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Expert-based multicriteria assessment of near-future scenarios for the automation of collective transport services in Helsinki

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Abstract of master's thesis

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Abstract

Near-future implementations of services operated with connected and automated vehicles (CAVs) have received little attention in the scientific literature even though an increasing amount of service pilots are organised every year all around the world. This study aimed to systematically, through expert and stakeholder interviews, identify alternative collective transport service designs for connected and automated, rubber-tire vehicles and criteria based on which these services should be evaluated. Additionally, the relative importance and the viability of the criteria were investigated alongside the performance of the imagined services with a multicriteria scenario evaluation exercise.

The participants had rather similar views about the future CAVs but some divergence occurred as well. All participants viewed CAVs, in the early stages, as a way to complement the collective transport system. The vehicles were mostly associated with feeder and last/first mile services. Two service designs were frequently mentioned in the interviews: point-to-point fixed-route services and point-to-point flexible-route services. Flexible services were associated with loosely populated suburban neighbourhoods and fixed services with densely populated areas. However, a conflicting result was obtained from the multicriteria process, as the participants expected that the imagined fixed-line services would distinctly outperform the flexible ones in both densely and loosely populated settings. Nevertheless, the participants expected that the CAV-services, fixed or flexible, would be an improvement from the conventional bus lines that were used as a reference point. Besides the service designs and the locations of implementation, divergence occurred in the expected rate of technological development and in the services' presumed ability to advance equal mobility.

For evaluating the service designs, thirty-three criteria were identified and grouped into six main criteria: safety, reliability, transport system effects, travel experience, resource efficiency, and environmental effects. Safety was regarded, by far, as the most important criterion followed by reliability, transport system effects, travel experience tied with resource efficiency, and finally environmental effects.

Keywords Connected and automated vehicle, CAV, Self-driving vehicle, SDV, Automated vehicle, Autonomous vehicle, AV, Multicriteria assessment, Analytic hierarchy process, PROMETHEE, Collective transport, Public transport

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Tiivistelmä

Joka vuosi järjestetään yhä suurempi määrä itseohjautuvilla ajoneuvoilla liikennöitävien joukkoliikennepalveluiden pilottikokeiluja. Siitä huolimatta lähitulevaisuuden automatisoidut joukkoliikennepalvelut ovat saaneet osakseen vain vähän huomiota tieteellisessä kirjallisuudessa. Tässä tutkimuksessa pyrittiin asiantuntija- ja sidosryhmähaastattelujen avulla tunnistamaan joukkoliikennepalvelutyyppejä, joita tullaan lähitulevaisuudessa liikennöimään itseohjautuvilla kumipyöräajoneuvoilla sekä kriteereitä, joiden perusteella näitä palveluita tulisi arvioida. Lisäksi palvelumallien toimivuutta sekä kriteerien riittävyyttä ja suhteellista tärkeyttä tutkittiin skenaariopohjaisella monimuuttuja-analyysillä.

Haastattelujen perusteella pystyttiin tunnistamaan yhtenevyyksiä sekä eroavaisuuksia osallistujien odotuksissa ja näkemyksissä. Kaikki osallistujat pitivät itseohjautuvia ajoneuvoja ensisijaisesti tapana parantaa joukkoliikenteen syöttö- ja niin kutsuttuja ”viimeisen mailin” yhteyksiä. Kaksi palvelumallia toistuivat valtaosassa haastatteluista: kiinteällä reitillä liikennöitävät sukkulalinjat sekä kutsupohjaiset sukkulalinjat. Kiinteät linjat yhdistettiin tiheästi asuttuihin naapurustoihin, kun taas joustavat reitit yhdistettiin pientalo- ja haja-asutusalueisiin. Monimuuttuja-analyysi tuotti kuitenkin havaitun ajatusmallin kanssa ristiriitaisen tuloksen, sillä vastaajat arvioivat kiinteiden linjojen toimivan huomattavasti paremmin sekä tiheästi että väljästi asutuilla alueilla. Kaiken kaikkiaan osallistujat uskoivat, että molemmat palvelumallit kehittäisivät arvioitujen alueiden joukkoliikennettä nykyisestä. Palvelutyyppien ja niiden toimialueiden lisäksi ristiriitoja asiantuntijoiden välillä ilmeni näkemyksissä teknologisen kehityksen nopeudesta sekä palveluiden kyvystä palvella kaikkia ihmisryhmiä tasapuolisesti.

Palvelumallien arviointia varten tunnistettiin kolmekymmentäkolme kriteeriä, jotka ryhmiteltiin kuuteen pääkategoriaan: turvallisuus, luotettavuus, liikennejärjestelmävaikutukset, resurssitehokkuus, käyttäjäkokemus ja ympäristövaikutukset. Kyselyvastausten analyysin perusteella osallistujat pitivät turvallisuutta selvästi tärkeimpänä kriteerinä, ja sitä seurasivat luotettavuus, liikennejärjestelmävaikutukset ja resurssitehokkuus yhdessä käyttäjäkokemuksen kanssa. Vähiten tärkeänä kriteerinä osallistujat pitivät ympäristövaikutuksia.

Avainsanat itseohjautuva ajoneuvo, autonominen ajoneuvo, automaattinen ajoneuvo, PROMETHEE, Analyyttinen hierarkia prosessi, joukkoliikenne, julkinen liikenne

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Abbreviations

AHP	Analytic hierarchy process
CAV	Connected and automated vehicle
DRT	Demand responsive transport
MCDA	Multiple-criteria decision analysis
PROMETHEE	Preference ranking organization method for enrichment evaluation
PTA	Public transport authority
VKT	Vehicle kilometres travelled

1 Introduction

In the field of transport, anticipatory actions have been traditionally based on future predictions. The predictions of the future have been based on analysing past trends. The epitome of this paradigm is the infamous phrase “predict and provide” and what has come of it. By the 21st century, it has become painfully clear that as the world grows more and more complex, the traditional forecasting methods fall short in supporting decision making (Lyons et al. 2016).

Currently, the transport sector is facing revolutions that some expect to cause impacts of the same magnitude as Henry Ford’s Model T. The implementation of connected and automated vehicles (CAVs) into the transport system may fundamentally disrupt our way of living. A vast amount of literature has been written about the anticipated effects of CAVs, yet the future of the technology is clouded in obscurity. The expectations for CAVs are incredibly high; stemming from the promises of tech-developers, who have a financial interest in the industry, they are further inflated by enthusiasts and activists alike (Currie 2018; Docherty et al. 2018; Litman 2020; Shladover 2018).

