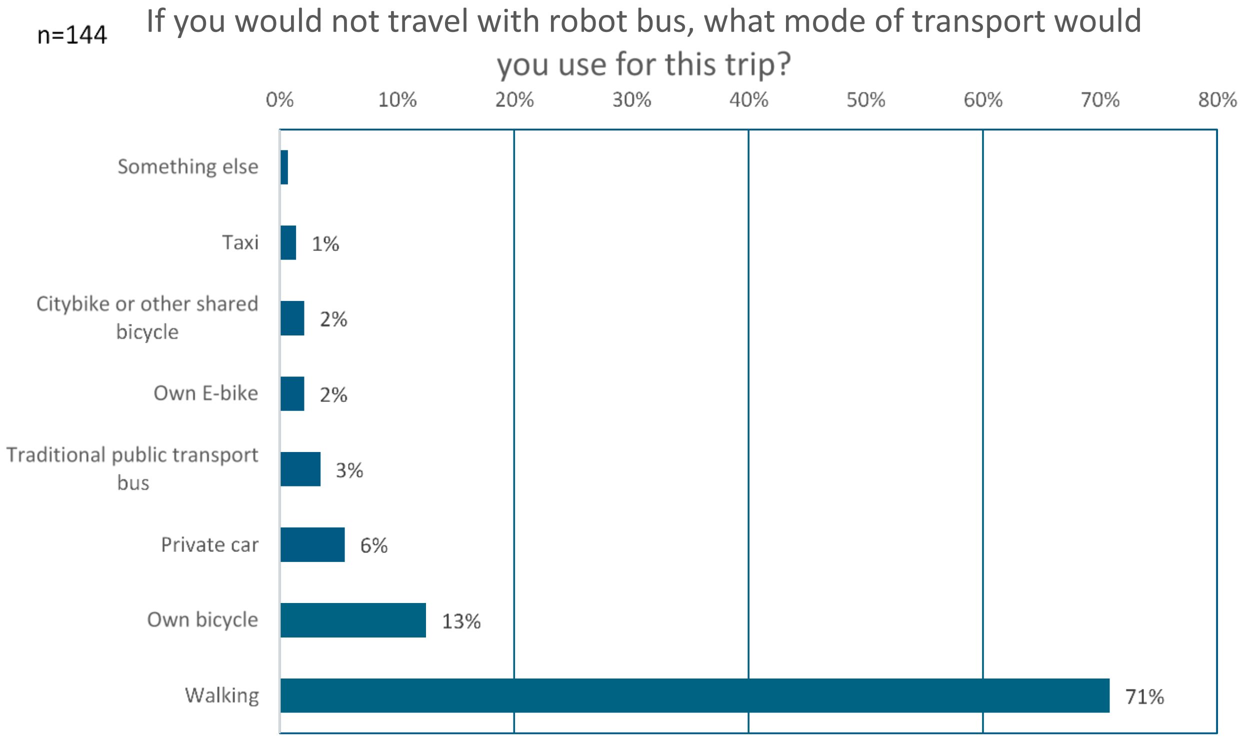

Figure 53: Survey question of which mode of transport would the passenger use for the robot bus trip in Kalasatama if he/she would not be travelling with the robot bus.

4.2.3.3 Summary of passengers

The type and the number of the passengers in a means of public transport is highly dependent on among other things of the driven route as well as the quality and the schedule of the service. Moreover, the service has to be able to meet a real demand to attract as well as gain genuine passengers on board. The pilot service and routes in Kivikko and Kalasatama were not able to meet these needs in the best possible way. Thus, the pilots were attracting more passengers who were only trying out the shuttle without using it as part of their actual travel chain. If the public transport in the city is already comprehensive and the demand for mobility solutions has been met to a large extent, it complicates finding viable routes. This is further aggravated if a solution cannot be deployed everywhere and meet the demand on a required level due to technological constrains. With one available shuttle in a pilot, it is also unreasonable to expect that the demand can be fully fulfilled. At this point, it is expected and somewhat acceptable that shuttle pilots are attracting more people who are only testing the shuttles and not use them truly as part of their travel chains. The pilot routes are also advertised for the public to gain more passengers on board which further increases the amount of “test” passengers. This is, of course, one of the purposes of pilots to introduce new technology to the public.

The pilot like nature of the shuttle service and especially the presence of an on-board safety driver prevents from getting reliable results of a future remotely supervised driverless shuttle service. The presence of the on-board safety driver can certainly affect how passengers feel during the ride. However, referring to the

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result from the pilots in Kivikko and Kalasatama, people's attitude towards automated public transport seems to be positive, and it may well be that for most people it does not matter whether there is a driver or not inside the vehicle. It seems that most of the people would use this kind of vehicle as part of their everyday mobility like any other public transport vehicle, as long as the reliability is improved and the route as well as schedules meet the passengers' demands. Specific requirements from passengers regarding the shuttle's features (e.g. internal equipment or seats) were not registered.

The operational speed of the shuttle in Kivikko was considerably slower compared to conventional buses and other road users on the site, which was together with occasional sudden braking the predominant complaint relating to the shuttle according to the passengers. The same complaints were present also in Kalasatama, even though the speed difference was not that high. The passengers hoped that the shuttle would have operated at a higher speed. As speeds increase it should be noted that seatbelts inside the shuttle are necessary as they were already needed especially in case of small children during the pilots even in the low speeds below 18 km/h. In conventional public transport buses, it is also allowed to stand during the trip, but this could not be recommended in case of the pilots in mySMARTLife and standing during the ride was not allowed. Generally speaking, the passengers were pleased with the ride and they were interested in the technology.

On relatively short routes of Kivikko and Kalasatama, it seemed that the shuttle was replacing mostly walking and cycling as an additional complementary service. Normally people would have mostly walked these distances and now they were offered the possibility to travel the same trip in a shuttle. This is, of course, the purpose of a complementary first/last mile mobility service which does not replace any existing public transport bus. It remained somewhat uncertain whether the automated last mile shuttles can affect private car users by increasing the modal share of public transport. In areas and cities where public transport does not work very well and the shuttles are deployed on routes where public transport does not already operate, the likelihood of increased modal share of public transport is certainly higher.

4.2.4 Operator's conditions and tasks

According to the Finnish road traffic legislation, automated shuttles (as well as any other vehicle in road traffic) need to be supervised when driving on open road conditions among other road users. A designated responsible person, an operator, can be either inside supervising the vehicle or must be at least remotely and safely capable to stop the vehicle. A shuttle's operator can currently have multiple tasks relating to for instance with manually manoeuvring the vehicle when necessary. These tasks can vary to some extent between different shuttle suppliers and especially the way of intervening in the operation can be different. In other words, there can be different manual remote controllers and screens through which the interventions are done by the operator – still mainly on board in the shuttle. Speaking of specially the shuttle used in the pilot and referring to gained experiences, the operator's tasks can be divided into tasks before start of the operation, during the operation and after the operation which can be listed as follows:

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- **Before the operation**
  - Check that everything is okay with the shuttle from outside and inside, for instance, clean the LiDAR radars if necessary.
  - Disconnect the shuttle from charging.
  - Turn the shuttle's power on and drive it manually to the bus stop where the operation starts. Of course, the path to the first actual bus stop could be also programmed so that the shuttle could drive it automatically, but after turning the power on it may require still some manual driving or other measures for the shuttle to localize itself on the path.
  - Initiate the automated driving mode. This was done by choosing the desired operation mode, bus or metro mode, choosing the desired bus stop from the on- board control panel seen in Figure 54 and by pressing the "GO" button from the bottom right hand corner of the screen to start the operation.
  - Before starting the actual operation and taking passengers on board, it is recommended to perform a test drive: drive the route around to see that the shuttle works as it should, and that there is nothing special which can affect in the operation. Although the environmental conditions of the route could be checked even by a normal car, it is advisable to do the check by the shuttle used on the route to be sure that everything is fine.
- **During the operation**
  - Start the operation according to the schedule and follow the schedule after the first departure. In Kivikko and in Kalasatama the shuttle was operated in so called bus mode according to fixed schedules with three departures per hour during the day. The schedule could not be programmed to the shuttle which is why the operator had to take care of timely departures. The shuttle could have been operated also in so called metro mode, in which case the shuttle would have automatically departed in around 20 seconds after arrival at a bus stop. However, this was not a sensible solution in case of the pilots.
  - Choose the next bus stop and give permission to leave the bus stop from the on- board control panel by pressing the "GO" button.
  - Monitor the ride and intervene in the operation whenever necessary. Traffic situations may require operator intervention, for example in Kivikko the operator had to give permission to cross an intersection by pressing the "GO" button from the on- board control panel in the shuttle. There might also be a need to manually overtake an obstacle with the remote controller, such as parked vehicles on the roadside. Most importantly the operator should have always been ready to stop the shuttle either by pressing a stop button from the on-board control panel (located on the same spot as the

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“GO” after the shuttle is moving), using the remote controller or by pressing one of the two emergency stop buttons seen in Figure 54.

- Contact the bus supplier in case of an issue in the operation. If any problems came up in Kivikko or in Kalasatama, the operators were directly in contact with the supplier’s supervision centre. Contact could be taken by instant messages, emergency phone inside the shuttle, phone calls or email, depending on what the problem was about. Issues were usually explained by instant messaging and taking pictures as well as videos of the situation. The supplier could use remote connection to collect data logs to an USB stick (placed on shuttle’s computer by the operator) which was later uploaded to the supplier by the operators. Remote connection was used also to make software updates on the shuttle. After the updates it could have been necessary to check that the update was successful and carry out a test drive without passengers.
- Act as a guide for passengers and keep track of the number of passengers. Among other things the operator advised passengers to sit and use seat belts for safety reasons, collected user feedback and answered many questions asked by the passengers. These tasks can be, of course, dependant on the nature of the pilot or service. The operator also acted as a kind of security guard maintaining the order in the bus.
- Monitor the overall functioning of the shuttle: battery charge, connection to the RTK base, adjust air conditioning/heating, seek for disruptive factors such as growing vegetation, et cetera. Approximately every two weeks the RTK reference station on the roof of the skiing hall in Kivikko had to be restarted, this was done by the operator.

- **After the operation**
  - Drive the shuttle manually back to the charging place.
  - Check that everything is fine with the shuttle.
  - Put the shuttle in charge and turn the power off.

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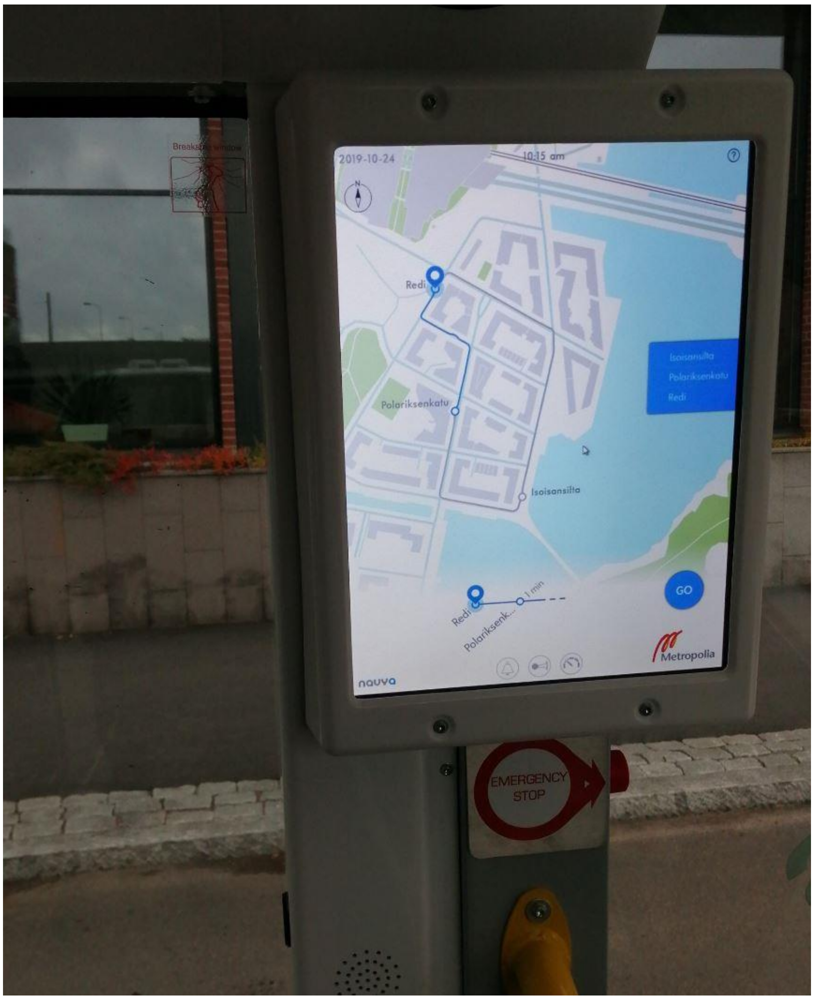

Figure 54: Onboard control panel of the shuttle, “GO” button and one of the two emergency stop buttons [Bremer 2019].

Even though the robot buses currently need a responsible person inside the vehicle in road traffic in open road conditions (at least, for technical reasons), there is no designated space for them to safely and comfortably operate the bus. In the pilots the operator was sitting and holding the remote controller in his hands during the ride as shown in Figure 55. This kind of positioning inside the bus guaranteed that the operator was able to face forward in the driving direction and have good visibility. It was also possible to act quickly and use for instance the on-board control panel inside the shuttle without constantly detaching of seatbelts. However, on a street legal and type approved passenger car all passengers and the driver should use seatbelts. In case of automated bus pilots and buses that are not type approved and have been equipped with test plates, these rules have been circumvented to some extent.

As long as automated vehicles need a driver inside the vehicle, it would be preferable to have a proper ergonomic driver’s compartment and traditional driving control devices, such as steering wheel and pedals, even though it may lower the immersion of a driverless vehicle. If a person is needed to communicate with passengers during the ride in pilots, for safety reasons it is recommended to have another person to do this

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task and separate this person from the safety driver. A safety driver should focus on the task that he/she is meant to do – monitor the ride and intervene in the operation whenever it is necessary. In addition, when having a person operating the bus on-board in the shuttle it should be noted that one person cannot do this for several hours in a row. There should be social facilities or other resting places near the route for the operators.

Traditional driving control devices as well as a drivetrain and other features that would allow a shuttle to be driven manually in high speeds (80-100 km/h) would ease the transport of the shuttle on longer distances. A trailer would no longer be needed and a storage and charging depot could be located further away from the operational area. In case of emergency situations, the rescue personnel would be directly capable of driving the automated vehicle out of the way (for instance with some standard key or similar), if it cannot be done by the on- board safety driver or operator in the remote control centre. Currently every shuttle supplier has their own specific way of controlling the vehicle manually and it requires special training to master the driving. If such equipment is used for controlling the vehicle manually, at least there should be some standard way of manually driving the shuttles.

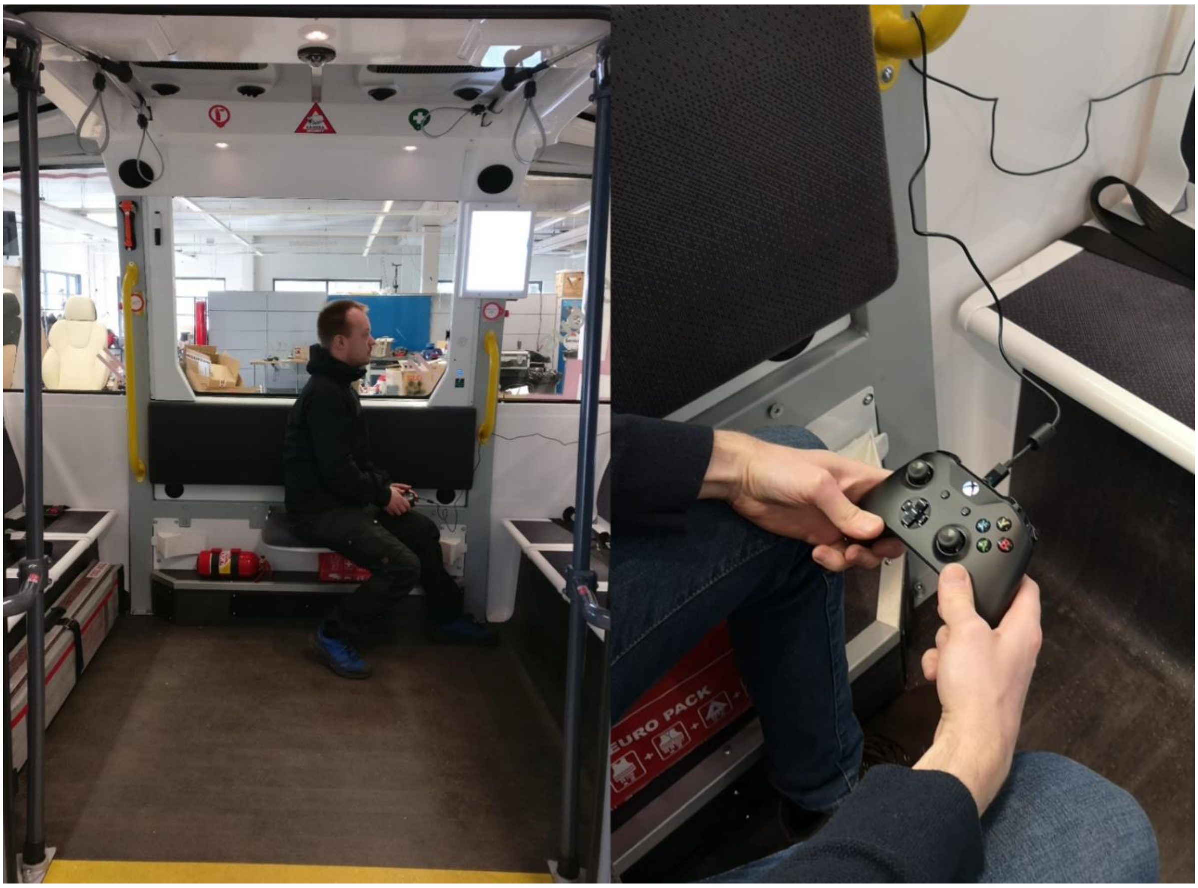

Figure 55: Operator’s position inside the shuttle and remote controller [Rutanen 2019].

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4.2.5 Storage, energy consumption and CO_2 emissions

During the pilots in Kivikko and in Kalasatama, the energy consumption of the shuttle was measured. The amount of charging current was measured with a meter, which was installed to the power supply. The shuttle's 80V-33 kWh drivetrain battery could be charged by 16-to-32 amps current. Energy consumption measurement data were collected only from charged energy. It was not possible to specify the source of the consumption. However, it could be noted that for instance the use of the air conditioning on a warm and sunny day was a significant consumer of energy and reduced the operating time and range to a large extent. Also, some consumption was caused during the charging after the battery of the shuttle was fully charged. The following chapters explain how the shuttle was stored as well as what the shuttle's energy consumption and relation to CO2 emissions during the pilot was.

4.2.5.1 Kivikko

Outside of the operational hours, the shuttle was stored and charged on a yard behind the Skiing hall located at the Kivikko sports park. There was not any suitable indoor storage and charging place at the Skiing hall nor near by the pilot route. Thus, the shuttle was stored and charged outside completely uncovered (Figure 56). In Kivikko a socket of 32 amps power supply was used to charge the shuttle.

Figure 56: Charging and storing robot bus at Kivikko Skiing hall [Rutanen 2018].