That is not to say that the technology could not be harnessed for significant improvements in the way we live. Numerous possible positive effects of CAVs have been identified in the scientific literature. Some of the main benefits attributed to the automation of transport include increased traffic safety, reduced congestion, reduced emissions, more efficient use of transport infrastructure and urban area, enhanced transport equality, and increased attractiveness of urban environment (Milakis 2017a; Narayanan et al. 2020; Stead and Vaddadi 2019). However, the way CAVs will operate in the transport system is still very unclear, and consequently many of the implications are based on assumptions.

Few would argue that these are not ends to pursue. On the other hand, laissez-faire governance could lead to grievous externalities (Cohen & Cavoli 2019; Papa & Ferreira 2018), and some research indicates that cities’ and governments’ preparation for the transition – although the threats are acknowledged – is not on a solid basis (Freemark et al. 2019; Guerra 2016; Legacy et al. 2018; Täihagh and Lim 2019). Learning from past experiences with disruptive technologies, decision-makers must find the right balance between controlling the phenomenon and enabling innovation. At the heart of this process is the ability to treat technological development as a political and value-driven choice rather than as an inevitability or an intrinsic value (Mladenović 2019). The technology must be viewed as a mean to achieve agreed-upon societal goals, not as an end itself.

For this to happen, it is critical to examine alternative desirable futures (Blyth et al. 2016) – to figure out what is the goal, what is probable, what is possible, and what should be prioritised as the technology is implemented into society. As merely analysing past trends is insufficient, qualitative projecting methods may prove to be a better help for steering the development into a desired direction. A vast amount of research has already addressed the matter. However, most of these studies examine the effects of system-wide automation or the transport system at a high market penetration of CAVs. Apparent research gaps can be found in studies that examine the near-future implementations and implications in local contexts. It is important to examine the “end state”, as it helps us define the goals, but it is equally important to examine the near future, as it is the time when we make the initial choices on what path we choose to follow. Furthermore, different countries, cities, and neighbourhoods have different characteristics in terms of the existing transport system, land use, and socio-demographics among other factors that heavily affect the applicability of the technology. As the implementation of this technology has already begun with the service pilots, the need for studies examining CAV-services in local contexts is imminent.

This study aimed to fill this niche by seeking answers to the following questions:

- What kind of collective transport service designs, based on connected and automated rubber tire vehicles, could be implemented into Helsinki in a period of ten to fifteen years?
- What criteria should be used to evaluate the performance of these services, and how should they be prioritised?

To answer these questions, a combination of methods was applied. First, semi-structured interviews were carried out with ten experts and stakeholders dealing with transport automation to identify their views and expectations of CAV-services as well as criteria based on which the success of these services should be evaluated. Second, alternative local service scenarios were designed according to the views and expectations expressed in the interviews. Third, the participants answered a survey where they evaluated the importance of the identified criteria and how well the imagined local service scenarios would perform with them. Fourth, the survey responses were analysed with a combined AHP–PROMETHEE method.

To the author's best knowledge, this approach has not been used previously to investigate transport automation, and even relatively similar studies are hard to find. Owczarzak and Żak (2015) used a heuristic approach to design alternative demand-based CAV-services and ranked them according to several criteria with the ELECTRE III/IV method. Innamaa and Kuisma (2018) conducted a survey study about the importance of key performance indicators (KPIs), which can be seen as "close relatives" of the evaluation criteria that are identified in this study. Kim et al. (2019) identified and prioritised value attributes associated with CAVs with the Analytic hierarchy process. However, none have tried to systematically identify alternative service designs and the essential evaluation criteria for them simultaneously.

The purpose of this study is not to provide a comprehensive set of criteria and possible service designs and validate their ranking from best to worst. Such a consensus is impossible to achieve at this point, and when it eventually is achieved, if it is achieved, it will be through trial and error. However, by directing intellectual effort and discussion to the matter, certain undesired paths are possible to avoid, and hence the ultimate goal of this research is to examine and increase the current understanding of the phenomenon and to underline uncertainties obscuring it.

2 Background

CAVs and their implications are currently among the most popular topics of research in the field of transport. Even though every year vast amounts of studies – with exhaustive amounts of intertextual references to the book "Brave New World" – incrementally enhance our collective knowledge of the phenomenon, research gaps can still be identified. The idea-work for CAV-service designs is scattered. Though almost all studies include assumptions of how CAVs will be utilised, only a few studies examine the service designs of collective and private transport in detail. Numerous modelling studies examine the effects of certain designs, but as transport systems, in general, are incredibly complex, the models are either oversimplified or examine a disconnected system component. Scenario research, which does not aim to measure specific variables but generally tries to imagine plausible futures, may offer a better reference point for identifying alternative service designs.

Another useful reference point for this research is provided by studies examining the implications of the technology. As the specific way CAVs are implemented into transport systems is still very unclear and may vary among places, many studies present conflicting results (Narayanan et al. 2020). Therefore, a direct comparison of the anticipated impacts does not make sense. The aim of reviewing literature describing CAVs' implications is to identify some of the essential evaluation criteria for the emerging services. In this section, a brief review of recent literature regarding scenarios and implications is presented.

2.1 Possible futures of connected and automated collective transport

Scenario studies provide an excellent baseline for this research. Although quantitative methods such as simulations and calculations provide comprehensible numerical results, they tend to disregard the socio-technical nature of transport automation by placing an emerging technology into an already established system. Qualitative scenario construction should anticipate the possible societal changes (Banister & Hickman 2013), and therefore provide justifiable suggestions of what the future service designs for CAVs could look like. Thirteen scenario studies were identified through a non-systematic search of scientific literature (Table 1). Three studies used a forecasting approach (Gruel & Stanford 2016; Jones & Leibowicz 2019; Thakur et al. 2016), two used a backcasting approach (González-González et al. 2020; 2019), and eight used an exploratory approach (Enoch et al. 2020; Fulton et al. 2017; Heinrichs 2016; Kovacs 2020; Meyboom 2019; Milakis et al. 2017b; Pernestål Brenden et al. 2017; Townsend 2014). The author notes that this is by no means a comprehensive scenario research review. Numerous other studies utilising scenario methodologies exist – especially ones using a forecasting approach. These, however, do not greatly diverge in terms of service designs. Subsequently, an effort was mainly directed in grasping a significant mass of the studies utilising the exploratory approach. Only studies published in conventional academic and scientific distribution channels were examined. Also, one book was taken into the examination (Meyboom 2019). It should be noted that grey literature could also offer useful insights into the future of CAVs (see for example ITF 2015; Tillema et al. 2015), but these were disregarded altogether for the difficulty of classifying reliability. A more comprehensive scenario review on CAVs' effects on the urban form was conducted by Stead and Vaddadi (2019), which included also grey literature.