Table 7 shows the monthly energy consumption during the Kivikko pilot and its relation to passengers as well as kilometres driven. Instead of the actual pilot period and operation of the shuttle on 14 May - 4 November 2018, the monitored months are shown in Table 7 as full months to match with the 12-month monitoring period of mySMARTLife. In Table 7, only the energy consumption is counted considering the operational days. The shuttle was plugged in charging always when it was staying at the storage place, also during those days when issues were encountered and the shuttle could not be operated on the route. Because of the battery related issue, the data from November is not listed in the table. The total consumption from June is calculated by multiplying the driven kilometres (660 km) with the average consumption per

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kilometre from July to October (0.79 kWh/km), as the energy meter was not installed until July. The total amount of charged energy during the measurement period would then be 2111 kWh. The travelled distance was 2681 km, including the operation on the actual route and manual driving from the storage place to the operational route and back. The distance to the storage place was 180 m from the nearest bus stop where the first departure of the day was started and where the last departure was stopped at the end of the day. Considering this the total ratio of used energy to distance travelled was 0.79 kWh/km.

Table 7: Monthly energy consumption, passengers and distance travelled in the Kivikko pilot.

Month	Distance travelled [km]	Passengers	Energy consumption [kwh]	Energy consumption per distance travelled [kWh/km]
6/2018	660	360	521	0.79
7/2018	668	322	590	0.88
8/2018	728	287	551	0.76
9/2018	389	136	279	0.72
10/2018	236	45	170	0.72
11/2018	0	0	0	-
Total	2681	1150	2111	0.79

As the shuttle in Kivikko was working as a complementary first/last mile transport service, it did not replace any normal bus line. The potential CO_2 emission savings and energy efficiency of the shuttle could be compared generally to private cars and their reduction due to the shuttle service. During the pilot the objective was to find out how many private car trips can be compensated by means of public transport, as the coverage and service of public transport has potentially improved because the last mile of the travel chain can be travelled with a robot bus.

In Finland, the average distance of a single trip is 14.3 km and CO_2 emissions of private cars are 151 g/km in average. The average occupancy of private cars is 1.7 passengers/car so emissions per person is 89 g/km and energy consumption is 0.62 kWh/km. [Henkilöliikennetutkimus 2010-2011: 33; Henkilöautot keskimäärin Suomessa vuonna 2016.] In this case, the average CO_2 emissions of private car passengers on a round-trip would be

$$\frac{14.3\,km * 2 * 151\,CO2\frac{g}{km}}{1.7\,psgr.} = 2540.4\,CO2\frac{g}{psgr.}$$

Respectively the energy consumption of passenger cars on a round-trip would be

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$$\frac{14.3\ km * 2 * 0.62\ \frac{kWh}{km}}{1.7\ psgr.} = 10.4 \frac{kWh}{psgr.}$$

These values are used to examine the overall effects on CO_2 emissions and energy consumption of the robot bus on the route in Kivikko. Approximately 30% of all robot bus passengers came to Kivikko by private car and 6% by taxi or charter bus. Also, approximately 69% of all the visitors answered that the robot bus ride was not a part of their travel chain. 23% of the passengers who arrived at the Kivikko sports park with public transport (n=202) said that the robot bus service affected positively their decision to get to or leave the Kivikko sports park by public transport.

The average CO_2 emissions for a city bus are 52 g/km/passenger [Bussit ja linja-autot keskimäärin Suomessa vuonna 2016]. 1150 passengers took the ride on the robot bus during the measured period. Based on the survey, around 23% of the passengers left their private cars at home and used public transport for getting to the Kivikko sports park. It can be estimated that the overall CO2 emissions decreased by the following amount

$$202\ psgr. \ * 0.23 * 14.3\ km * 2 * \left(\frac{89 \frac{g}{km}}{psgr.} - \frac{52 \frac{g}{km}}{psgr.} \right) \mathrm{CO2} = 49164\ g\ \mathrm{CO2}$$

The average CO2 emission factor for electricity production in Finland is 141 kg CO2 /MWh (141 g CO2/kWh) calculated from the previous three statistical years of 2016, 2017 and 2018 [CO2-päästökertoimet]. Energy consumption of the robot bus was 0.79 kWh/km in Kivikko. CO2 emissions per one-way trip can be thereby calculated to be

$$1\ km * 0.79\ kWh/km\ *\ 141\ g\ CO2\ /kWh\ =\ 111\ g\ CO2$$

The average number of passengers per departure was 0.83, so the shuttle’s CO2 emissions per passenger/departure was

$$\frac{2\ km * 111g\ CO2/km}{0.83\ psgr.} = 267\ g \frac{CO_2}{psgr.}$$

During the measured time period the total energy consumption of the shuttle was 2111 kWh. Total CO2 emissions caused by the robot bus can be, therefore calculated as follows

$$2111\ kWh * 141\ g \frac{CO_2}{kWh} = 297651\ g\ CO_2$$

Considering the amount of CO2 emissions that were reduced by the decreased number of passenger car usage, the overall CO2 emissions caused would be

$$297651\ g\ CO_2 -\ 49164\ g\ \mathrm{CO2} =\ 248487\ g\ CO_2$$

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The above calculations are simplified and are based to large extent on assumptions. For example, in terms of actual CO_2 emissions and their reduction, more accurate background information would be needed about the travellers' private car use and driven distances which have been replaced by public transport. Also, it was not considered how the actual CO_2 emissions increased because of the passengers who came only to test the shuttle by arriving on site with a passenger car. Hence, the aim of these calculations is to present what the difficulties in determining and measuring the effects on CO_2 emissions of a complementary first/last mile service which is not able to replace current fleet (or intended deployment of a new official public transport route with conventional fleet) are. In addition, the calculations present the importance of having a viable route contributing to increase the modal share of public transport – not only by replacing walking and cycling with or without being as part of the passengers' travel chain.

4.2.5.2 Kalasatama

Outside of the operational hours the shuttle was stored and charged in a service tunnel of the Redi Shopping mall in Kalasatama as seen in Figure 57. An indoor storage as such in the pilot provided better protection against weather variations compared to Kivikko. In Kalasatama, a socket of 16 amps was used as power supply to charge the shuttle.

Figure 57: Charging and storing robot bus at Redi shopping mall's service tunnel [Rutanen 2019].

Table 8 shows the monthly energy consumption during the Kalasatama pilot and its relation to passengers as well as kilometres driven. Instead of the actual pilot period and the operation of the shuttle on 21 May - 22 November 2020, the monitored months are shown in Table 8 as full months to match with the 12-month monitoring period of mySMARTLife. In the same way as in Kivikko, in Table 8, only the energy consumption is counted considering the operational days. The shuttle was plugged in charging always when it was staying

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at the storage place. Also, during those days when issues were encountered and the shuttle could not be operated on the route. Total amount of charged energy during the measurement period was 1325 kWh. The travelled distance was 1325 km, including the operation on the actual route and manual driving from the storage place to the operational route and back. The distance to the storage place was 500 m from the nearest bus stop where the first departure of the day was started and where the last departure stopped at the end of the day. Considering this the total ratio of used energy to the distance travelled was 1.09 kWh/km.

Table 8: Monthly energy consumption, passengers and distance travelled in the Kalasatama pilot.

Month	Distance travelled [km]	Passengers	Energy consumption [kwh]	Energy consumption per distance travelled [kWh/km]
6/2019	146	530	158	1,08
7/2019	189	869	255	1,35
8/2019	241	631	217	0,90
9/2019	142	311	210	1,48
10/2019	324	786	255	0,79
11/2019	283	457	350	1,24
Total	1325	3584	1445	1,09

Without similar kind of calculations made in case of Kivikko, it can be stated that also in case of the Kalasatama pilot the shuttle only produced more CO_2 emissions than reduced them. This was because the shuttle was working as a complementary first/last mile transport service and did not replace any existing bus line and the average CO_2 emissions caused by electricity production are still prominent. In addition, the shuttle could not considerably lower the use of private cars to compensate the emissions caused by the energy production of the energy that the shuttle was using during the pilot. If thinking of the energy consumption per passenger·km, the consumption was significantly lower in Kalasatama (0.4 kWh) compared to Kivikko (1.84 kWh) even though the total energy consumption per distance travelled were higher, 1.09 kWh in case of Kalasatama and 0.79 in case of Kivikko. This is explained by the fact that there were more passengers in Kalasatama and less kilometres were driven than in Kivikko.

4.2.5.3 Summary of energy consumption, storage and CO_2 emissions

In the Kivikko and Kalasatama pilots, the shuttle was operating on a completely new established pilot routes as a complementary first/last mile public transport service and did not replace any existing conventional bus with a combustion engine. In the circumstances the shuttle should have been able to lower the use of private cars to reduce CO_2 emissions. Despite of the electric drivetrain of the shuttle, it can be concluded that the shuttle caused more CO_2 emissions indirectly during the pilots than reduced them if taken the consumption

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of the shuttle into account and CO2 emission factor for electricity production in Finland (141 gCO2/kWh) as the shuttle was just mainly replacing walking and cycling. At the current stage of the development, it is assumed that no reduction of CO_2 will be achieved if the shuttle is operated according to such operating model and cannot be operated with the required service level by meeting the demand and specifically attracting private car users. An electric vehicle is not automatically sustainable, a lot is dependent on how the used electricity is produced and how the vehicle is manufactured. Though compared to private sector, within public transport it is better possibilities to effect on what kind of vehicles are deployed on certain routes and what kind of energy is used by the vehicles as well as how the energy is produced.

If it would be possible to establish a bus line on a certain route or replace a bus used on some route and an automated shuttle would be used instead of a conventional diesel bus on this route, the local emissions caused would be lower. However, it should be noted that the energy consumption of the shuttle in the pilots was comparatively high, 0.79 kWh/km in Kivikko and 1.09 kWh/km in Kalasatama, when thinking of the size and the capacity of the shuttle. The mass (empty weight) of the shuttle was approximately 2400 kg and the capacity 15 persons[2], whereas the mass of an electric bus with capacity of 70-80 persons used in Finland is varying between 9500-12500 kg. Such electric buses consume around 1 kWh/km in average in optimal conditions, but the consumption may increase to 1.5 kWh/km in cold, snowy and slippery conditions. [Lehtinen & Kanerva 2017: 26; 48.] In the operating conditions of the pilots, the shuttle was thus consuming almost the same amount of energy as a normal electric bus with 5 times greater passenger capacity. It should also be noted that some electric buses as well as automated shuttles can use additional means, such as fuel powered auxiliary heater to heat the passengers' cabin. However, for instance production of near CO_2 neutral renewable diesel has made good progress in Finland which is improving the sustainability of fuel usage.

At this stage, it can be said that the autonomy or self-driving features of the shuttle do not provide any specific notable means to lower the consumption compared to human driven electric vehicles. Therefore, shuttles can be compared generally to vehicles of the same size when investigating the energy consumption. In addition to the drivetrain of the shuttle, weather, and thus, the use of air conditioning or heating were significant consumers of energy in the pilots. Otherwise the potential operating time and range is affected among other things by topography and the type of the route as well as the schedule of the operation. In the pilots, the shuttle was staying idle at the end stops for around 10 minutes between every departure, often with air conditioning or heating on as well as other electrical components (sensors, computers, screens etc.) in operation which were consuming energy. The overall efficiency of the shuttle can be enhanced to some extent with a route and service that meets better the demand as well as by reducing the off-duty hours while increasing the number of departures (provided that there is a demand for such a densely operated service). Ways for shutting down or putting the shuttle's components to sleep mode at the times when the shuttle

[2] Only 8 passengers and the operator was taken on board in the pilots as the shuttle was registered with test plates as a passenger car

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would not be in operation (staying at bus stops or other places waiting for next departure) could further enhance the efficiency and sustainability of the service and should be investigated. On more sparsely populated areas, this could be combined with an on-demand shuttle service that would be operational only when requested and could optimize the route and could have several passengers on board simultaneously. But this kind of service would also require a certain number of potential users to differ from mere private car usage or taxis.

In the pilots, temporary depots were used for storing and charging the shuttle outside of operational hours. In Kivikko, the shuttle was stored outside completely uncovered which is not an optimal solution due to effect of weather and increased possibility for vandalism. In Kalasatama, it was possible to use an indoor depot which was found to work well. However, equipping the depots with necessary tools and machines for maintenance work was impossible within the pilots and it was necessary to transport the shuttle with a trailer in a proper maintenance garage in case of more demanding maintenance tasks. Finding a depot for one shuttle has proven to be a difficult task not to mention a situation where it is necessary to store several vehicles:

- Already existing depots of public transport operators are often located too far away from the route where the shuttle is operated.
- Parking garages are usually too low for storing a shuttle with the height of around 3 meters.
- Electricity for charging is not available directly in every place.
- Space for a temporary (or long-term basis) established depots can be limited especially in a densely built environment. Costs of such heated and well-equipped temporary storage place may rise significantly high, especially if several vehicles should be fitted there.

Depending on the operating conditions on a route, high power charging pantograph solutions – similar to what are used in case of bigger electric buses to charge the buses at end stations from the roof of the bus – could be studied also in case of shuttles. Another option is already introduced within shuttles, inductive charging, but the charging speeds have been slow. These options would potentially allow more automated solutions for charging without human intervention. A shuttle operates automatically within few centimetres' accuracy, which would ease the positioning of the shuttle beneath a charging pantograph or on an inductive charging pad.

The mode of operation in the pilots has so far been overnight charging or charging otherwise off the route outside of the operational hours. In the pilots in Kivikko and Kalasatama in mySMARTLife, the maximum range of the shuttle was not statistically measured, but it could be estimated that the shuttle could have been operated 2-3 days with six hours of operation per day without charging in optimal conditions (e.g. temperature around 15ºC without using much air conditioning/heating). In case of Kivikko that would be 70-05 km if the kilometres that were driven per day (35 km) were taken into consideration and when all the

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departures could be driven. The days where the capacity of the battery remained over 70% after operation of 6 hours and 35 km were witnessed during the pilots, but the shuttle was still put to charge every time after the day's operation.

4.3 Technology Readiness Level

In mySMARTLife, Technology Readiness Level (TRL) is used to assess the performance maturity of a given technology. TRL is measured on a scale from 1 to 9, as presented in Table 9. In mySMARTLife, all given technologies are expected to be at TRL 7 or higher. In case of action 23 (Autonomous Electric bus pilot to address Urban last mile mobility issues), addressed in this deliverable, the TRL is said to be on scale 7. Automated electrical vehicles are currently prototype solutions that are not fully commercial. In mySMARTLife, the pilot has contributed to reach level 8 "System complete and qualified", but based on the experience of the pilot, it is clear that the level 8 will not be reached during mySMARTLife. If the goal is to use shuttles in road traffic among other vehicles as well as part of public transport, there are still several challenges and development targets related to them, the most relevant of which are listed below:

- **Overall technology should be more advanced**. Shuttles should be able to operate in a variety of environments and in all kinds of weather conditions in the same way as normal buses and other vehicles in road traffic. Operational speed of the shuttles should be increased to at least 30 km/h so that they are able to keep up with the traffic flow in suitable environments and compete especially against private cars. This is also necessary for increasing the amount of realizable and viable routes. Shuttles should have the ability to automatically deviate from the programmed trajectory (e.g. overtake obstacles) and should not be disturbed by random bugs in the software, of cars that are parked a few centimetres outside of the allowed area or vegetation next to the shuttle's trajectory – the overall edge intelligence should be enhanced. Shuttles should handle different types of intersections and deal with traffic lights without noticeable hesitation. The inability of the technology cannot be justified by the fact that there would be a problem with the infrastructure or the environment and not with the technology itself. A situation has to be reached where the demand and assigner (e.g. organizer of public transport or a private organization) can dictate the conditions of a route to be taken, not the bus technology or its supplier. This should be possible to be done without major traffic arrangements and other changes to the environment. Shuttles should adapt to the existing environment, not the other way around. Of course, some changes can be done to the existing or newly built environments to ease the uptake of the current generation of shuttles: establish 5G networks, consider charging and depot options, build wide enough streets with clear road side parking spots, equip traffic lights with necessary communication modules, install comprehensive VRS RTK network, consider also shuttles when building new transport hubs etc.
- **Reliability of shuttle operation should be improved**. A variety of issues that affected the realization of the planned schedule of operation were noted in mySMARTLife shuttle pilots. Pilot-like

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nature of the operation without the resources and fleets of official public transport operators had its own effect on the results and not all of the issues were caused only due to the shuttle. Despite that significant deviations could be still noted when comparing the operation to conventional buses and bus traffic. Keeping up with the schedule would have neither been possible without the intervention of the on-board safety driver as basically already every start for departure required at least that the operator took care of the timely launch from the bus stops. Shuttles should be able to operate within the same level of reliability than conventional buses to have a viable service and attract users, less should not be expected nor allowed in the future. Pilots, test drives and development allow to improve reliability to the required levels.

- **Take the operator outside of the vehicle**. As long as a safety driver/operator is inside a shuttle, it cannot be operated more cost effectively than conventional buses and through this have improvement in public transport services with self-driving technology. Moreover, one operator should be able to operate at least two vehicles simultaneously to achieve some improvements. Technically, it has not been possible to remove the on-board operator in open road conditions and in several countries, it is not even legally possible yet. Further, it is not yet fully known what kind of systems are needed in a remote control centre, for instance what kind of visual information must be provided for the operators and what the most viable solution to remotely intervene in the operation is. It is not necessarily safe enough to directly remotely drive a shuttle and possibly it would be safer that a shuttle would suggest an alternative path for instance to pass bigger obstacles on the trajectory. This alternative route would be then approved by the operator. Though the frequency of these requests for intervention cannot be dense to make the service viable, provided that one operator should simultaneously be able to supervise several shuttles and possibly also act upon requests from passengers for instance. It is not either clear who would take the responsibility of this approved manoeuvre, especially if an accident happens.
- **How to operate and supervise fleet of shuttles remotely**. Even though one operator would be able to remotely supervise and control more than one shuttle simultaneously, it requires that the on field human intervention on site would be minimized to as low as possible to have a viable service. It is presumable that there will be situations where human intervention is needed on the spot-on operational areas and routes of the shuttles. These can be in relation at least to maintenance and charging measures outside of the operational hours but most likely it is possible that every now and then actions on site are needed during the service hours. The level of autonomy of the shuttles and the amount of onsite human intervention will determine when the service will be more cost-effective than just having a driver inside every vehicle. It is not yet known how many vehicles one operator could monitor. This is strongly linked to the level of autonomy of the vehicles as well as legislation.

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- **Where to store and charge the shuttles outside of operational hours**. Because of the way the shuttles have been built – capable to only operate with low speeds (currently usually below 30 km/h, at max 18 km/h in mySMARTLife) and not having proper driver's compartment as well as driving equipment – it has not been possible to use existing bus depots which are located further away from the operating route. Deviating from the route to roads with higher speed is not safe and considering the speed that the shuttles can be driven it takes an unreasonable amount of time to drive several kilometres. Basically, on longer trips, shuttles have been transported with trailers and storage and charging depots have had to be found near the operational area to realize the pilot. Lack of potential depots is an area and route-specific issue, but the problem can come up in several places and it can affect the routes that could be implemented with shuttles. The problem is highlighted in densely built-up areas where there is no room to build up new depots for the shuttles. To be able to store the shuttles, for instance, next to the roadside, would require charging options installed in specific locations and that the shuttles could stand the variation of weather in different climatic conditions year around. In these cases, it is most likely necessary to carry out more complicated maintenance actions and cleaning in some other place located further away from the operating route.
- **Liability issues and type approvals**. In Finland, there has to be still a dedicated person in charge of a vehicle. However, this person does not have to keep his/her hands on the steering wheel nor be at all inside the vehicle while it is moving. This is a prerequisite for operating automated vehicles in road traffic. It is not yet clear if one person would legally be able to monitor several vehicles. It is unlikely that a single person would even want to take responsibility of one or several vehicles that are driven by a computer and be an operator, unless it is 100% certain that the automated vehicle would not end up to be the guilty party in an accident. Hence, the liability should be at least at company's level, either with the vehicle supplier and/or operator company. Depending on the case, the single person acting as an operator and supervising the vehicles should, of course, take some responsibility (being under influence of substances, sleeping etc.). While supervising several shuttles simultaneously, it is unreasonable to expect that an operator could act fast enough to prevent an accident from happening, for instance, being able to stop a shuttle remotely in time if something unexpected happens and the shuttle deviates from the programmed path to an oncoming lane for instance. A vehicle that is driving only 30 km/h is moving 8.3 meters during one second, around the length of two cars in a row. A remote operator should only be a quite passive and assisting final backup component in the system as well as serve the passengers remotely when possible and necessary. Regarding the shuttles' vehicle class, there has been still some flexibility. In Finland, shuttles have been operated in road traffic with test plates granted by the Finnish Transport and Communications Agency (Traficom), and, basically, they have been registered as passenger cars. It is not clear which vehicle class the shuttles fit into. They lack features stated for instance for buses and passenger cars, and therefore, cannot yet be type approved officially for road legal use. Current

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vehicle approval relies heavily on the technological validation of only a vehicle which is driven by a detachable component, the driver. Some changes have to be made to the legislation so that shuttles can be operated as part of an actual service in road traffic.

Table 9: Technology Readiness Levels

TRL 1 Basic	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Principles observed	Technology concept formulated	Experimental proof of concept	Technology validated in lab	Technology validated in relevant environment	Technology demonstrated in relevant environment	System / Prototype demonstration in operational environment	System complete and qualified	Actual system proven in operational environment

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5. Conclusions

Automated shuttles are introduced as a mobility solution for the first/last mile of the travel chain covering the gaps in public transport especially in sparsely populated areas. In case of cost savings, the benefits of well working automated technology are clear. When one person could supervise several vehicles remotely from a remote control centre, costs per operational vehicle reduces significantly. The need for subsidization could be lowered and/or for instance departure frequency increased. Shuttles could work on demand responding to the current need and not necessarily operate by fixed schedules. By making public transport achievable by more people providing personalized service, it could potentially affect on private car usage increasing modal share of public transport, while reducing CO2 emissions.

One of the challenges of the public transport system is to provide cost-effective and demand-responsive service in sparsely populated areas where the number of potential public transport users is small. Especially the departure intervals are often long in these kinds of areas, and if they do not match with the current need, it increases the probability of choosing a car over public transport. In case of cost savings, the benefits of well working automated technology are clear. When one person could supervise several vehicles remotely from a remote control centre, the need for subsidization could be reduced, and/or for instance departure frequency increased. Public transport could be offered in areas where it has not been possible before, possibly even as a paratransit service working on demand

As part of mySMARTLife, an automated bus (Navya Autonom Shuttle) was piloted during two separate 6-month periods in Helsinki in road traffic among other road users. This deliverable describes the experiences of the pilots where the shuttle was operated in 2018 in Kivikko and in 2019 in Kalasatama. The round driven last mile routes were 1-2 kilometres long and consisted of 2-3 bus stops between which the robot bus operated with fixed schedules. A responsible person (operator) was on-board ensuring the safety and fluent operation of the shuttle. Altogether, it became clear that both of the routes did not remain within the specified ODD’s regarding the road characteristics even though representing completely different environments. In Kivikko this was especially due to the speed limit and speed difference between the shuttle and other road users, which is why the shuttle could not operate in the best possible way increasing the amount of operator intervention during the operation. Considering the limitations in the current technology it seems that a perfectly suitable open road operating conditions are impossible to be found which would allow shuttles to operate without the assistance of an on- board operator.

Route planning for shuttle in the Helsinki area has been constant balancing between various aspects. Factors that affect the route selection are both technical challenges related to the maturity of automated bus technology as well as the effort of finding a route that would meet the real demand. Shuttles are a new phenomenon in road traffic, which is why they attract a lot of pure interest rather than work as a real means of transport. However, this is also strongly linked to the route design, available fleet and other resources as

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well as coverage of other public transport in the area in general. While searching robot bus routes and gaps in public transport coverage, it has been found out that public transport is very comprehensive in Helsinki. It is difficult to find a place where normal buses are not already operating and shuttles would provide significant added value.

Especially in areas where public transport already works well, it is most likely that current bus lines have to be at least partly replaced to be able to fully uptake shuttles in the future. Routes suggested for instance by HSL and the city have been largely too challenging for the current technology. The routes have had to be chosen mainly on the basis of what the shuttles are capable of rather than where there is a real need for mobility. Diverging from this can lead to unsafe operation and increased need for operator's intervention. Serving as a local means of transport especially in commutation is not largely possible as shuttles currently do not keep up with other traffic and cannot provide same service level and reliability as conventional buses can.

Specific routes for shuttles in road traffic do not exist. There is a demand for mobility and this demand is covered with available resources and solutions. Therefore, it should be considered where and how the shuttles are really needed. The more different vehicles are used as part of the travel chain, the more shifts are needed to be made which increase the effort as well as layover times and eventually the whole travel time. This is also often a threshold for choosing public transport over passenger cars. The choice between a passenger car and public transport is a sum of many variables, and the decision comes among other things from the availability of public transport, personal preferences, the destination and purpose of the trip as well as different set of values and economic opportunities to use a car. In areas where last mile shuttles would not be able to cover the whole part of the route to traffic hubs, shifts from one vehicle to another would be increased while emphasizing the functionality of the entire travel chain. Shuttles should be able to provide a direct connection for instance from a residential area to a traffic hub which can often be located several kilometres away and may require driving on roads with at least 50 km/h speed limits. Therefore, there is no reason to assume that the features of shuttles should largely differ from conventional buses. This is why the properties of shuttles should be designed keeping in mind the environments and use cases where they are intended to be provided.

Serving the current public transport users with a complementary mobility solution while replacing walking and cycling on short last mile trips which could be easily walked by the majority of people it is necessarily not a sustainable way of deploying shuttles. Electric vehicles do cause CO_2 emissions as well, not locally but surely at some point of the vehicles´ lifespan, either during the production of the vehicle or energy that the vehicles are using. In addition, some of the shuttles can use alternative sources of fossil- based energy, such as diesel, to heat the cabin especially in extremely cold temperatures. However, there are better possibilities to affect what kind of energy is used by the vehicle fleets and how the energy is produced within public transport. If it is not possible to replace current buses with shuttles, future actions regarding the implementation of shuttles in cities should focus on areas where public transport is not already

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comprehensive and/or where there is a good potential on affecting private car users while increasing the modal share of public transport. In general, the ambition in Helsinki is to increase the number of public transport buses with electric drivetrain and shuttles on the market and under development are mainly contributing to this. Safe, affordable, congestion-free and low-carbon mobility requires a holistic approach and cooperation between different sectors. The hierarchy of mobility decisions is formed from everyday mobility decisions as follows, depending on the region and each person's own opportunities:

1. I walk.
2. I cycle if walking is not possible
3. I travel by rail if walking is not possible.
4. I travel by bus if the other options are not possible.
5. I travel by car, with passengers on board; I lend my car; I take a taxi. [Salonen 2020: 7.]

In some cases, the smaller size of shuttles aims to increase the number of vehicles at busy times rather than operate big buses with low occupancy during off-peak hours. It is hoped that shuttles would work also as an on- demand service flexibly responding to current demand. For instance, the pilot route in Kivikko, or a similar route in a quiet area, would be more sensible to carry out as a service where a passenger would request the shuttle to be at a bus stop at a certain time. Or a passenger would present the need for further transport while travelling on a trunk line bus closer to the final destination. The shuttle would know the arrival time of the trunk line bus at a certain stop along or near the robot buses' route and it would be at the stop at correct time. This way the shuttle would only drive when needed and the number of empty seats per departure would be possibly reduced. A more advanced system could take the requests of other passengers into account as well and optimize the route and waiting time accordingly. However, in sparsely populated low demand areas the shuttle could be occupied often by only one or few passengers at a time which questions the overall use of a shuttle instead of own car or taxi like (automated) service, especially if the trunk line bus operates with low occupancy as well. However, the use of shared vehicles instead of private vehicles generally lower the number of existing vehicles. Of course, everyone does not either have an opportunity to use a car but for instance in case of elderly and disabled people it should be noted that it is not the intention to have an assisting driver inside the vehicle at all.

The benefits of robot buses are based on cost savings of drivers' salaries. As long as the driver is needed inside the vehicle, there will not be any difference to conventional buses in that sense. Theoretically one person should be able to monitor at least two vehicles simultaneously for shuttles to be more cost-effective. However, this may not be enough as a lot is dependent on the autonomy level of the shuttles – what kind of background on field services are needed to have the vehicles operational. Currently operators still have a lot of different tasks before, during and after the service. During the operation it is presumable that a close by on field actions are needed to quickly respond on issues on the field if the vehicles can be otherwise

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controlled from a remote control centre. It is still impossible to say in what extent these on field services are needed and when, and in what kind of conditions shuttle services will be more cost- effective than conventional human driven vehicles. Currently a safety driver has been needed on board in the vehicles due to technical reasons as well as due to legislative and liability issues.

As long as the operator is needed inside the shuttle, there should be dedicated space for her/him to be in control of the vehicle. Now the operator has been in the same compartment with the passengers making it more difficult to focus on the main task: monitoring the drive and intervening when necessary. Immediate intervention on self-driving buses equipped with a joystick is different and challenging compared to conventional buses which are operated with traditional driving control devices (steering wheel and pedals). In practice the self-driving bus is the driver and even the operator is mainly a passenger. In different traffic situations the threshold for intervening increases and the response rate gets worse, while waiting for the bus's decision and action. Now that the operating speeds have been relatively slow and the buses have been stopping reliably, it has been manageable. Since the responsibility has been still with the operator, they rather preferred to rest assured, than take unnecessary risks, intervening also when it seems to be needed. As it is essential to increase the speeds to keep up with traffic flows, the operation gets more difficult and riskier. A traditional driving compartment with a steering wheel and other necessary equipment would be safer and allow driving manually (or automatically) on roads with higher speeds, provided that the drivetrain and design of the vehicle otherwise allows this. It should be also considered whether it is necessary to transport passengers as part of the pilots if real and viable use cases cannot be reached. However, the wishes and needs of the passengers should be considered when designing the vehicles and services. In addition, it seems that vehicle suppliers do not dare to test new features of the shuttles when having passengers on board, which is generally slowing down the development.

According to HSL the technology of robot buses is currently setting too many restrictions on cost- effective operation, and it is not yet profitable to bid them for bus lines. The potential benefits of robot buses will be refined as experiment progresses and technology advances. [Kyllönen 2019b.] In general, it should be considered if there is a reason to make exemptions whether the procured public transport buses have drivers or not. Usually the service and routes are procured due to a certain demand and other obligations where the determining factors are price and quality. If an automated solution cannot fulfil the set requirements with the lowest price, it is unlikely that this tender will win the procurement. In case of some service bus lines it could be even necessary to require to have an on- board driver for assisting passengers personally. Eventually when shuttles can be provided to certain routes without any specific requirements related to an on- board driver with the requested service level more cost- effectively than conventional solutions, it is unlikely that conventional solutions can anymore win a request for tender for these routes. Thus, the circumstances can inevitably run into a situation where driverless shuttles become a more common solution for certain routes. However, this does not apply in use cases where shuttles are not able to replace any

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conventional bus lines (planned or existing) and they are provided and used as a mere complementary service in addition to conventional bus lines. These use cases will most likely only cause additional costs.

It is good to be aware of that shuttles have been developed and tested in road traffic just a few years. The technology of these vehicles is constantly improving and the future use cases are specified. Hardware can quickly become obsolete while a feature that has been worse on the other day, can be improved on the next with software updates. Further pilots should mainly focus on developing the technical functionalities of the shuttles as well as related background services, such as remote control centre and efficiency of on field actions. To tackle the technological, legal and business-related challenges of automated buses, cities play an important role in providing real use cases in open road conditions and on feasible routes. There should be standardized testing practices when applying for instance for test plate certificates. Now the testing practices are different even in different EU countries making it more difficult to test vehicles in some places than others. However, when a (self-driving) vehicle is type approved, it can then be used legally in road traffic in every country which has recognized this type of approval in its legislation. Current vehicle type approval relies heavily on the validation of only a vehicle which is driven by a detachable component, the driver. In order to test the self-driving technology of a vehicle as part of a type approval procedure, a robotic license driver’s test has been thought as a solution for instance.

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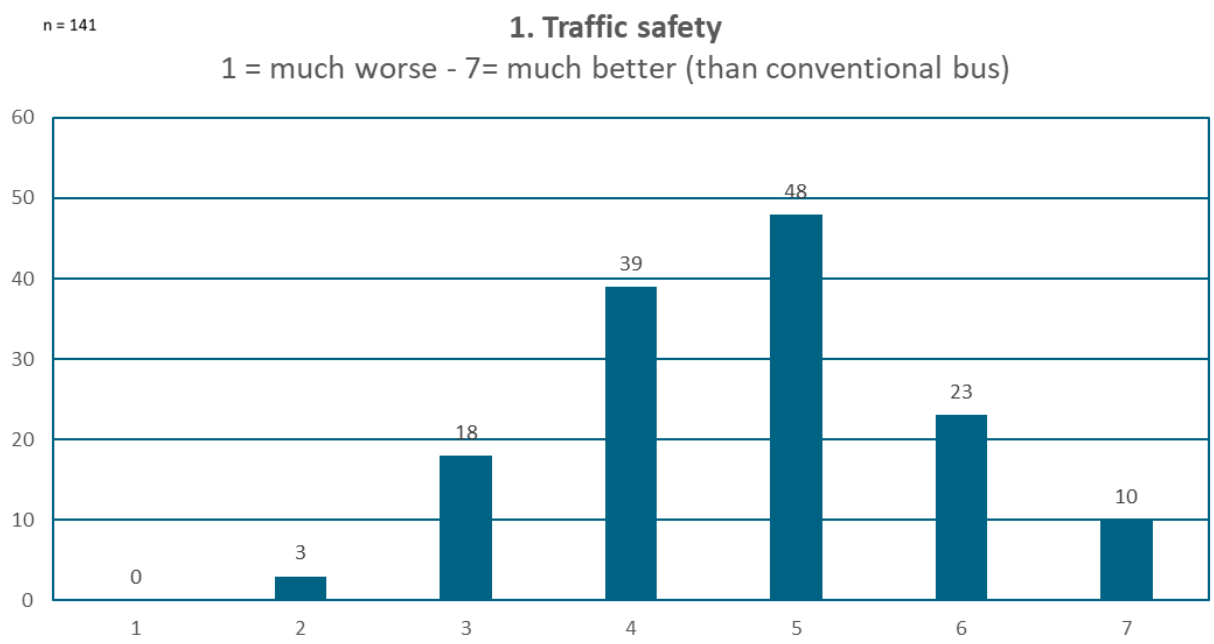
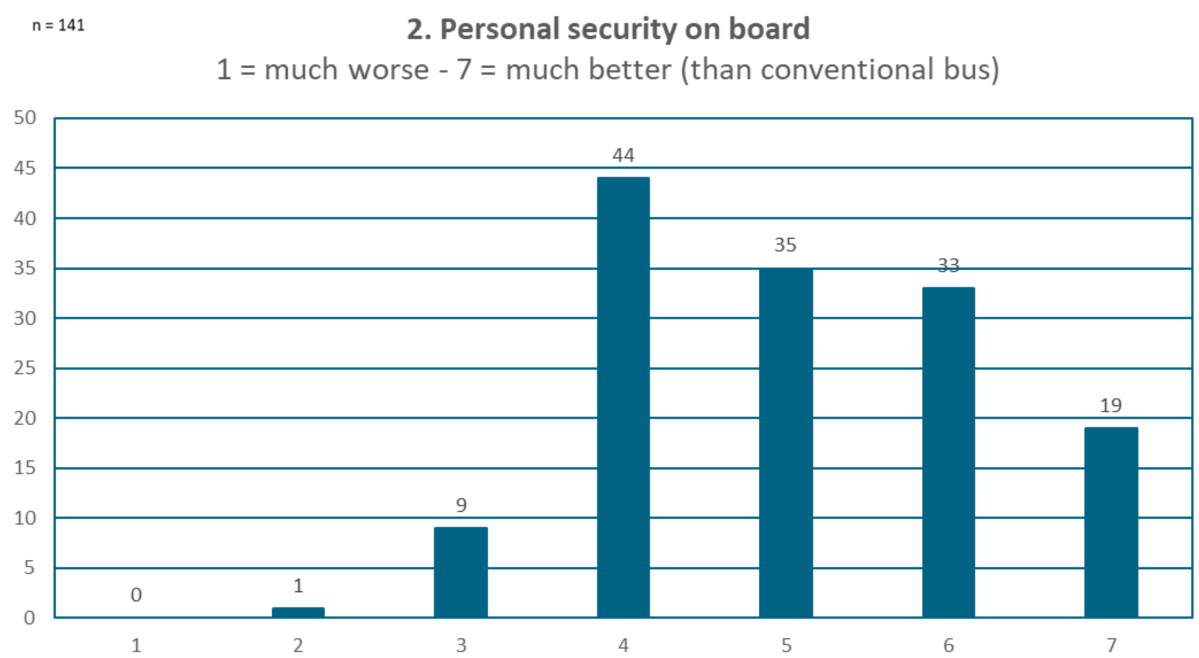
Annex I. Robot bus user survey Kivikko 2018

1. Please compare your experience of travelling in a robot bus to travelling in a conventional bus





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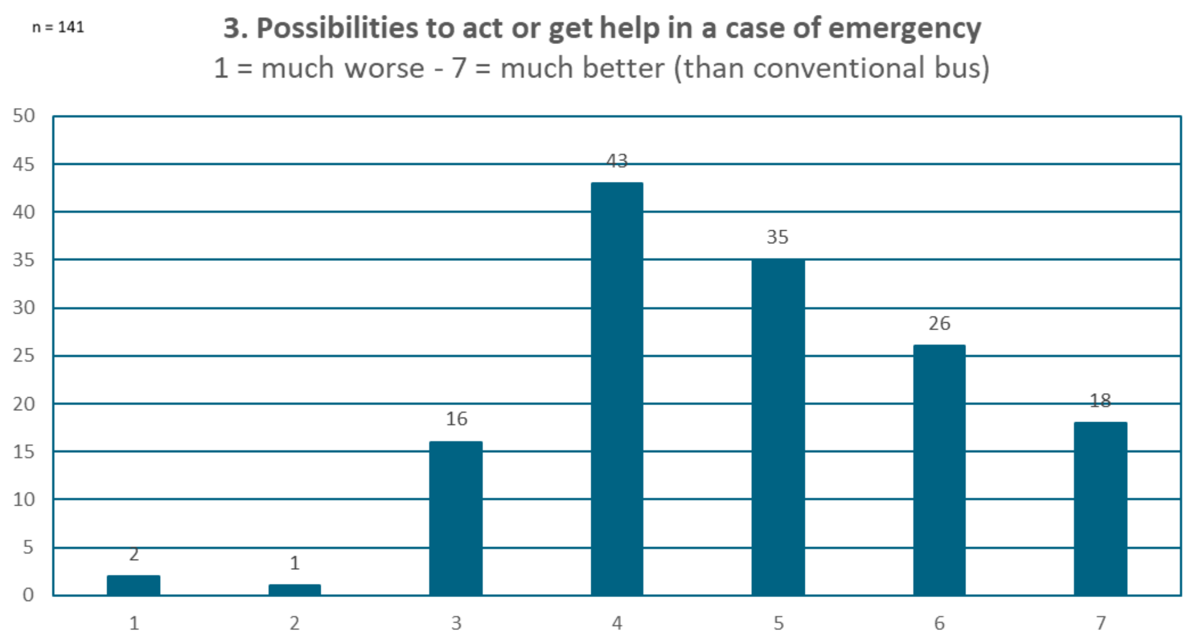