Table 1 Examined scenario research

Author(s)	Time frame	CAV market penetration	Geographic context
Enoch et al. 2020	2045	High	New Zealand
Fulton et al. 2017	2030–2050	Low–High	Undefined
González-González et al. 2020	2040–2050	High	Undefined
González-González et al. 2019	Undefined	High	Undefined
Gruel & Stanford 2016	Undefined	High	Undefined
Heinrichs 2016	Undefined	High	Undefined
Jones & Leibowicz 2019	2050	None–High	Austin
Kovacs et al. 2020	Unidentified	High	Unidentified
Milakis et al. 2017b	2030–2050	Low–High	Netherlands
Meyboom 2019	2060	High	North America
Pernestål Brenden et al. 2017	2030	Low–High	Sweden
Thakur et al. 2016	Undefined	High	Melbourne
Townsend 2014	2028–2032	High	Atlanta, Los Angeles, New Jersey, Boston

There is a significant body of work in the scenario studies examining transport automation. However, the research is quite unilateral. Most of the studies focus on high market penetration of CAVs or scenarios spanning up to forty years. Only four reviewed studies included a near-future (ten to fifteen years from 2020) scenario. Almost half of the studies examined the automation of transport through a global or geographically undefined viewpoint, whereas seven of the reviewed studies had a geographic context. Only three of them focused on a city.

2.1.1 Service designs

Scenario studies do not often explicitly discuss different service designs but rather tend to paint a larger picture of the anticipated consequences. Different service designs are, however, implicitly presented in the scenarios. The implied service designs range from minor changes to the transport system to replacing a significant percentage of the motor vehicle fleet for providing a range of entirely new mobility services. Table 2 presents the different service designs that were identified from the examined scenario studies.

Each of the identified service designs can be categorised roughly into one of three main groups: fixed-route shared services, flexible-route shared services, and non-shared services.

All of the reviewed studies included at least one scenario where CAVs were used as a ride-sharing service, and all but one included a scenario where CAVs were used as a private good or as a service where the rides are not shared. Six studies included a scenario where transport automation was discussed in the context of fixed-route services such as trunk or feeder bus lines.

Table 2 Identified service designs

Author(s)	Fixed-route shared service	Flexible-route shared service	Private vehicles/Non-shared service
Enoch et al. 2020	x	x	x
Fulton et al. 2017	x	x	x
González-González et al. 2020		x	x
González-González et al. 2019		x	x
Gruel & Stanford 2016		x	x
Heinrichs 2016	x	x	x
Jones & Leibowicz 2019		x	
Kovacs et al. 2020		x	x
Meyboom 2019	x	x	x
Milakis et al. 2017b		x	x
Pernestål Brenden et al. 2017	x	x	x
Thakur et al. 2016		x	x
Townsend 2014	x	x	x

The specificity used to describe different services designs varies between studies. Studies that used a forecasting approach did not describe the service designs at all or described them vaguely (Gruel & Stanford 2016, Jones & Leibowicz 2019, Thakur et al. 2016). These scenarios do not intend to present likely futures but underline the possible magnitude of the impacts caused by transport automation. Similarly to the forecasting studies, the examined backcasting studies did not discuss the different service designs for CAVs in great detail. These studies focused on imagining policy for the enablement and regulation of CAVs (González-González et al. 2020; 2019). The exploratory studies discussed the different service designs most rigorously. The studies reflect expectations that CAVs will be used for private transport, ride-sharing services as well as fixed-route services resembling the current public transport services. Two variations of a shared flexible-route CAV-service can be identified from the exploratory studies: a door-to-door service and a point-to-point service. The purpose of a door-to-door service is to cover the whole trip whereas a point-to-point service aims to fix the Achilles' heel of public transit – the last and the first mile.

A point-to-point service could be distinguished from four studies (Fulton et al. 2017, Heinrichs 2016; Meyboom 2019; Townsend 2014). Henrichs describes a feeder service that supports fixed high capacity connections such as rail rapid transit and light rail transit (2016, p. 224–225). The service is in constant operation and carries passengers from central nodes to more dispersed drop-off points and vice versa. The service does not operate on premeditated routes even though the stations are fixed. Relatively similar services are described by Meyboom (2019, p. 57) and Townsend (2014, p. 35–37), although Townsend does not clarify whether the feeder "jitneys" are shared or personal. A door-to-door service was identified from several studies (Enoch et al. 2020; Meyboom 2019; Milakis et al. 2017b; Pernestål Brenden et al. 2017; Townsend 2014). The service works similarly to most existing ride-hailing services with the exception of combining customers' trips. Although none of the reviewed studies explicitly discuss the ride-sourcing mechanism of the service, it is implied that people are expected to use them mainly as a shared service. The essential difference to the point-to-point service is that the door-to-door service does not have fixed pick-up or drop-off points.

Six studies included scenarios where an automated fixed-route service was mentioned (Enoch et al. 2020; Heinrich 2016; Fulton et al. 2017; Meyboom 2019; Pernestål Brenden et al. 2017; Townsend 2014). These services resemble the current public transport services provided by PTAs, and their characteristics do not greatly differ from the ones currently available. The main difference is that human involvement is expected to decrease significantly, and efficiency gains could be achieved through vehicle platooning and intelligent infrastructure. A more futuristic take on this service type is provided by Meyboom (2019, p. 57,63,75) who describes a high-speed shuttle system operating on fixed routes in an undefined North American downtown.

2.2 Implications of connected and automated vehicles

Studies addressing the implications of transport automation offer a good reference point for identifying evaluation criteria for CAV-services and understanding their relevance. One must note that it is the inherent nature of disruptive technologies to cause unanticipated implications. Therefore, none should believe that a comprehensive set of implications could have been identified in the scientific literature at this point. Nevertheless, the literature offers a useful foundation to build on.

2.2.1 Safety

Improved traffic safety is one of the impacts most often attributed to transport automation. Though the possible positive effect is often mentioned in the literature, it is extremely difficult to evaluate if, when, and how it will realise. The reason significant enhancement of traffic safety is expected is that most traffic accidents occur due to human error (Bagloee et al. 2016; Fagnant & Kockelman 2014; Täihagh and Lim 2019). As computers do not act irresponsibly, are not likely to fall asleep, and could more easily communicate with one another, traffic safety could improve. However, the automation of transport could introduce a myriad of new risk factors, such as software and hardware failures and hacking, that could contribute to traffic accidents (Litman 2020; Täihagh and Lim 2019). Additionally, the literature acknowledges the threat of emerging data privacy and misuse issues (Blyth et al. 2016; Mladenović & McPherson 2016). Furthermore, substantial traffic safety benefits may be achieved only at high-market penetration of CAVs (Litman 2020; Milakis 2017a), and especially at the early stages of automation, the improved safety of CAV users may come at the expense of exposing others to an increased risk (Fagnant & Kockelman 2014; Milakis 2017a).

2.2.2 Transport system

The CAVs' impacts on the transport system are very much dependant on the service designs and policies that will be implemented. Therefore, a comprehensive answer to how the introduction of CAVs will affect traffic volume, accessibility, or modal share does not exist, which is reflected by the contradicting results in studies. For example, Salazar et al. (2018) modelled a system where shared CAVs are used as a feeder service for public transit. In the model, tolling and pricing schemes that steered demand towards public transit were implemented, and consequently the authors reported that traffic volumes in the modelled environment decreased. Contradictory, plenty of modelling studies report minor to major increases in traffic volumes in a variety of geographic contexts with alternative service designs (Childress 2015; Fagnant & Kockelman 2018; 2014; Miaojia et al. 2018).

The studies examining CAVs' effect on the transport system often utilise models, and quite obviously, do not share the same presumptions, geographic contexts, or service designs. For these, as well as numerous other reasons, the reported effects should be interpreted with caution, and generalisations should be avoided. That being said: although studies that argue for both ends, the decrease and the increase of traffic volumes, can be easily found, most of the research seems to lean towards the latter. The assumption is often explained with the deduction that CAVs, shared or not, will most likely make empty trips (Bischoff & Maciejewski 2016; Fagnant & Kockelman 2018; 2014; Miaojia et al. 2018; Milakis et al. 2017a). Other contributing factors may be that the convenience of private or low capacity shared CAVs draw users from other transport modes (Bösch et al. 2018; González-González et al. 2020, Milakis 2019; 2017a), CAVs will provide mobility to those who previously were unable or reluctant to operate motorised vehicles (Harper et al. 2016), or that the enhanced travel comfort results in a willingness to travel longer distances (Childress 2015). Overall, it is reasonable to assume that the same basic principles of demand and supply will continue to apply in the connected and automated era of transport; a system based on low capacity vehicles generates more VKT than one based on high capacity transit (Bösch et al. 2018, Salazar et al. 2018). Furthermore, low-capacity CAVs may cause other unwanted externalities such as congestion in essential pick-up and drop-off points due to spatial inefficiency (Lawrie et al. 2020).

The accessibility implications are as nebulous as the impact on VKT. CAVs could enhance accessibility in the suburban and rural areas that are currently underserved by public transport (Childress 2015; Meyer et al. 2017; Owczarzak and Zak 2015), but without a strong policy framework, the generated accessibility benefits may not be distributed evenly among all social groups. If transport automation should occur mainly through private transport, the main beneficiaries, especially at the early stages, may be those who can afford the technology, whilst others may experience even negative impacts (Litman 2020; Milakis et al. 2018).

2.2.3 Public transport and transport service provision

Transport automation is a double-edged sword for public transport, which is reflected by equivocal projections in the scientific literature. Alongside other goals such as efficient resource utilisation and equitable use of funds, PTAs often have ridership and coverage goals. Superficially, these aims are not conflicted, but in reality, services advancing these goals are always “competing” for the same limited funds (Walker 2008). When one is emphasised the other is de-emphasised. Following the implementation of CAVs, making decisions about these trade-offs may become easier. As the automation of transport is expected to enable operational cost savings that surpass the overall (possibly increased) capital costs (Hatzenbühler et al. 2020; Tirachini & Antoniou 2020), PTAs could potentially increase coverage in underserved areas while not decreasing ridership. In general, many studies associate CAVs with the opportunity to solve the problem of last and first mile transport (Buehler 2018; Fraedrich et al. 2019; Owczarzak and Zak 2015; Salazar et al. 2018; Scheltes & de Almeida Correia 2017; Shen et al. 2018).

On the other hand, the convenience of private or shared CAVs could potentially decrease the modal share of public transport (Bösch et al. 2016; González-González et al. 2020, Milakis 2019; Milakis et al. 2017a), and the lack of coordination and policy work in implementing CAV-services by public authorities may lead to the unbalanced and unjust provision of transport services (Alonso Raposo et al. 2019; Milakis et al. 2017a). If policies are made to favour the use of private CAVs, a consequence may be the decline of public transport services, which affects the low-income social groups the heaviest by reducing their accessibility. This effect may be amplified by the potential urban sprawl resulting from the decrease in the value of travel time for CAV users (Milakis et al. 2018). However, findings by Zhang and Guhathakurta (2018) indicate that the threat of uncontrolled sprawl will not realise, and some argue that shared CAVs could even increase the popularity of public transport (Gruel & Stanford 2016).

It does not seem implausible that in the long term CAVs could disrupt the current transport service provision model. From the reviewed scenario studies, two included scenarios that described radically altered collective transport service provision model (Pernestål Brenden et al. 2017; Townsend 2014), and almost all depicted significant changes to the collective transport system. The assumption is also reflected in many impact studies that simulate how CAVs could serve a significant percentage of peoples’ trips, including those made with public transport. Then again, total abolishment of PTAs and the complete overhaul of transport services seems very unlikely. Many cities are, and will be, greatly dependant from mass transit, which in turn justifies the existence of PTAs (Currie 2018). Nevertheless, new private sector service providers are expected to enter the field, as has been the trend for some time now, and there may be ideological conflicts between these actors, who may be mostly concerned with maximising travel commodity of individuals, and public authorities who pursue sustainable and efficient transport (Legacy et al. 2018). To establish (or to sustain) a sustainable and functional transport system, the collaboration of these actors is imperative. Currie (2018) suggests that transit fusion may be the way to do this.