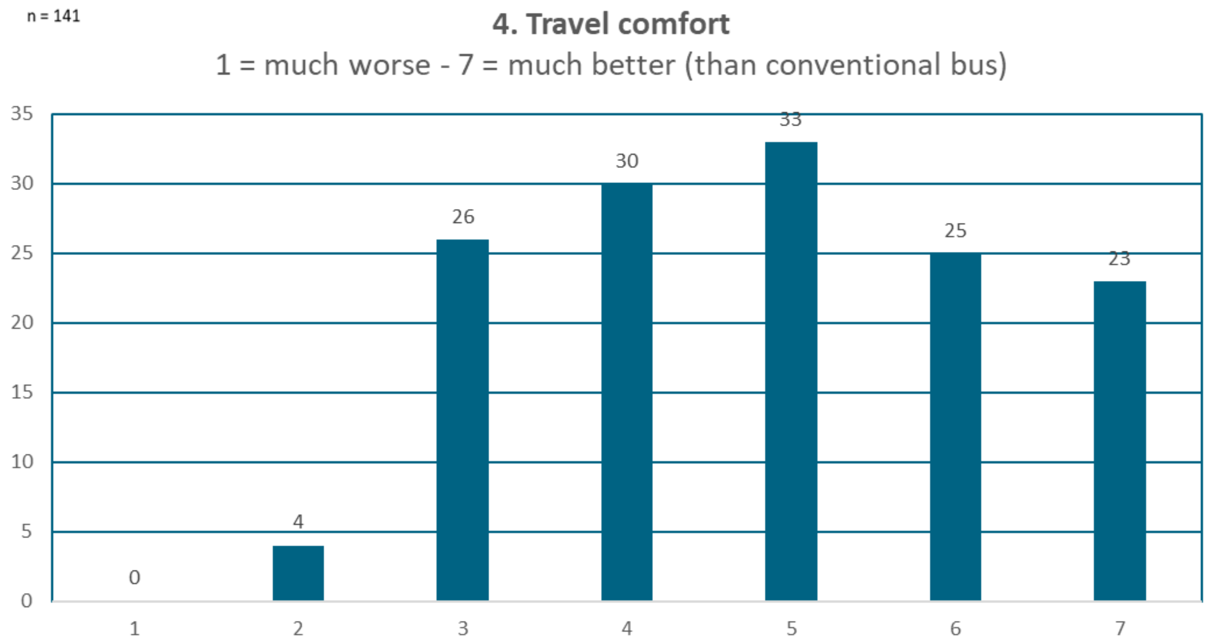

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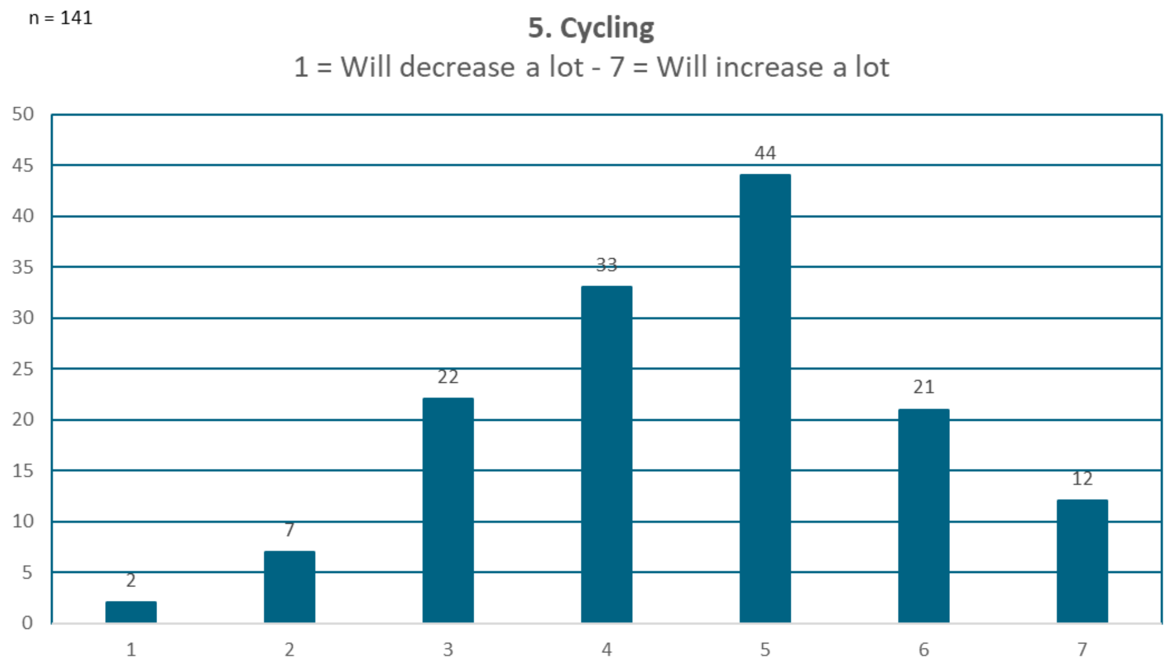
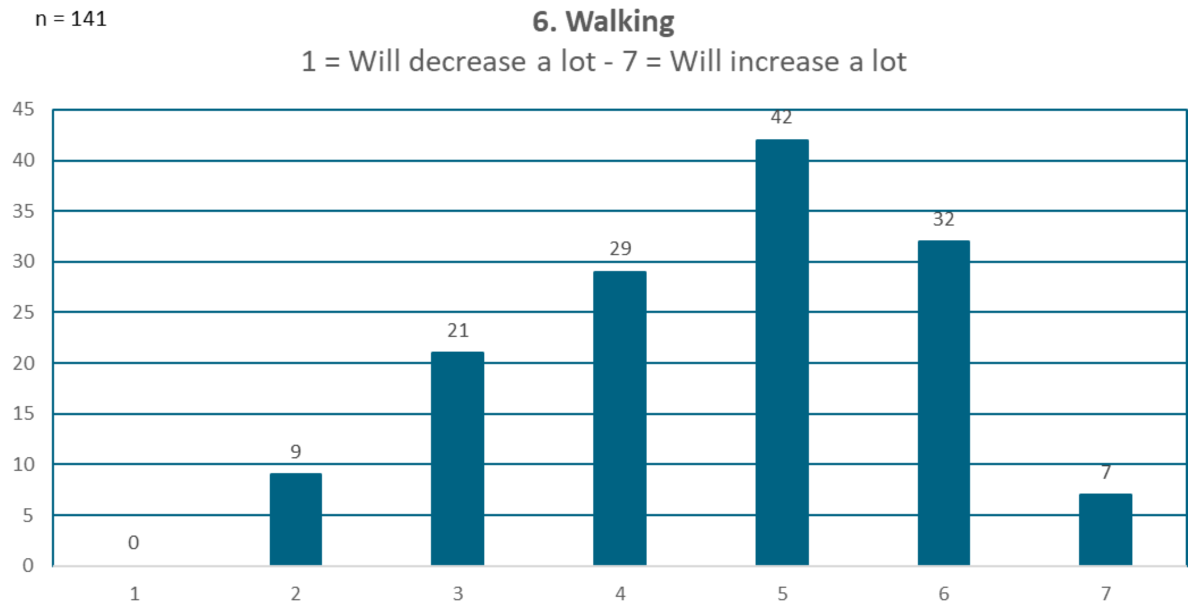
2. What is your estimation on changes that will happen in your mobility routines and habits by 2030?





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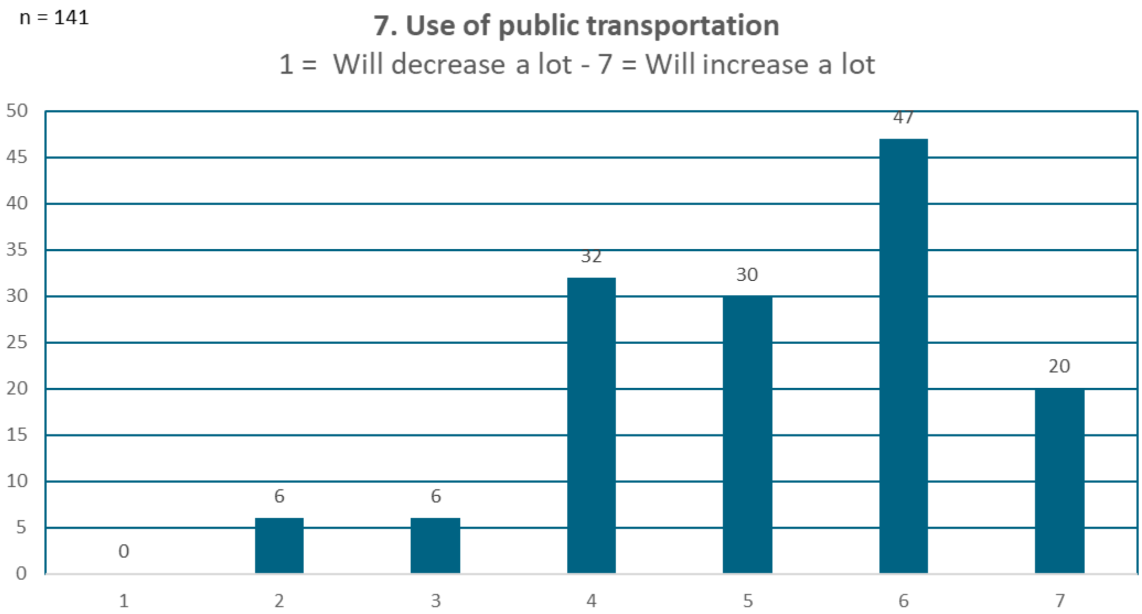

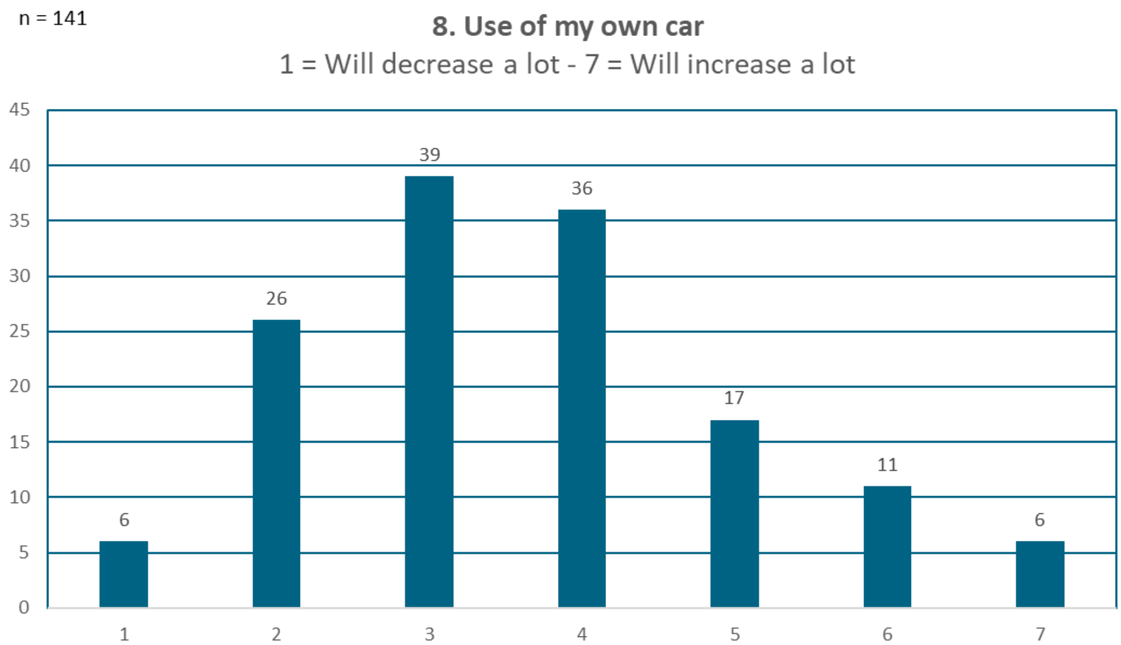

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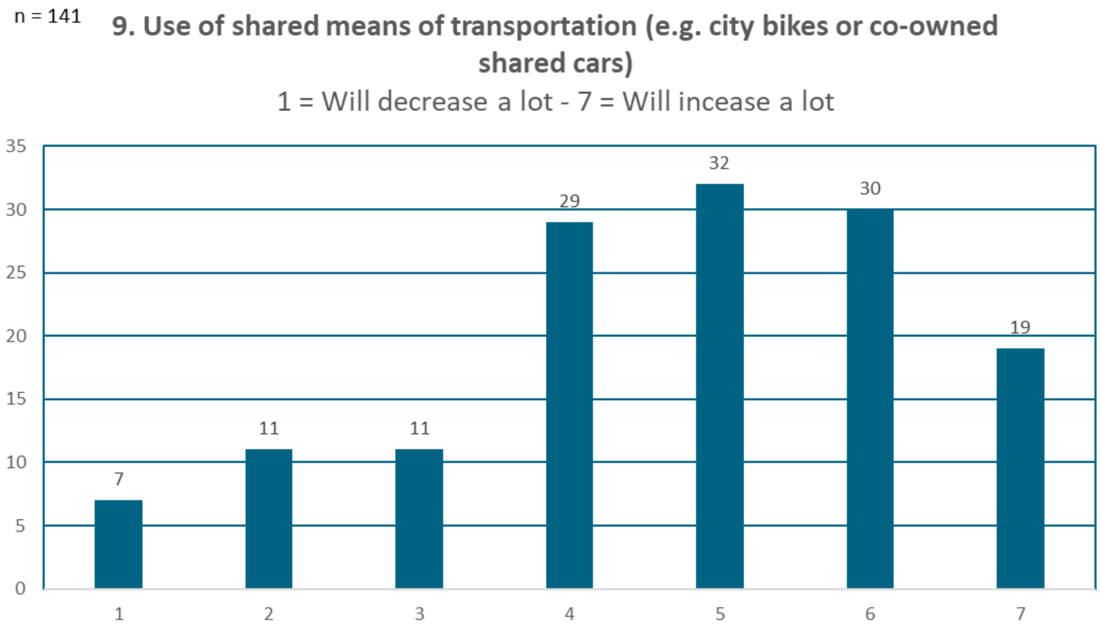
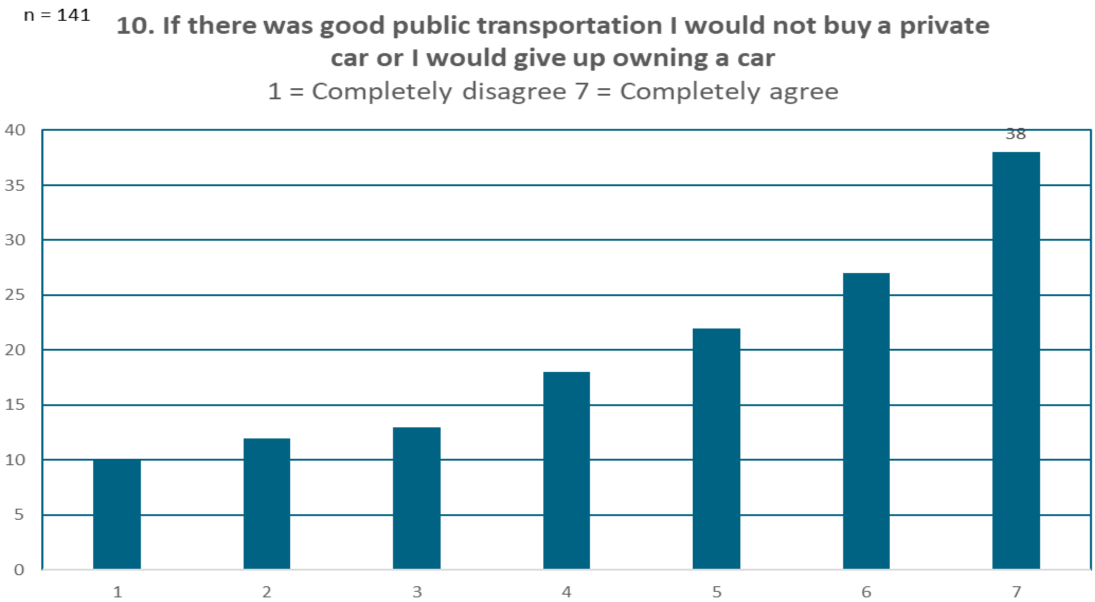


3. What is your vision about privately-owned cars in the future (by 2030)?



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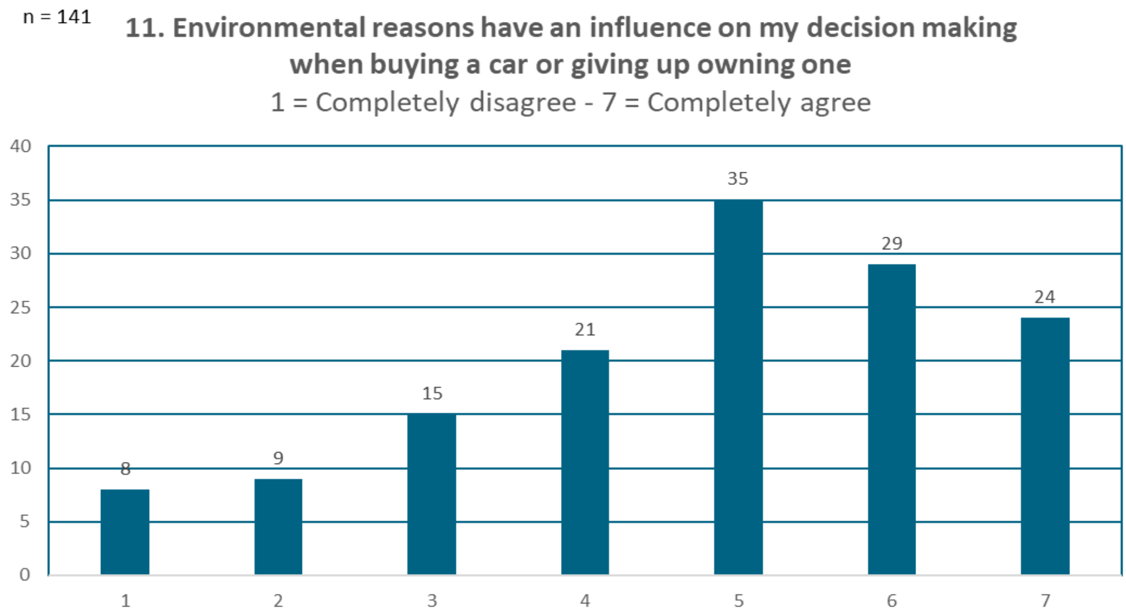

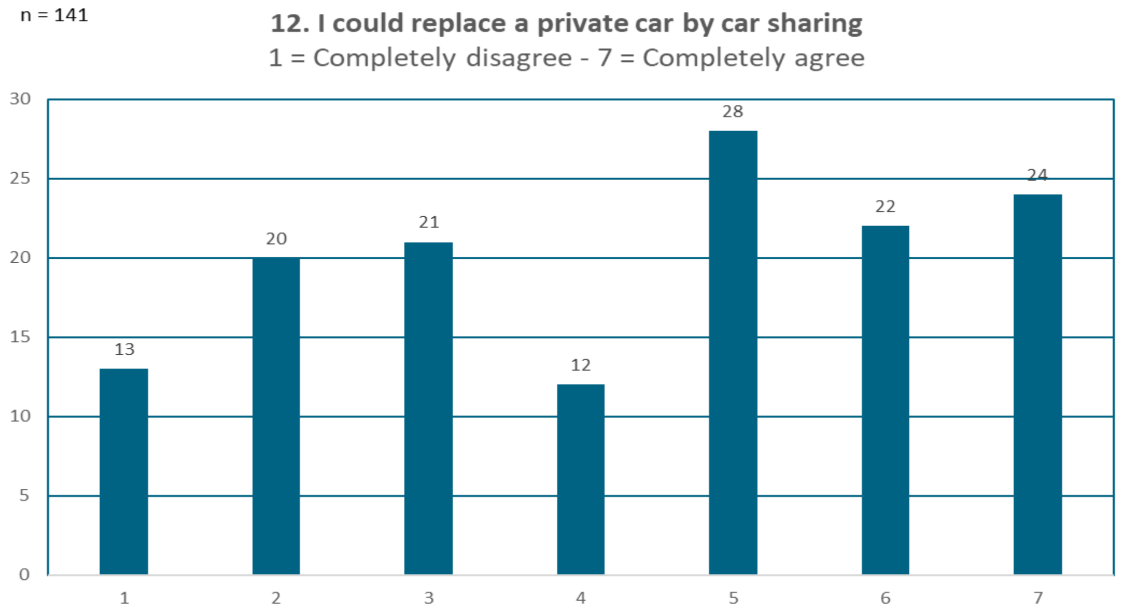

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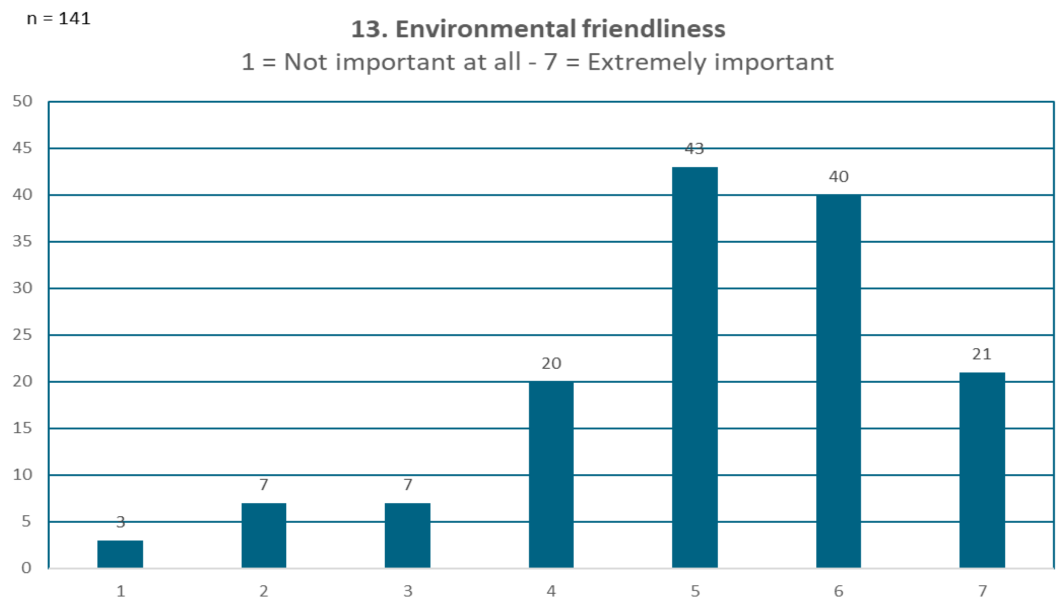
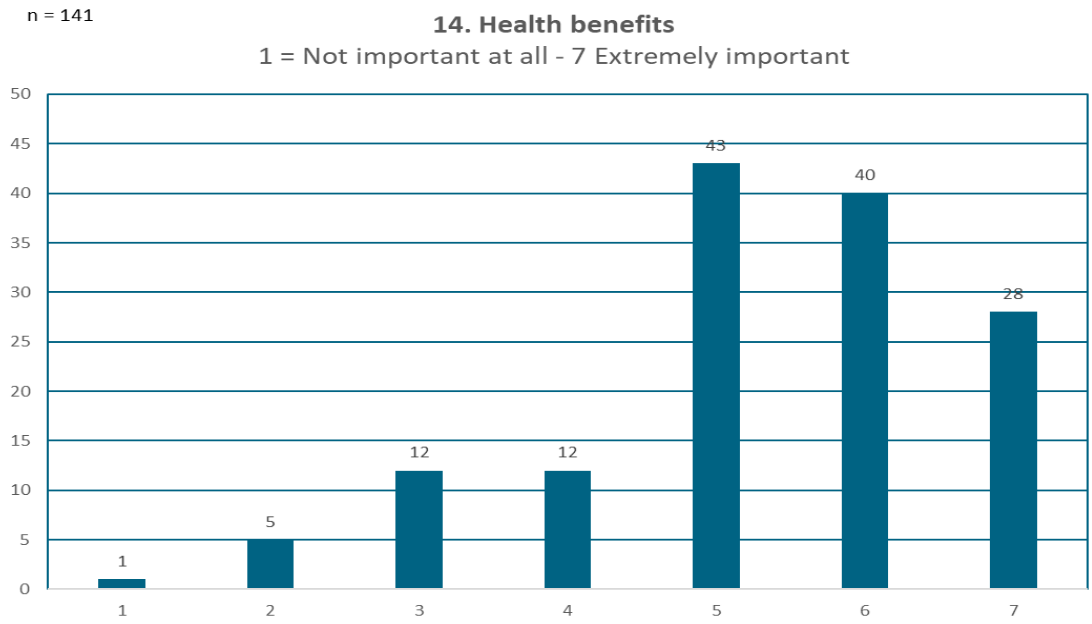
4. How important do you consider the following things when deciding how to move from one place to another?





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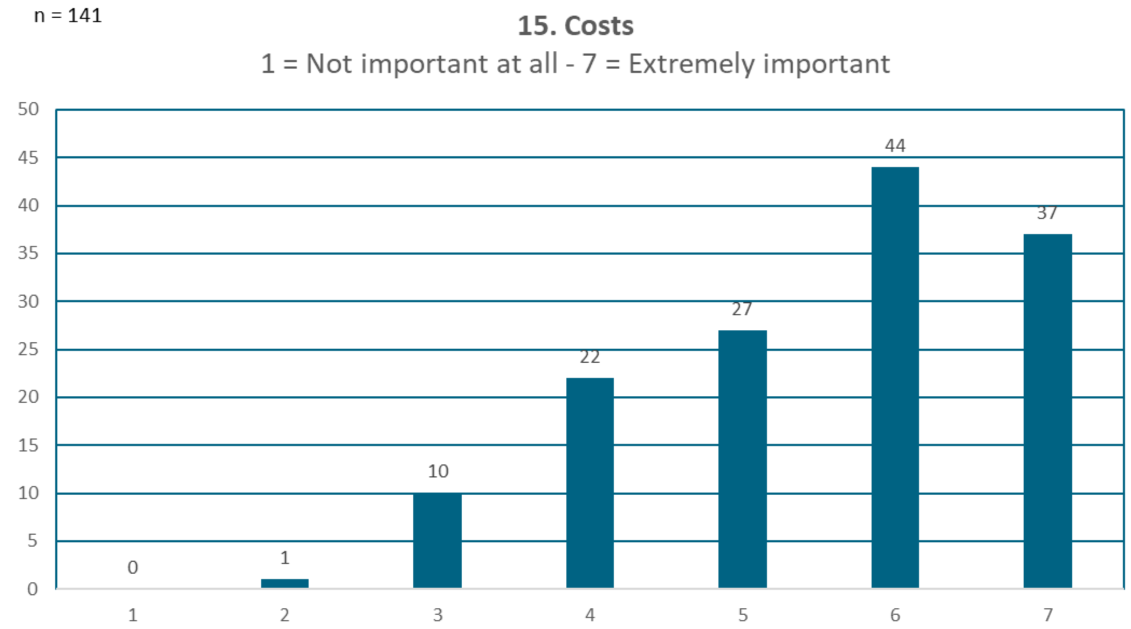

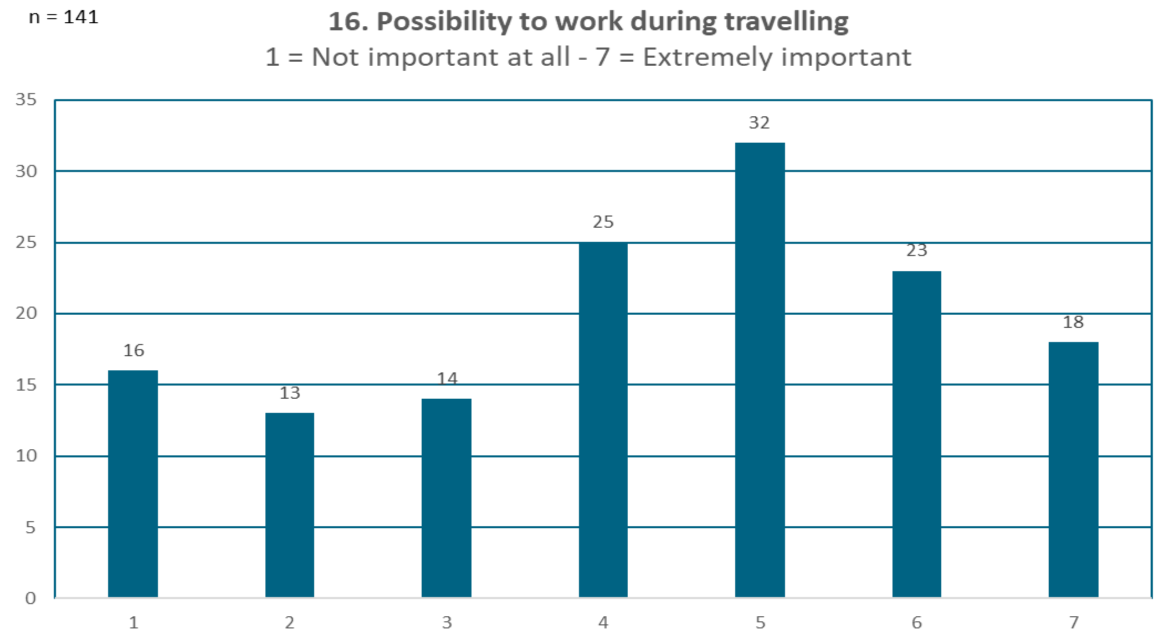

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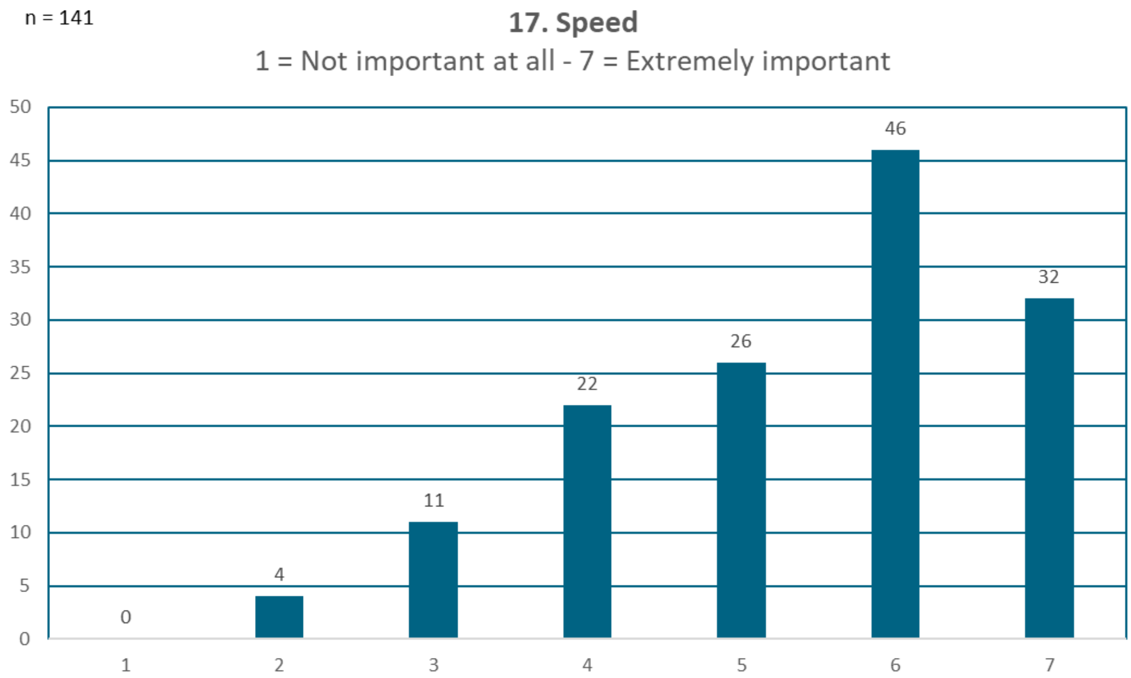

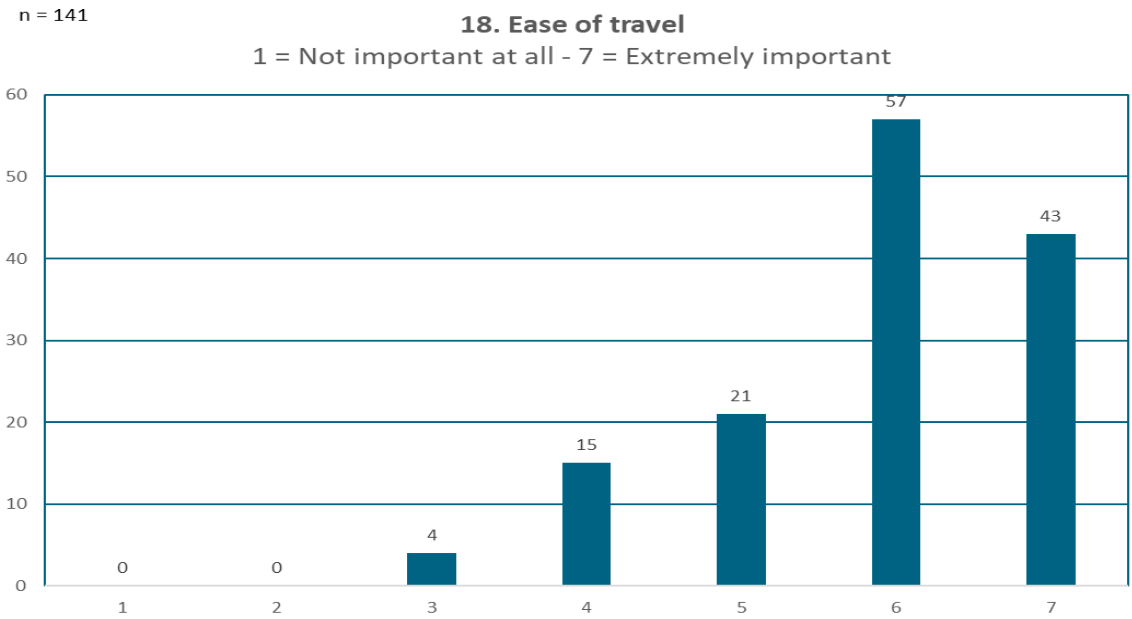

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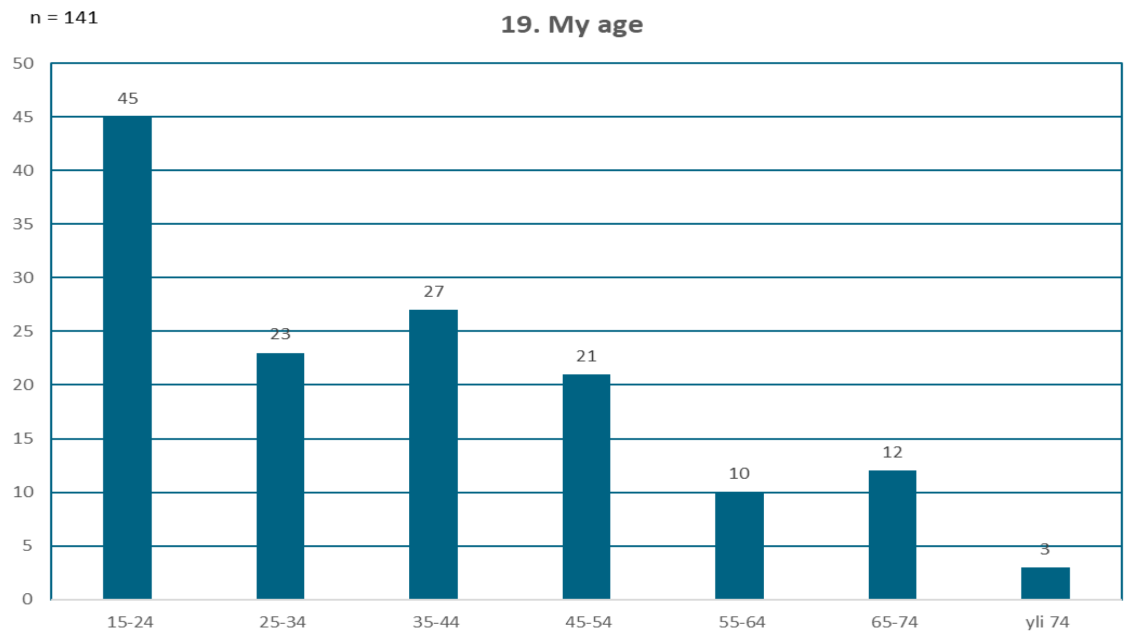
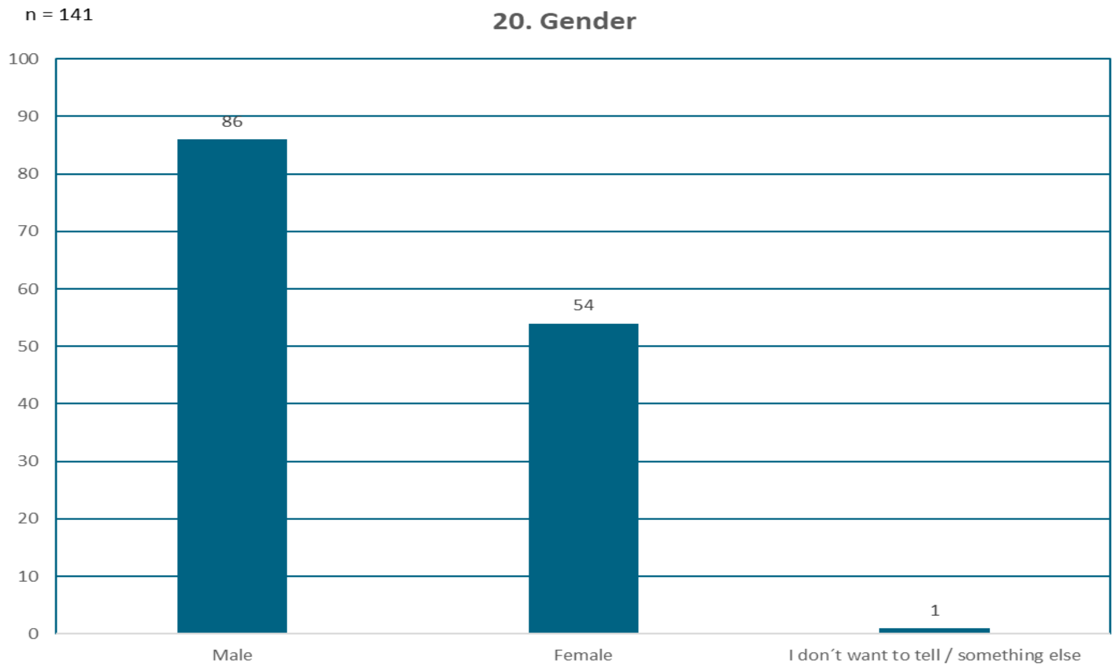
5. Finally, some socio-demographics