2.2.4 Environmental impacts

Many studies associate CAVs with the increased environmental sustainability of transport. Again, the effects are highly dependant on the service designs and policies that are implemented. For example, Salazar et al. (2018) show us that a combined shared CAV-public transit system would generate fewer emissions than one based solely on shared CAVs. The largest benefits are not necessarily caused by transport automation per se but the electrification of transport (Bauer et al. 2018; Fagnant & Kockelman 2014; Jones & Leibowicz 2019; Salazar et al. 2018). The co-operation of vehicles and infrastructure could result in highly optimised traffic flow in the long term, which in turn could lead to energy savings, but this is highly uncertain. Increased travel demand, willingness to travel longer distances, and increased mobility of the ones suffering from mobility disadvantage among other factors could contribute to higher energy consumption. The same applies to greenhouse gases, particulate matter, and other emission types. Therefore, attributing positive environmental effects solely on vehicle automation is questionable, but if the right policies are taken with the right technology, improvements are possible. However, the benefits are not given, and CAVs could even increase energy consumption and emissions if the technological development does not follow the anticipated route or if the right policies are not taken (Litman 2020; Milakis et al. 2017a).

2.2.5 Human experience

Most of the literature addressing the question of how people will experience CAVs focuses on the travel experience. Very little can be said about the matter since only a few pilots simulating fully automated services have existed, but some opportunities and concerns are mentioned in the literature. One frequently mentioned benefit of CAVs is the “driver’s” ability to perform other activities while travelling. The value of travel time is expected to decrease, as CAVs provide the users with the ability to relax or to multitask (Milakis et al. 2017b). However, it is unclear whether multitasking utilities, such as the ability to work en route, are wished for. Analysis by Kim et al. (2019) shows that both the public and experts have a low preference for multitasking functions. Similar results were reported by Cyganski et al. (2015).

Another dimension of travel experience that the literature has addressed is sharing rides. The concept of sharing rides is not new. It has existed since the days of horse carriages and has been a quite central aspect of public transport. Nonetheless, removing the driver changes the dynamic, and people may experience sharing the ride more uncomfortable as “an official service person” is not on-board anymore (Lavieri & Bhut 2019; Nordhoff et al. 2020; Salonen 2018). Whether this discomfort can be overcome might be a matter of how well the service performs in other aspects such as ease of use and travel time. Interestingly, some studies report that people are surprisingly willing to share their rides (König & Neumayr 2017) and would even prefer a pooled service to a private (Stoiber et al. 2019).

It should be noted that CAVs will change the experience of mobility not only for those travelling inside the vehicle but also for the ones outside. Perhaps the most haunting example of this is the widely discussed philosophical dilemma, the trolley problem (Goodall 2014). Moreover, the holistic human experience of the technology is more multidimensional than the questions emphasised in the literature may lead one to think. Certain issues may relate to a wider set of ethical questions such as value-sensitivity in design, privacy and data protection, equality, and individual autonomy among many others (Mladenović et al. 2019).

2.2.6 Socio-economic dimensions

Like so many other implications, the socio-economic implications of CAVs are very complex and hard to predict at this time. As highlighted in previous sections, CAVs may create a positive effect or the very opposite effect on a given variable. Different segments of society will probably experience different effects. For example, if the implementation of CAVs boosts the economy by reducing traffic casualties and reducing emissions, it could still simultaneously displace jobs (Alonso Raposo et al. 2019; Epting 2019; Täihagh and Lim 2019). Another example is that CAVs could significantly improve travel opportunities of those who can pay but simultaneously displace public transport services and outprice low-income travellers (Litman 2020; Milakis 2018; Mladenović et al. 2019). People who are already in a position of mobility disadvantage are likely the ones most vulnerable to these implications, but simultaneously they are the ones who could benefit substantially.

Several studies mention that CAVs may extend the opportunity of using a fast and reliable mean of transport at will to those who do not own a car or for some reason are not eligible or willing to drive one (Fitt et al. 2019; Harper 2016; Kovacs et al. 2020; Milakis 2017a; Pettigrew & Cronin 2019). Therefore, CAVs may be a useful tool for combating issues such as unequal mobility and social isolation. On the other hand, CAV-services could worsen their travel opportunities if the preconditions of transitioning from conventional to driverless services are not sufficiently considered from alternative social perspectives (Cohen & Cavoli 2019). For example, all social groups may not be equally willing to adapt to new technologies. Older people are more concerned about CAVs and most likely will have a higher barrier in using new services (König & Neumayr 2017). The same may apply to other social groups as some recent studies have illustrated.

While there already is some research examining the hopes, fears, threats, and opportunities for the people who suffer from mobility disadvantage, some social groups such as children and people with disabilities have received little direct attention. The studies that have been conducted on children and CAVs show us that parents view CAVs as an opportunity to enhance the mobility of their children, but they have also expressed concern and presented specific conditions that should be met for the services to become viable (Lee & Mirman 2018; Tremoulet et al. 2020). People with physical disabilities have been found to have generally negative or ambivalent views of the technology (Bennett et al. 2019a), whereas people with mental health disabilities have been found to have mixed views depending on numerous factors such as generalised anxiety, intensity of one’s condition, and internal locus of control (Bennett et al. 2019b).

3 Methodology

The methodology of this research consists of three main components: stakeholder and expert interviews, a survey, and a combined AHP-PROMETHEE -method. By applying these methods, the author sought to answer the previously presented research questions:

- What kind of collective transport service designs, based on connected and automated rubber tire vehicles, could be implemented into Helsinki in a period of ten to fifteen years?
- What criteria should be used to evaluate the performance of these services, and how should they be prioritised?

Figure 1 depicts the study process. Activities are presented in sharp-cornered boxes and results in round-cornered boxes. First, ten interviews were conducted with experts and stakeholders. The goal of each interview was to formulate at least one possible local service scenario for CAVs in the collective transport system of Helsinki in the next ten to fifteen years and multiple criteria to evaluate the viability of said scenario. The interview method is described in section 3.1. Then, the interviews were reviewed, and the gained information was structured into six local service scenarios and six main evaluation criteria. A survey, described in section 3.2, was constructed and sent to the participants. In the survey, the participants were asked to evaluate the importance of each criterion and how well the suggested service designs would perform with them. They were also asked whether the presented criteria were sufficient for making a just decision about implementing a connected and automated transport service or if other criteria should be considered. Finally, the results of the survey were analysed with a combined AHP-PROMETHEE method described in sections 3.3 and 3.4 resulting in the ranking of the criteria and the service scenarios.