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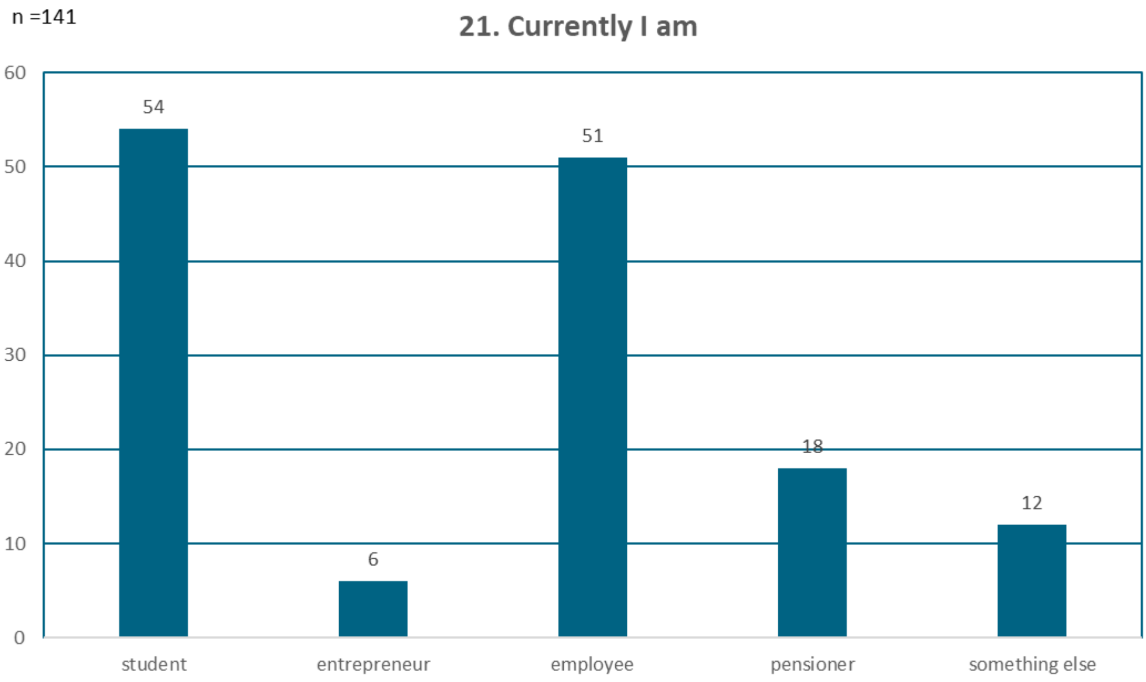

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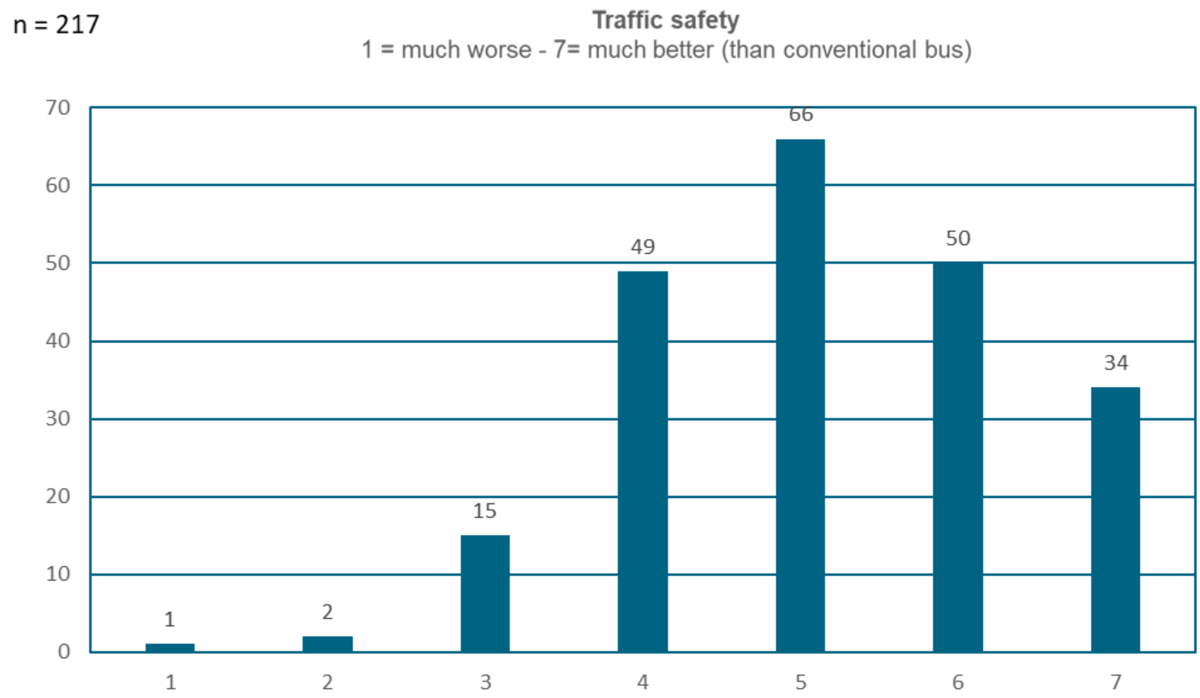
Annex II. Robot bus user survey Kalasatama 2019

1. Please compare your experience of travelling in a robot bus to travelling in a conventional bus



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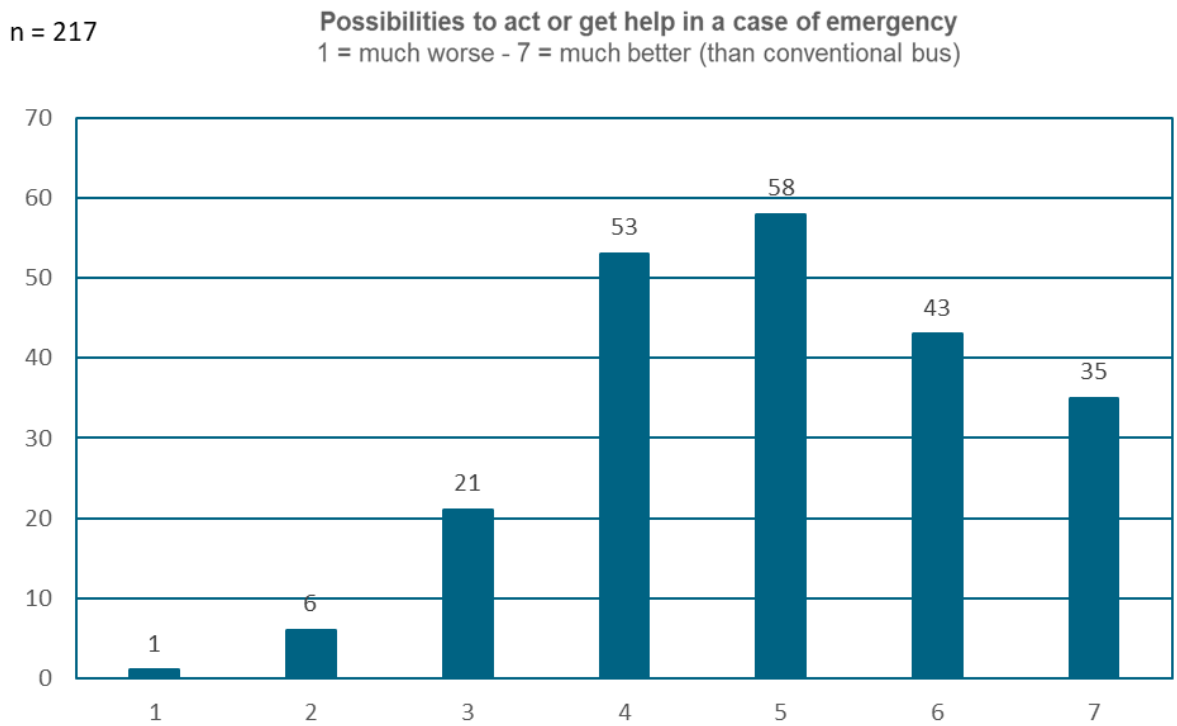

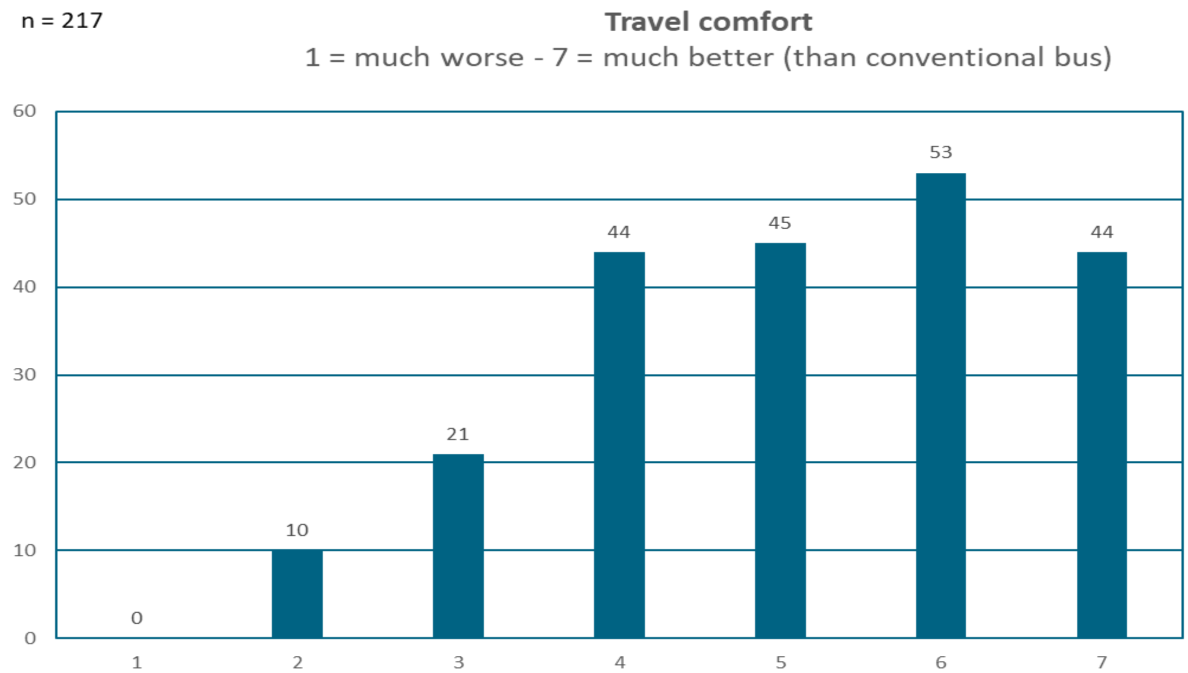

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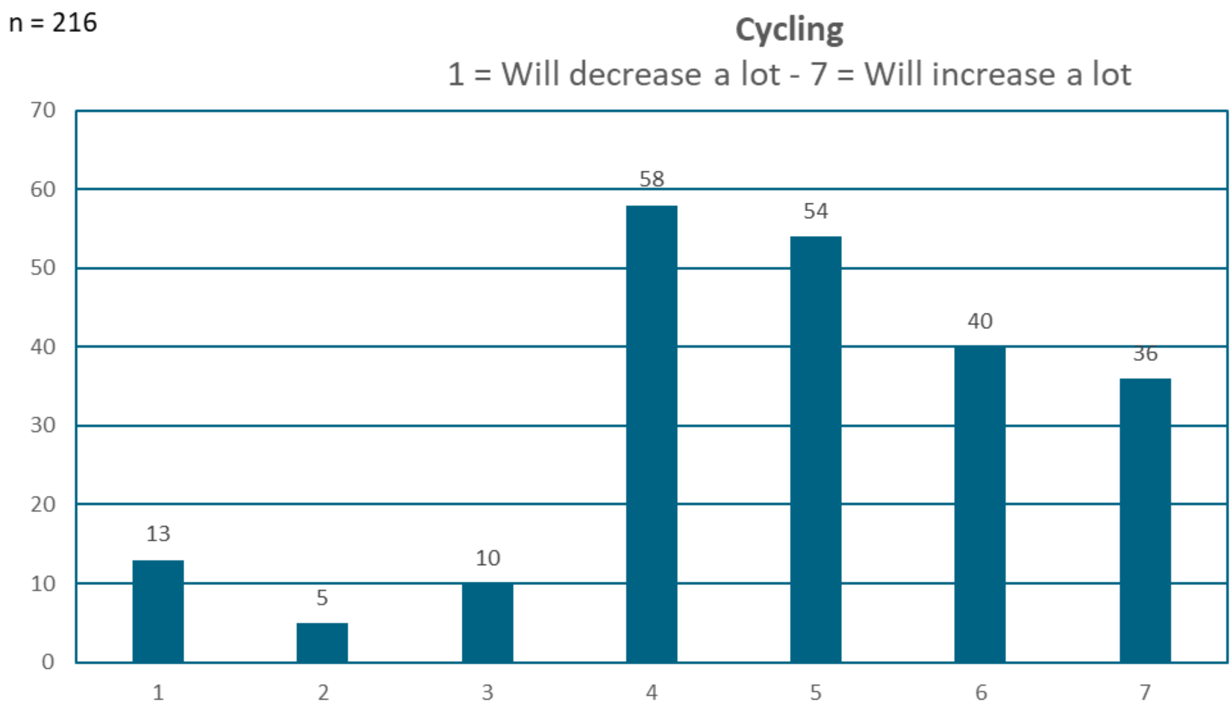
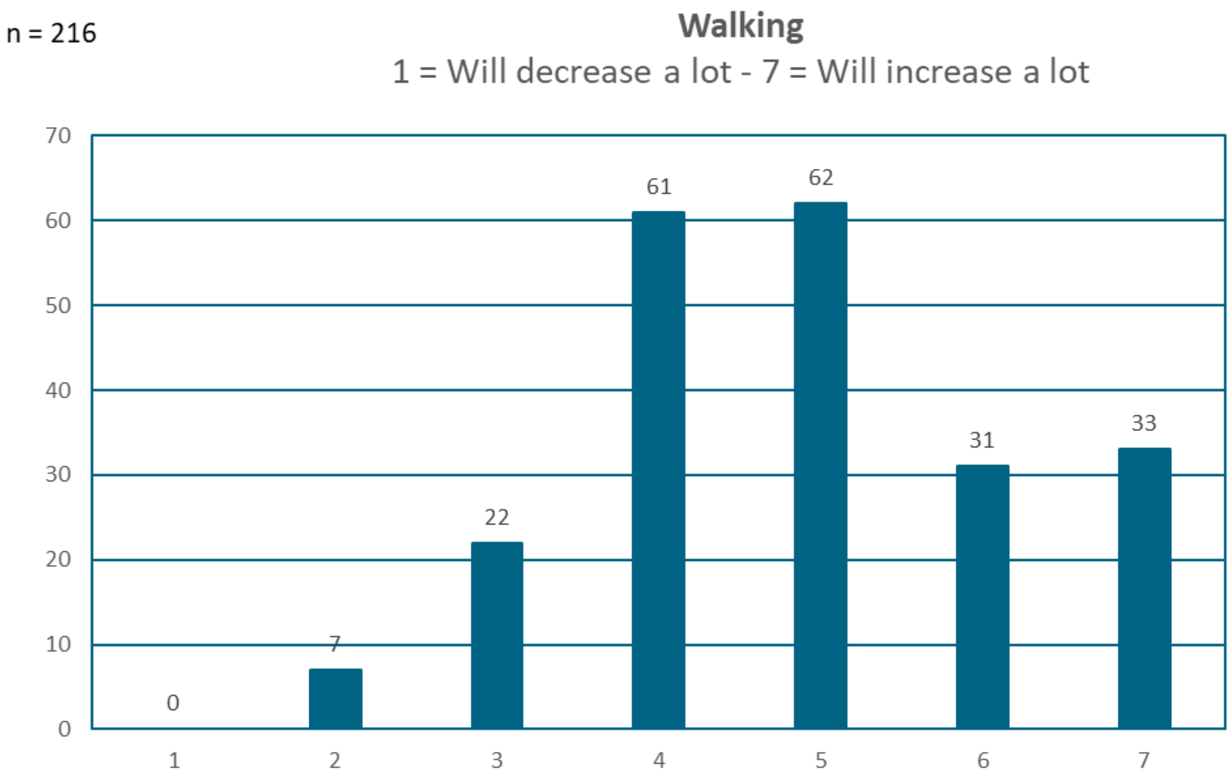
2. What is your estimation on changes that will happen in your mobility routines and habits by 2030?





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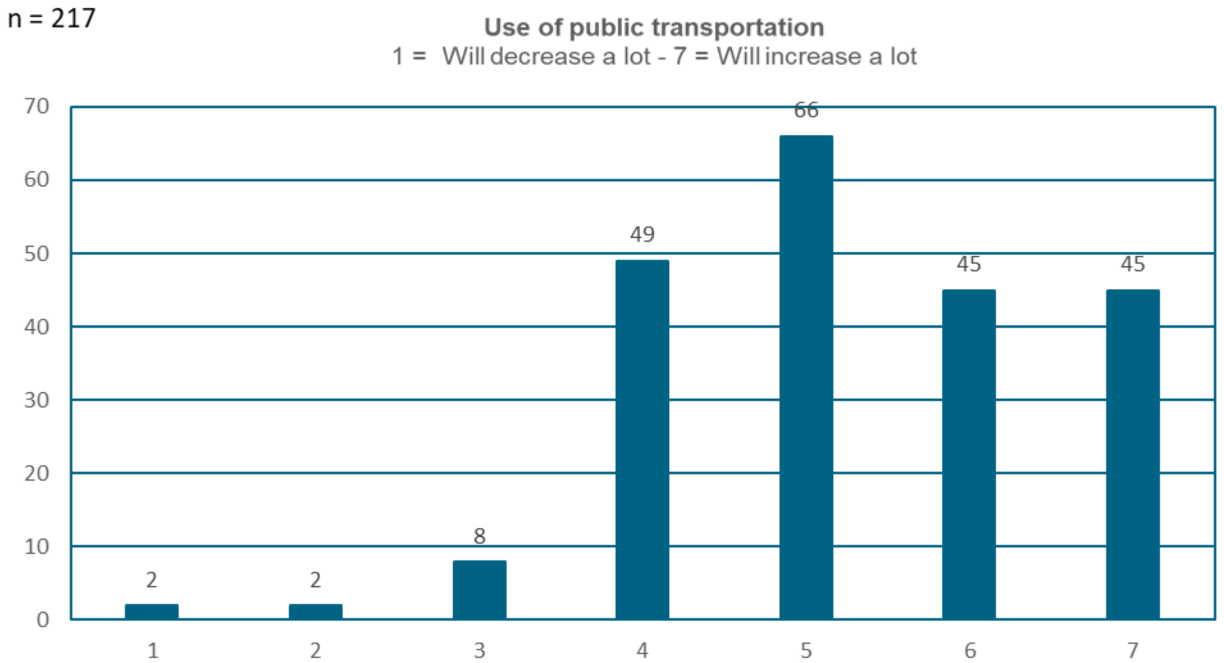

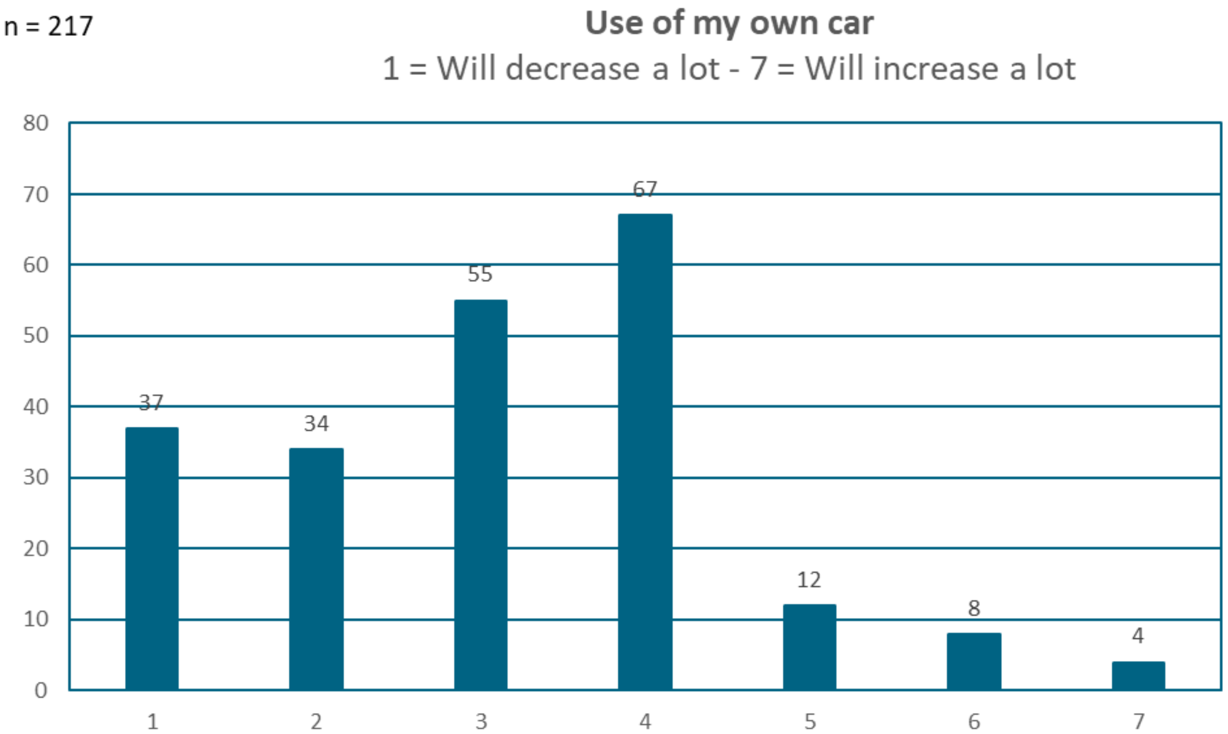

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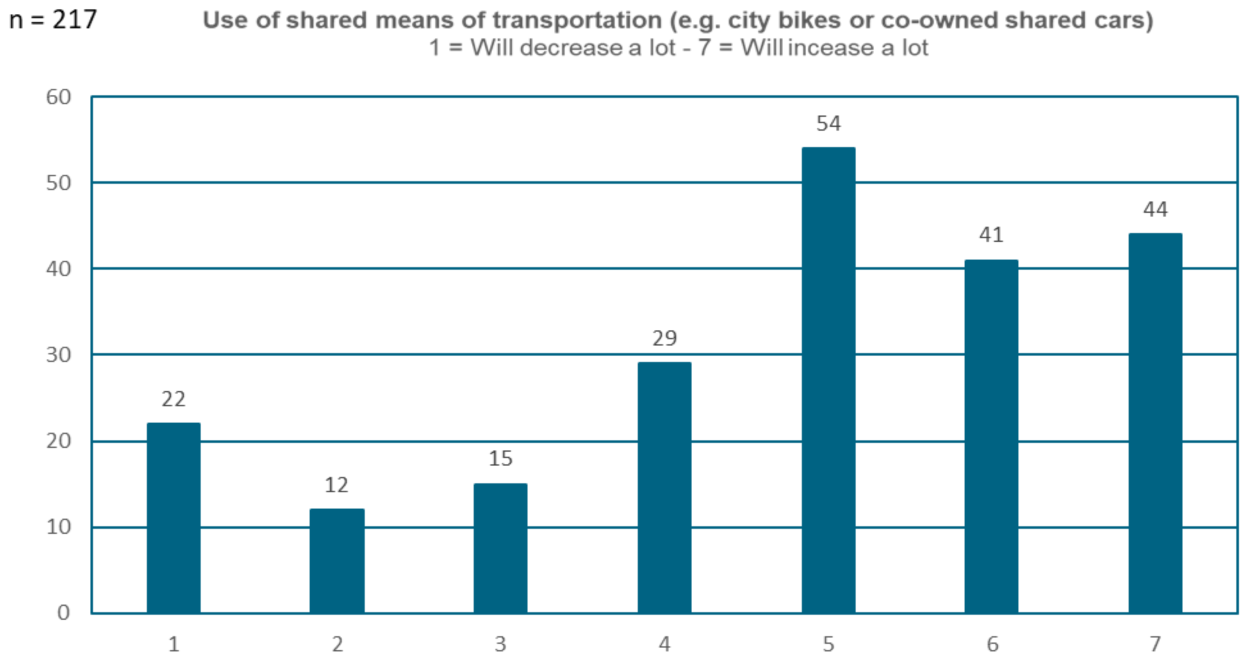
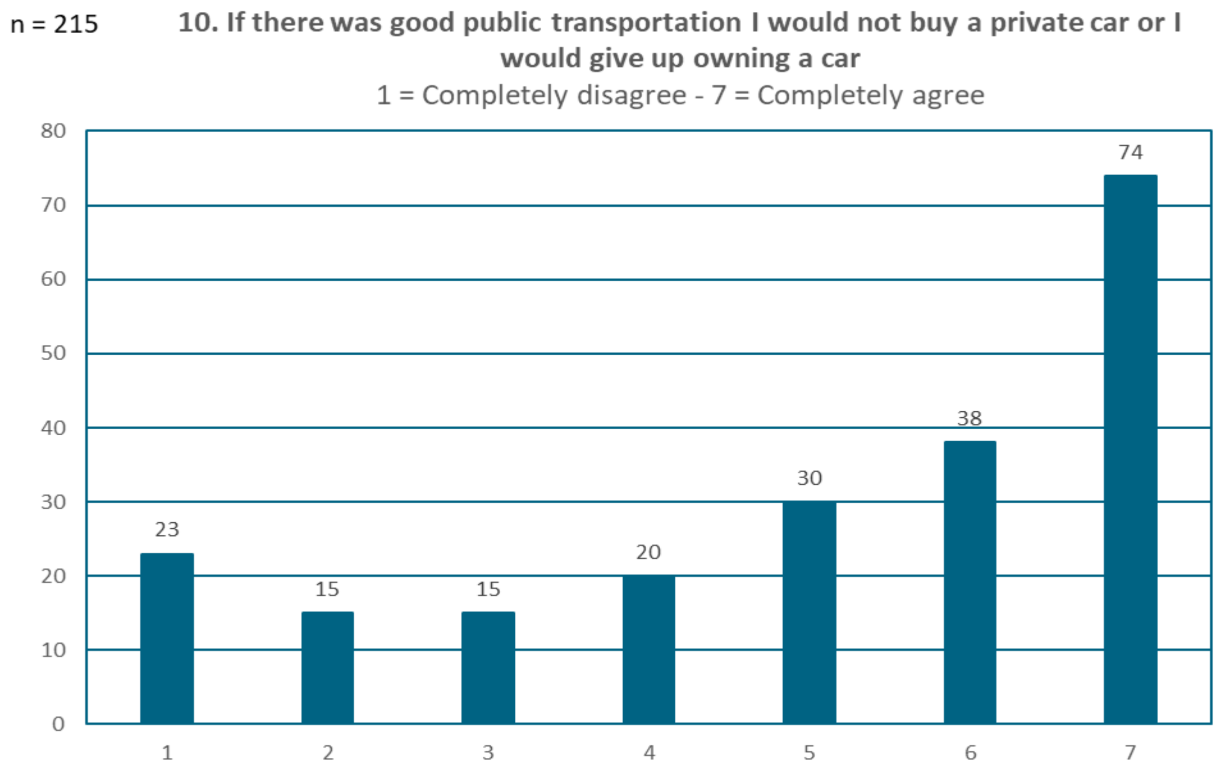


3. What is your vision about privately-owned cars in the future (by 2030)?



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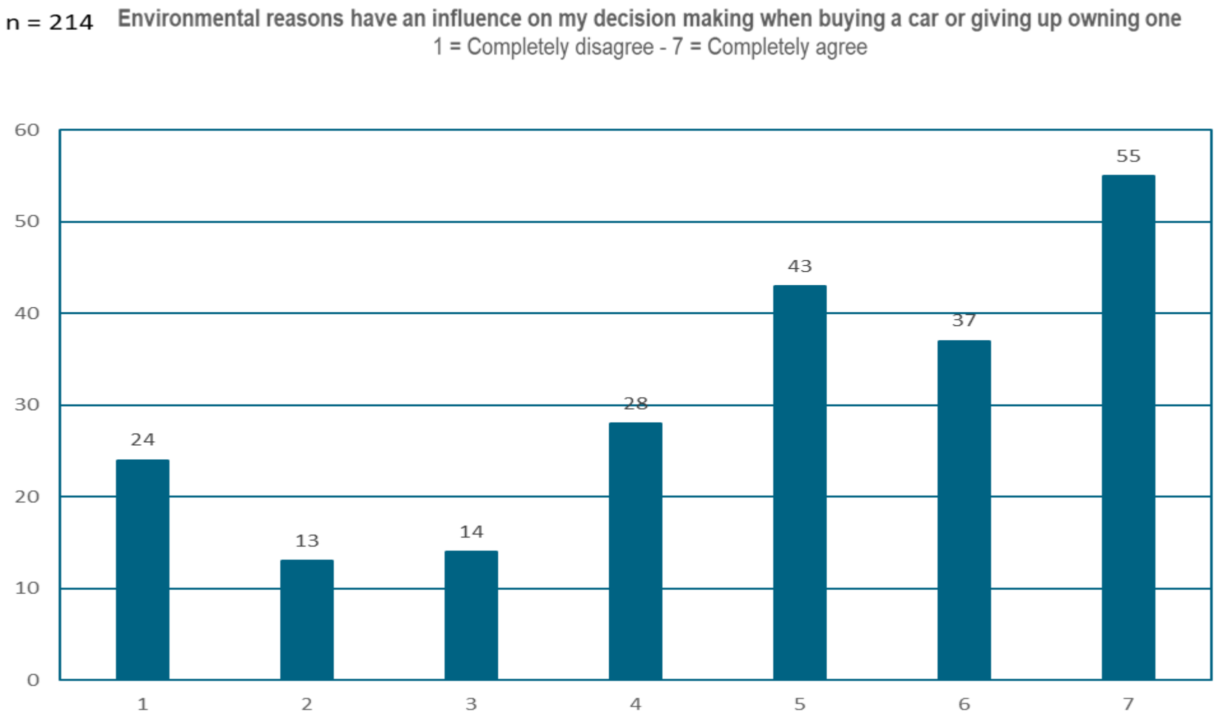

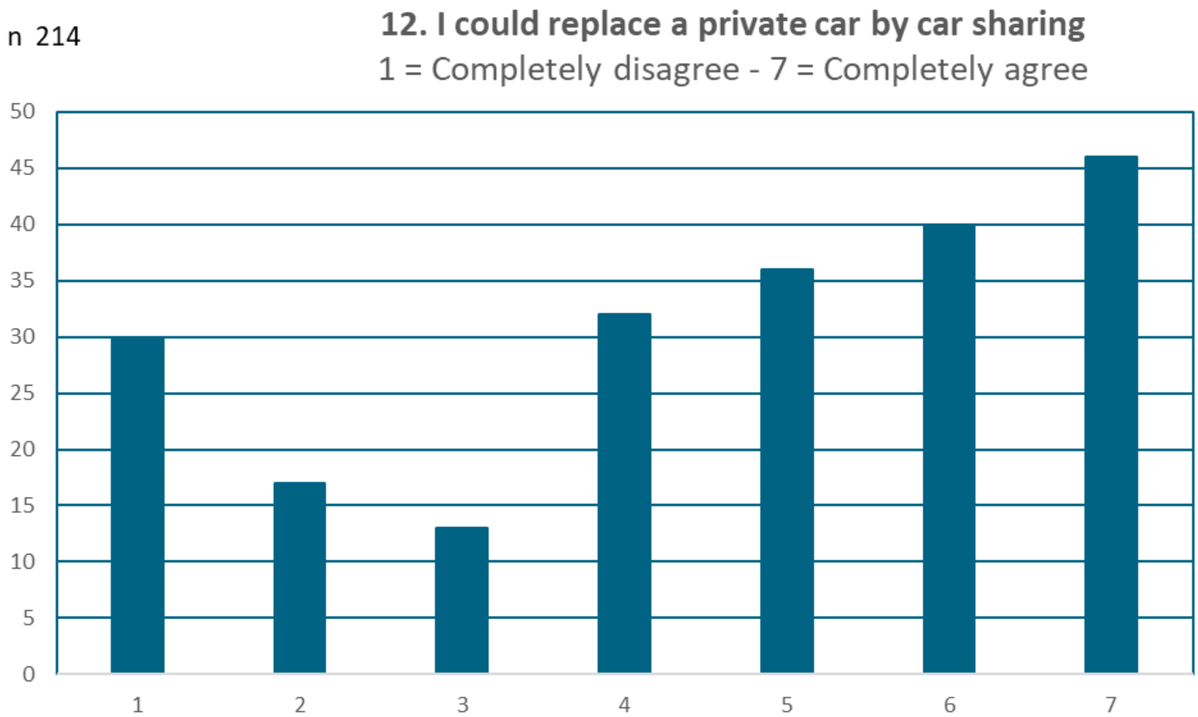

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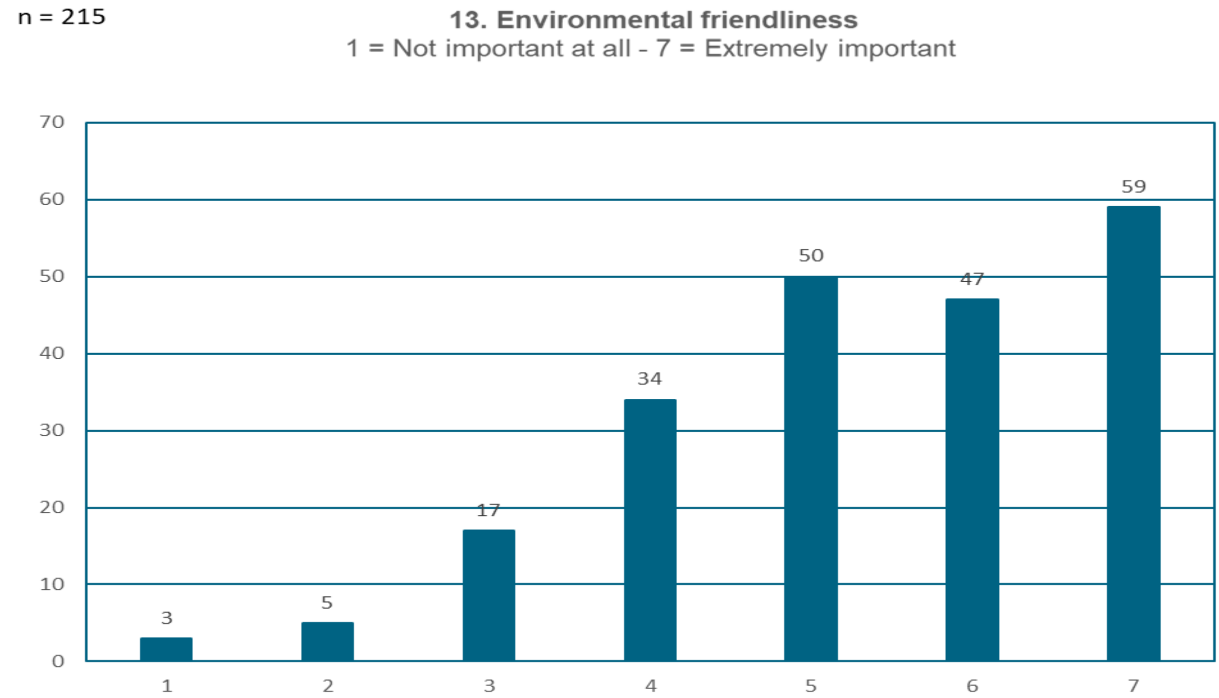
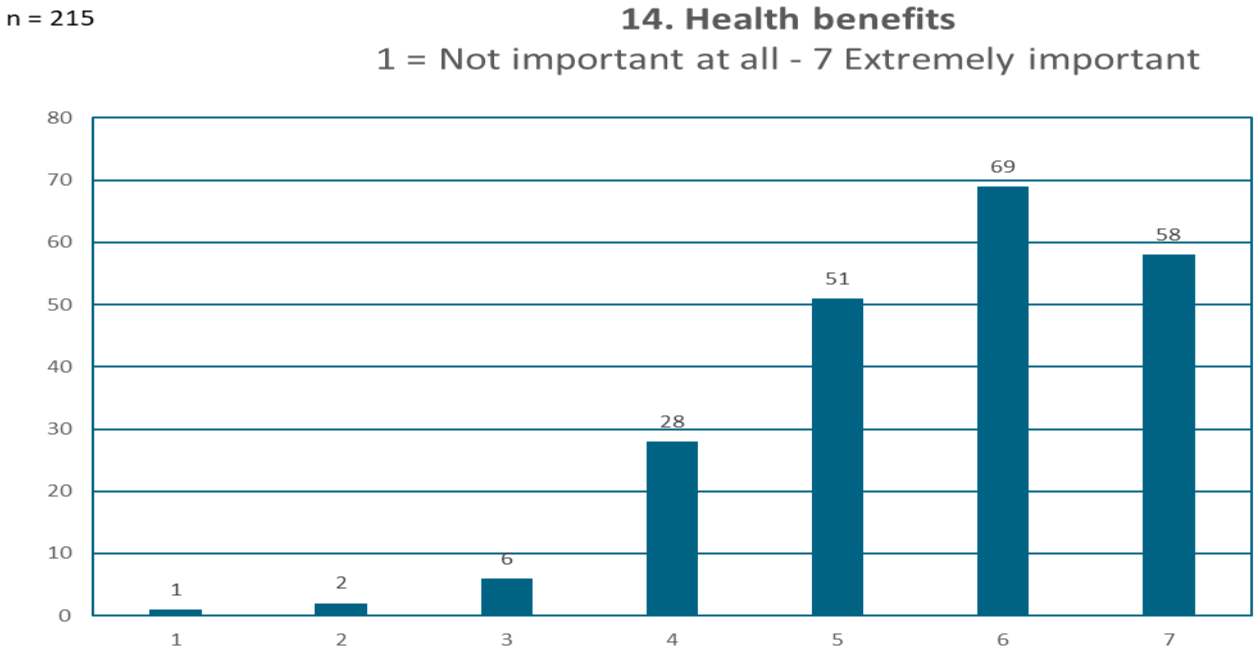
4. How important do you consider the following things when deciding how to move from one place to another?