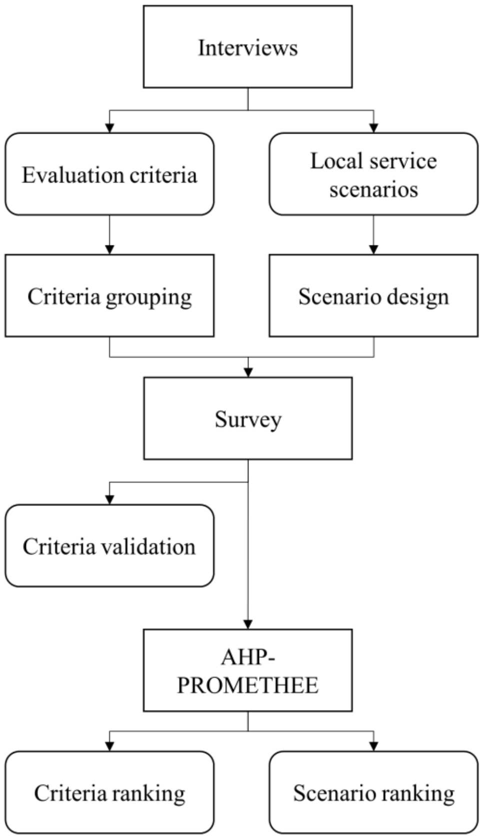

Figure 1 The study process

3.1 Interview method and scenario design

Semi-structured interviews were conducted with ten stakeholders and experts. The interviews lasted from one to one and a half hours and were conducted via Google Hangouts. The participants represented a relatively comprehensive and even sample of key actors currently working with transport automation: public authorities, municipal planning, consulting, research, vehicle and software development, vehicle operation, public transit planning, and innovation facilitation. Alongside validated expertise on the topic, the participants were required to have sufficient knowledge about the City of Helsinki. The participants were identified by the author, the supervising professor, and the steering group of this research and validated by the supervising professor and the steering group.

Before the interviews, a protocol document was constructed to ensure that all participants were presented with the same background information and to help the interviewer manage the time and direction of the interviews (Appendix 1). The protocol was tested successfully in two pilot-interviews before the actual interviews. At the beginning of each interview, the same information about the participation process and research was presented to the participants. Each participant was also given the opportunity to choose their preference for anonymity and asked whether the interview could be audio recorded.

Figure 2 depicts the goal of the interview as well as the interview process. The goal of every interview was to identify at least one local service scenario and multiple criteria to evaluate the implications of the scenario. These goals were worked simultaneously. The figure was presented to all participants at the beginning of each interview. Local service scenario is, to the author's best knowledge, a seldomly mentioned scenario type in the scientific literature that lacks a universal definition. In this study, it is defined as a possible future where a certain service is implemented into a geographically defined area. Local service scenarios were constructed in the interviews by examining four components: service, vehicle, infrastructure, and policy. In the context of this study, the criteria are standards that depict the effects of a scenario and through which the scenarios can be judged and compared. These should not be confused with key performance indicators (KPIs) that measure the operation of a service. The essential difference is that KPIs are followed as the service operates, whereas criteria should be thoroughly examined before implementation to determine the viability of the service. Although, in some cases, the same variables could be used for both purposes.

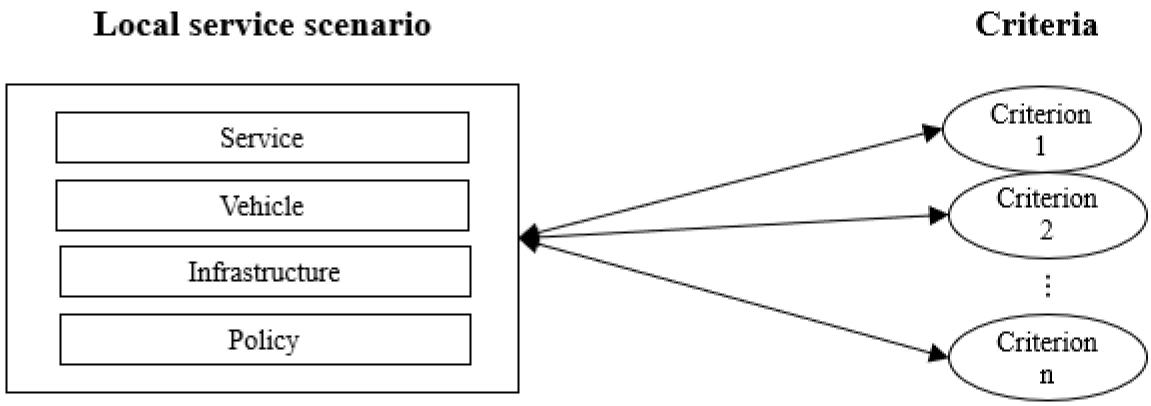

Figure 2 The interview process

To help participants identify the components and the criteria, each participant was asked a rigid set of questions throughout the interview. All the premeditated questions were asked in every interview. Besides the first question, which was asked at the beginning of every interview, the rigid questions were not addressed in any specific order. Additionally, unpremeditated questions were asked to steer the conversation. The rigid questions were:

- Describe freely how self-driving vehicles are present in the collective transport system of Helsinki in ten to fifteen years.
- In what environment do you expect self-driving vehicles to operate?

- Does the current physical infrastructure require development to enable the functional operation of the vehicles?
- Describe the different vehicle types you expect to see operating.
- What type of human involvement do you think will be required?
- What policies are required to guarantee the successful operation of self-driving vehicles?
- How would you measure the success of implementing self-driving vehicles into the collective transport system of Helsinki?

After the interview round, the participants' scenario drafts and the suggested criteria were reviewed. The suggested criteria were grouped into six main criteria according to their relevance. The suggested local service scenarios were formulated into six scenarios that reflect the generalised technological expectations as well as the major uncertainties that transpired in the interviews. A brief overview of the scenarios and the criteria are presented in sections 4.3 and 4.4 respectively. The full scenario descriptions and visualisations are presented in the appendices 2–8.

3.2 Survey

The second main component of the study process was the survey. The main purpose of the survey was two-fold. By creating an imaginary decision-making situation for the participants, in which they needed to evaluate the importance of the criteria they had come up with as well as the alternative scenarios according to the criteria, the aim was to find priorities of the criteria and to identify missing criteria. As a side-activity, the performance of the scenarios was investigated, as it could reveal some further uncertainties or obstacles in implementing collective transport CAV-services. Before sending the survey out, it was successfully piloted with two peers, both of whom clocked a total answer time of approximately forty minutes.

The survey form (appendix 9) consisted of three main parts. In the first part, the participants completed pairwise comparisons for the criteria. The importance of each criterion was compared to every other criterion on the Saaty's scale (table 3). It is acknowledged that Saaty's scale is not the most accurate scale for the Analytic hierarchy process (discussed in next section), and other scales, such as the balanced scale, have more empirical evidence supporting their use (Brunelli 2015). However, as the survey was merely an imaginary decision-making exercise, the elegance of Saaty's scale was preferred. The comparison data (the assigned scores and their reciprocal fractions) was later used to calculate weights for the criteria, as is explained in section 3.3. There are many ways to calculate weights for a set of criteria, but the pairwise comparisons were chosen here because of two advantages. First, it was assumed that the relative importance of criteria is hard to determine; by decomposing the problem into pairwise comparisons, the problem becomes more comprehensible for the respondent. Second, comparing the criteria to each other forces the participants to contemplate the significance of each criterion thoroughly.

In the second part of the survey, the participants assigned scores to the six alternative service scenarios according to how well they thought the scenarios performed with each criterion. The scale used here was one to ten, where one stands for the worst possible score, and ten stands for the best possible score. Each scenario was scored with respect to the other scenarios. The data from this assignment was used to calculate partial and complete rankings of the scenarios with the PROMETHEE I and II methods respectively, as is explained in section 3.4.

Table 3 Saaty's scale

Description	Numerical value
The two criteria are equally important	1
-	2
Moderate importance over the other criterion	3
-	4
Strong importance over the other criterion	5
-	6
Very strong importance over the other criterion	7
-	8
Extreme importance over the other criterion	9

Finally, the participants were asked whether a decision-maker could make a justifiable decision about implementing a connected and automated collective transport service by considering the presented criteria and to name the missing criteria if there were any. They were also given the opportunity to give feedback about any aspect of the study and the participation process.

3.3 Analytic hierarchy process

The general framework of this study comes from the Analytic hierarchy process (AHP), developed by Thomas Saaty (see for example Saaty 2008). The AHP is a decision support tool for formulating and analysing decisions, commonly used in transport studies (Berrittella et al. 2008; Mladenović et al. 2017). The purpose of the AHP is to compare different alternatives to each other according to how they fulfil the assigned criteria. The decision tree structure of the AHP, which was used in this study to formulate the research problem, is presented in figure 3.

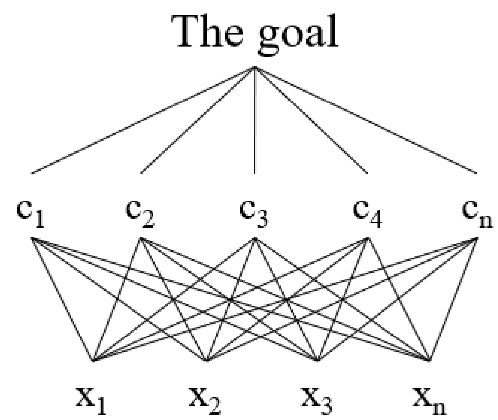

Figure 3 The Analytic hierarchy process decision tree

The AHP is useful for providing a complete ranking of a finite number of alternatives. However, the required amount of pairwise-comparison for the AHP is quite taxing and may seem abstruse for the participants answering the survey. Therefore, the AHP was not used for the scenario ranking. Instead, PROMETHEE I (partial ranking) and II (complete ranking) methods were used for this purpose. The AHP was used here to calculate the weights of the criteria – in other words, the relative importance of the criteria – for which the PROMETHEE methods do not offer an inbuilt tool. The PROMETHEE-methods are described in the next section. Below, the calculation process for determining the criteria weights is presented.

In the complete AHP process, a single goal is set, and a finite number of alternatives, X, and evaluation criteria, C, are identified. The method is then used to find the best alternative for reaching the goal. In this study, the alternatives are the previously mentioned six local services scenarios, and the criteria are the six main criteria identified from the interviews. However, at this point, a goal was not set, nor were the alternatives considered, as the purpose of using the AHP was solely finding the criteria weights.

$$X = \{x_{1,}x_{2,} \dots, x_n\} \tag{1}$$

$$C = \{c_{1,}c_{2,} \dots, c_n\} \tag{2}$$

It was expected that the participants do not consider the criteria to be equally important. Therefore, in the survey, the participants were asked to make pairwise comparisons of the criteria. From the entries, a pairwise comparison matrix, $\boldsymbol{A}$, was constructed for all participants.

$$\boldsymbol{A} = (a_{ij})_{n \times n} \tag{3}$$

$$\boldsymbol{A} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & a_{3n} \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \tag{4}$$

Each entry of the pairwise comparison matrix is approximately the ratio of the weights associated with the compared criteria.

$$a_{ij} \approx \frac{w_i}{w_j} \quad \forall i, j. \tag{5}$$

Note that from the survey structure it follows that the participant's pairwise matrices are reciprocal.

$$a_{ij} = \frac{1}{a_{ji}} \quad \forall i, j. \tag{6}$$

Also, the following rules apply for all entries in the matrices.

$$a_{ij} > 0 \quad \forall i, j. \tag{7}$$

$$a_{ii} = 1 \quad \forall i. \tag{8}$$

To reach a "consensus" between the participants, the individual matrices were merged. The weighted geometric mean was used to aggregate a single matrix.

$$a_{ij}^{G} = \prod_{h=1}^{m} a_{ij}^{(h)^{\lambda_h}} \tag{9}$$

Participants' input was considered equally important for the ranking, so it follows that

$$\lambda_h = \frac{1}{m} \quad \forall h. \tag{10}$$

A priority vector, w, depicting the relative importance of the criteria (the weights) sufficiently can be calculated from the pairwise comparison matrix with several methods. Here, the geometric mean method, proposed by Crawford (1987), was used.

$$w_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} / \sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \tag{11}$$

$$\mathrm{w} = \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} \tag{12}$$

3.4 PROMETHEE methods

For further analysis of the survey results, two decision analysis methods were used: PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) I and II (As presented by Brans & Mareschal 2016). The PROMETHEE I provides a partial and II provides a complete ranking of the alternatives. Like the AHP, PROMETHEE methods are commonly used in transport studies (Glavić et al. 2019; Milenković et al. 2019; Turcksin et al. 2011). Visual PROMETHEE software was used for the calculations. The calculation processes for I and II rankings are presented below.