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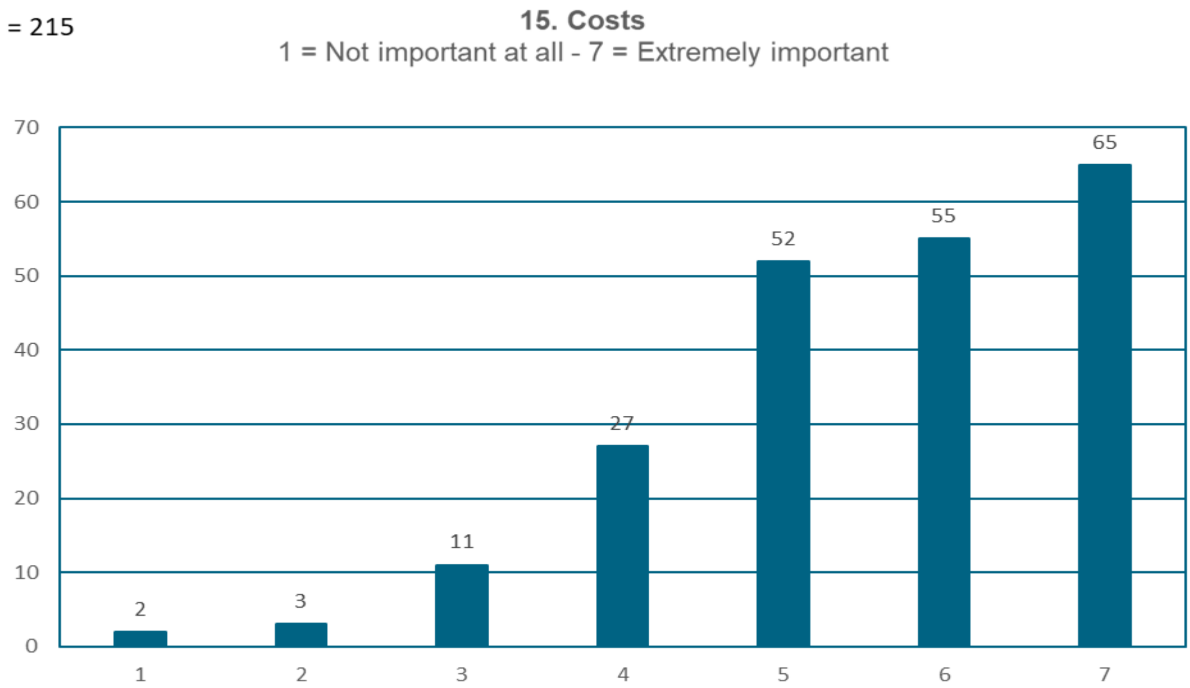
n = 215



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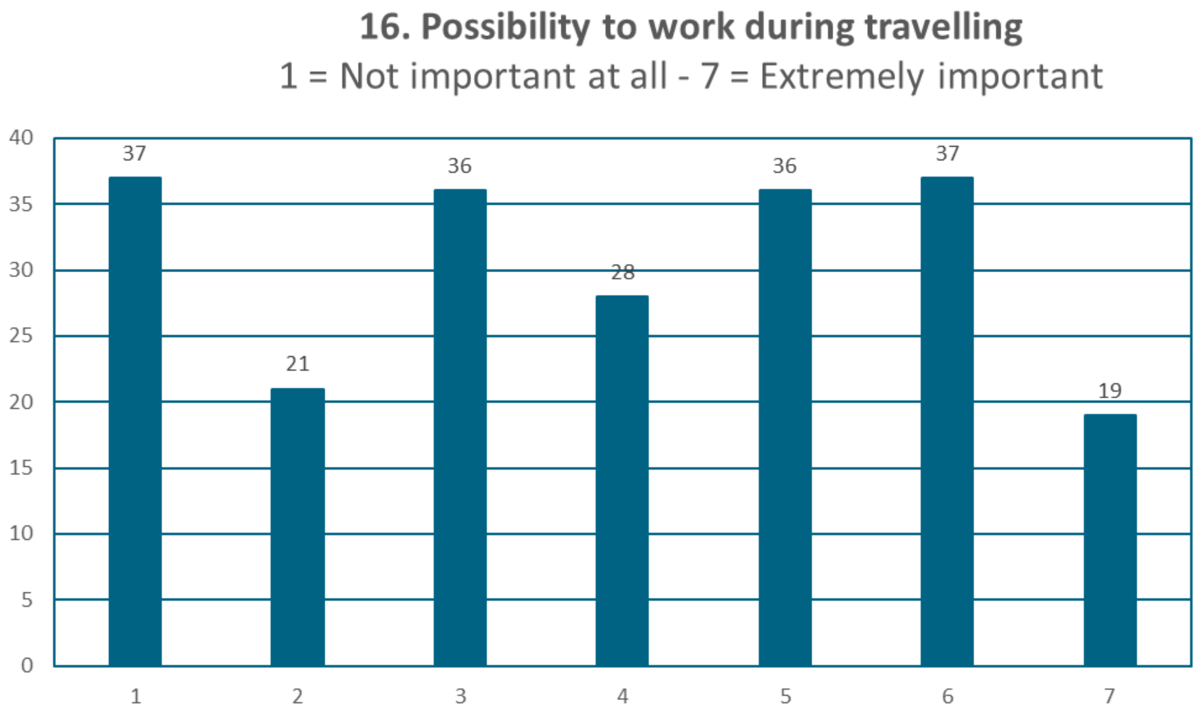

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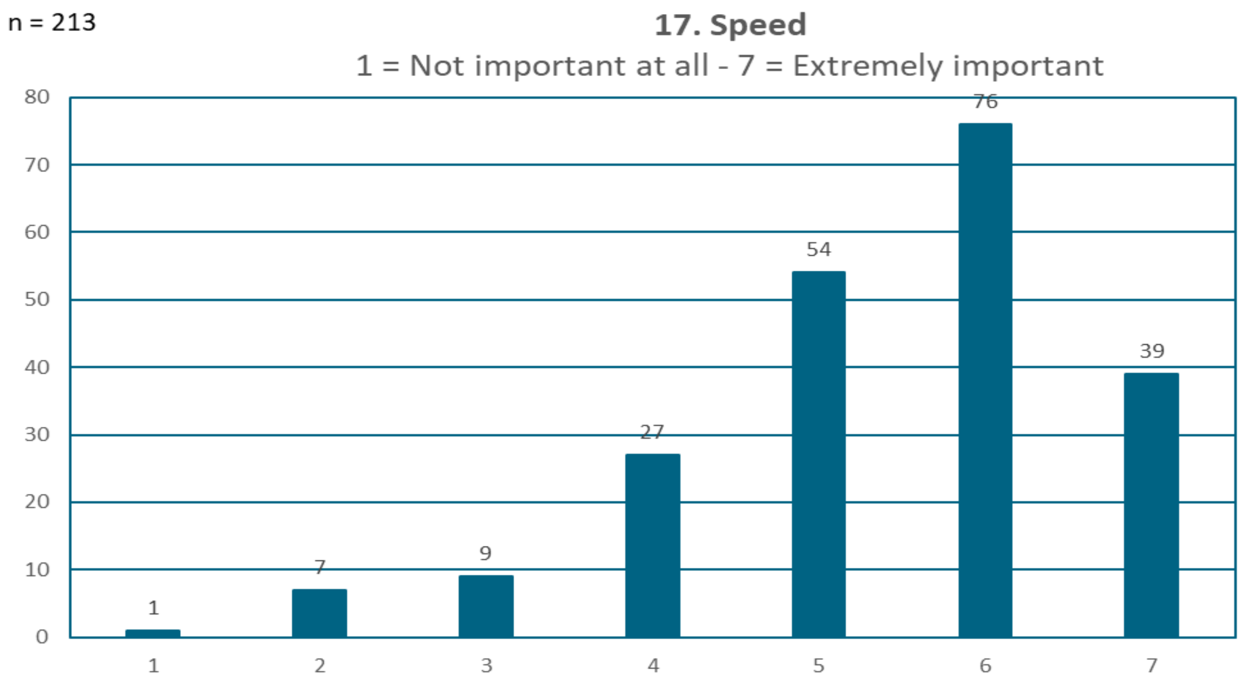

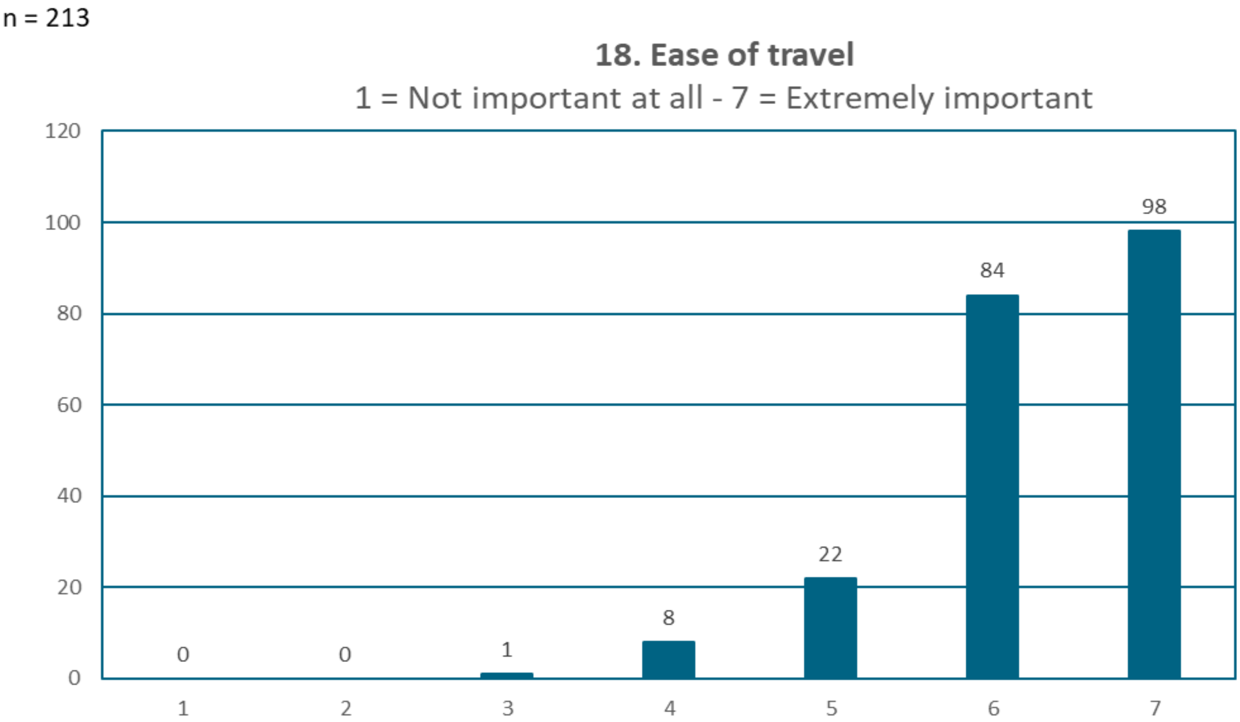

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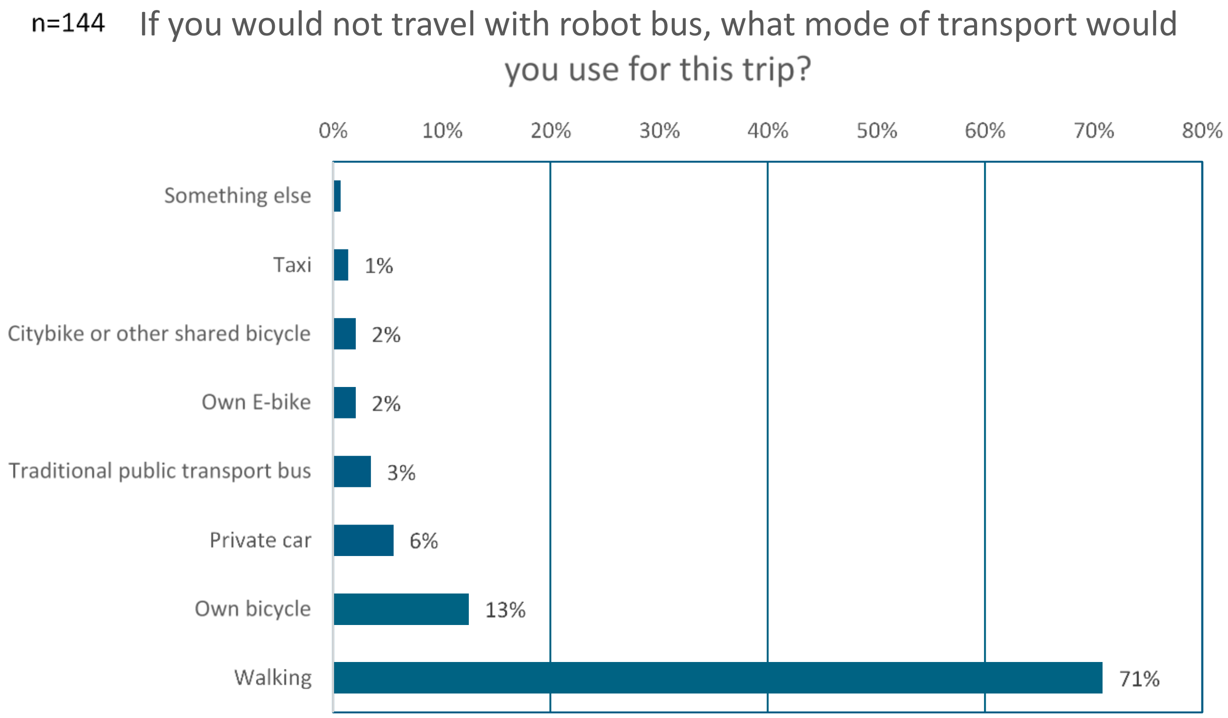
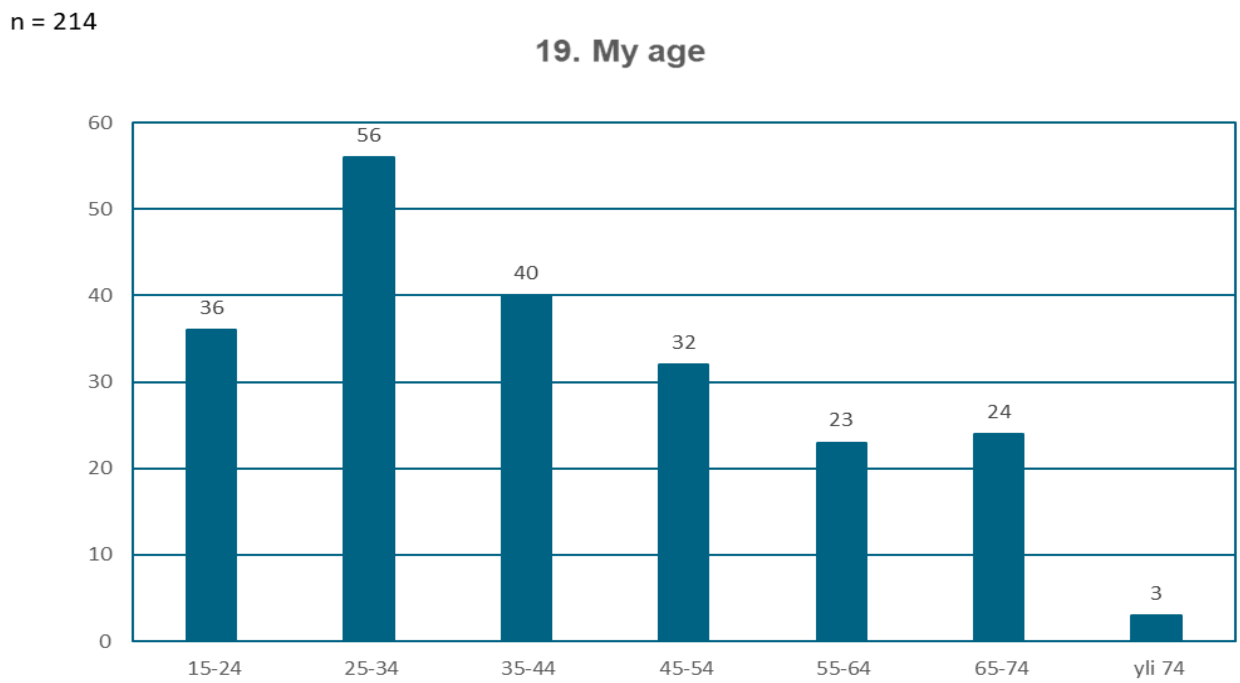


5. Finally, some socio-demographics



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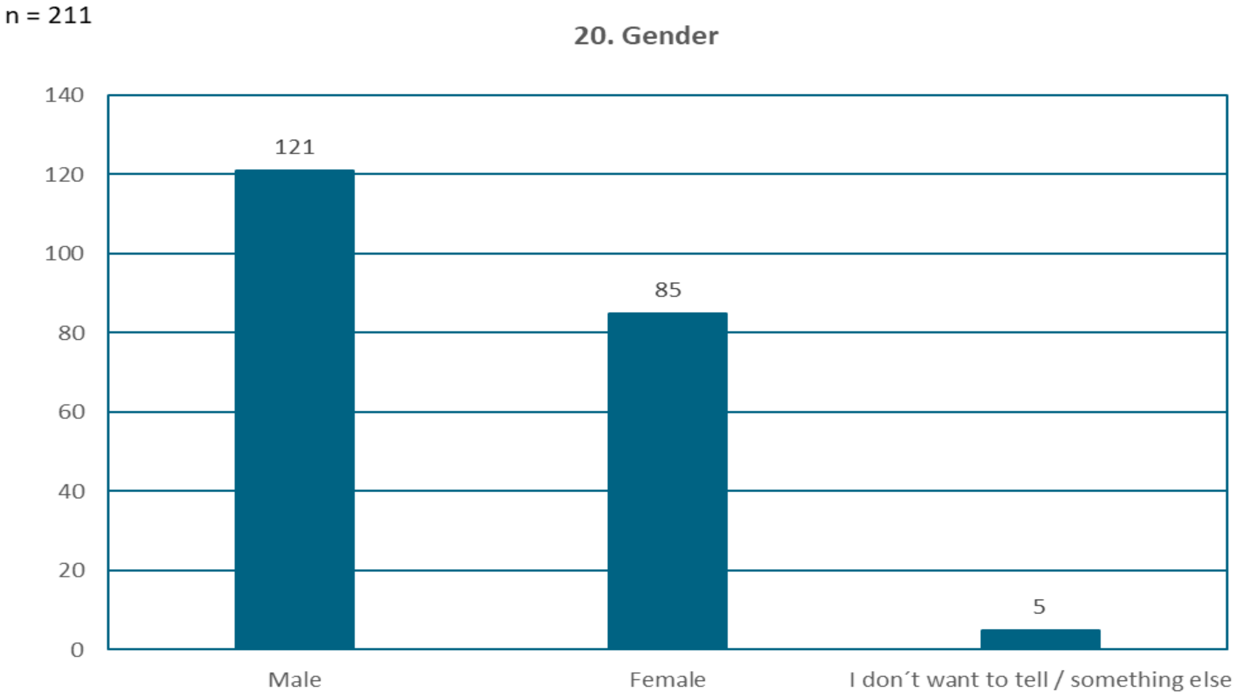

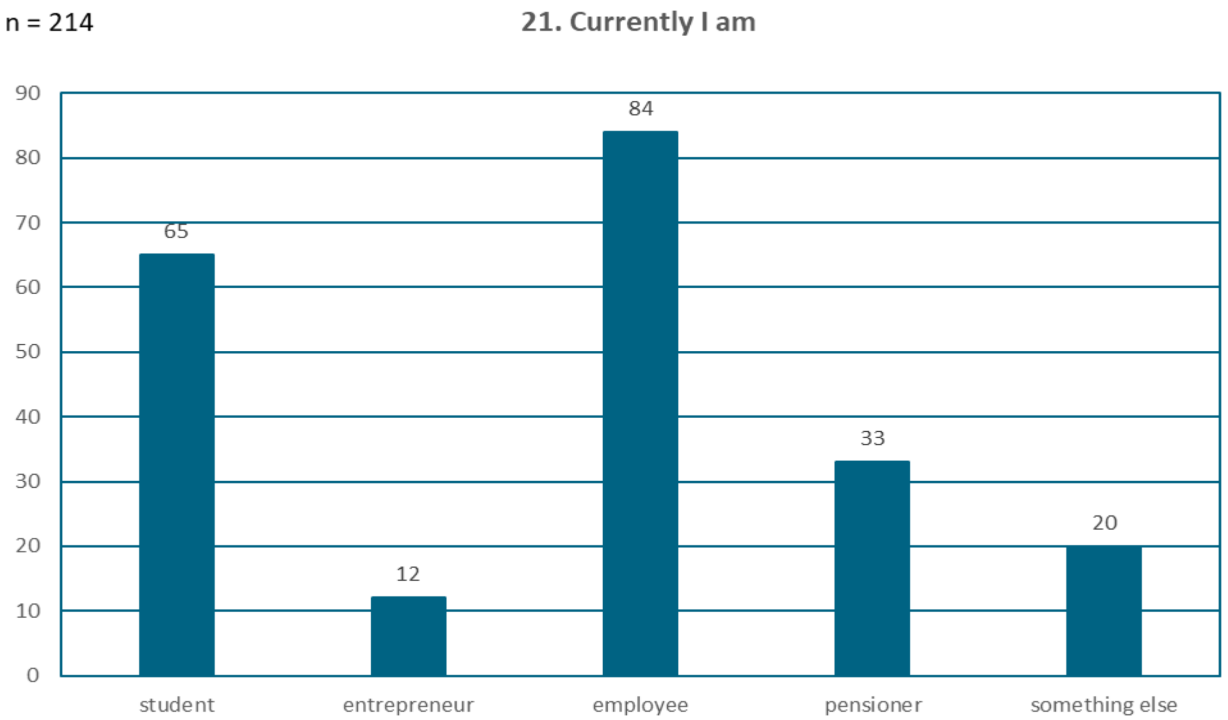

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