Fist, deviations of variables are determined through a pairwise comparison. $d_j(a,b)$ denotes the difference between scores of "a" and "b" on a criterion "g". Note that the alternatives and the criteria are still the same as in 3.3. The notations used here to present the PROMETHEE methods are the same as in the original work by Brans and Mareschal (2016).

$$d_j(a,b) = g_j(a) - g_j(b) \tag{13}$$

For every pair of alternatives, a preference can be calculated with a function that uses the difference of the scores given in the survey. The scores used here are the arithmetic means of the survey answers.

$$P_j(a,b) = F\left[d_j(a,b)\right] \tag{14}$$

for which:

$$0 \leq P_j(a,b) \leq 1 \tag{15}$$

PROMETHEE offers six alternative preference functions. As the criteria scores depict only the opinion-based relative importance, and multiple decision-makers were involved, determining the thresholds of indifference and strict preference would have been very difficult and not necessarily beneficial. Consequently, a very simplistic preference function was deemed sufficient. This function was used for all criteria.

$$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 & d > 0 \end{cases} \tag{16}$$

For the ranking, PROMETHEE uses outranking flows. These flows require aggregated preference indices. An aggregated preference index, $\pi(a,b)$, expresses how much a is preferred over b over all the criteria. As mentioned, PROMETHEE methods do not offer an inbuilt tool for determining the weights. The weights, w, were assigned by the AHP method as described in the previous section.

$$\begin{cases} \pi(a,b) = \sum_{J=1}^{k} P_j(a,b) w_j \\ \pi(b,a) = \sum_{J=1}^{k} P_j(b,a) w_j \end{cases} \tag{17}$$

For clarity, it should be noted that

$$\pi(a,b) \approx 0 \tag{18}$$

denotes a weak preference and

$$\pi(a,b) \approx 1 \tag{19}$$

a strong preference of a over b globally.

The following properties hold:

$$\begin{cases} \pi(a,a) = 0 \\ 0 \leq \pi(a,b) \leq 1 \\ 0 \leq \pi(b,a) \leq 1 \\ 0 \leq \pi(a,b) + \pi(b,a) \leq 1 \end{cases} \tag{20}$$

Two flows are used to calculate the rankings of PROMETHEE I and II. These are the positive outranking flow and the negative outranking flow. Positive outranking flow expresses how the alternative "a" outranks all the other alternatives. The negative outranking flow expresses how all the other alternatives outrank "a". The formulas for these flows are respectively

$$\varphi^{+}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x), \tag{21}$$

and

$$\varphi^{-}(a) = \frac{1}{n-1}\sum_{x\in A}\pi(x,a). \tag{22}$$

Multiple criteria decision-making processes may often include alternatives that perform very well with one criterion and very badly with another criterion. Complete ranking methods such as the AHP and the PROMETHEE II do not consider these trade-offs, and therefore valuable information may be lost in the process. Therefore, it is beneficial to examine PROMETHEE I ranking parallel to the PROMETHEE II, as it may reveal such incomparabilities.

The partial ranking of PROMETHEE I is determined by considering three components: P^{I}, I^{I} and R^{I}, which stand for preference, indifference, and incomparability. An alternative is preferred to another alternative if, and only if, a higher power of one alternative is associated with a lower weakness of that alternative with regard to the second alternative. If, and only if, both positive and negative flows are equal, the alternatives are indifferent. Two alternatives are incomparable if, and only if, one's higher power is associated with the second's lower weakness.

$$\begin{cases} aP^{I}b \;\Leftrightarrow \begin{cases} \varphi^{+}(a) > \varphi^{+}(b) \; and \; \varphi^{-}(a) < \varphi^{-}(b), or \\ \varphi^{+}(a) = \varphi^{+}(b) \; and \; \varphi^{-}(a) < \varphi^{-}(b), or \\ \varphi^{+}(a) > \varphi^{+}(b) \; and \; \varphi^{-}(a) = \varphi^{-}(b); \end{cases} \\ aI^{I}b \Leftrightarrow \; \varphi^{+}(a) = \varphi^{+}(b) \; and \; \varphi^{-}(a) = \varphi^{-}(b); \\ aR^{I}b \;\Leftrightarrow \begin{cases} \varphi^{+}(a) > \varphi^{+}(b) \; and \; \varphi^{-}(a) > \varphi^{-}(b), or \\ \varphi^{+}(a) < \varphi^{+}(b) \; and \; \varphi^{-}(a) < \varphi^{-}(b); \end{cases} \end{cases} \tag{23}$$

The PROMEMTHEE II complete ranking considers only the preference, P^{II}, and the indifference, I^{II}. The ranking is based on the net outranking flow

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \tag{24}$$

so that one alternative is preferred to another if, and only if, the net flow of the first alternative is higher than the net flow of the second alternative. If, and only if, the net flows are equal, the alternatives are indifferent.

$$\begin{cases} aP^{II}b \Leftrightarrow \varphi(a) > \varphi(b), \\ aI^{II}b \Leftrightarrow \varphi(a) = \varphi(b). \end{cases} \tag{25}$$

4 Results

The results of the study are presented in this section. A summary of the interviews, the suggested local service scenarios, and the criteria are presented in sections 4.1.1. and 4.1.2. A brief overview of the final scenarios is presented in section 4.2 and the results of the AHP-PROMETHEE method are presented in section 4.3.

4.1 Interviews

4.1.1 Local service scenarios

The interviews reflected some divergence in the participants' expectations about the evolution of collective transport. Some participants expected significant changes to the collective transport system following technological development, while others felt that the obstacles are too great for any major reforms to happen in ten to fifteen years. Nevertheless, all participants expected that a service utilising full automation would be introduced during this time. A few participants expected that automation would also be implemented incrementally into existing services, and in ten to fifteen years, buses and taxis would use conditional or partial automation. The two quotes from participants one and five reflect the greatest divergence of expectations present in the sample group. Even though some participants' expectations diverged significantly, overall, the participants had relatively similar views.

Participant 1: *"The (connected and automated) vehicles will be able to operate in any operational domain. Dare I say, even in the air."*

Participant 5: *"Well, let's say that I don't believe in fully automated robo-taxis travelling from anywhere to anywhere by the year 2035… Some form of lower automation could be implemented into buses and taxis so they could drive automatically in some parts of the road network… Probably there are going to be some (fully automated) shuttle buses… There could be a case for these types of vehicles in some contexts, for example, between a park and ride and a ferry terminal."*

Technological development was not considered as the sole condition for implementing CAVs into the collective transport system. Some expected that the technology could be applied to a variety of services in fifteen years, but other factors could hinder the implementation.

Participant 7: *"I think it could be possible (to implement an automated service that operates on arterial roads), but I don't think it would be in line with the ethical principles (of the society). Politicians could not make such decisions."*

Table 4 presents the numerous different service scenarios that were suggested in the interviews. All participants viewed the automation of transport, in ten to fifteen years, as a way to support the established public transport system by providing new or enhancing existing feeder connections. Additionally, a few participants expected that trunk line services, fully or conditionally automated, would be introduced, and a few participants viewed door-to-door type of services as possible. The suggested service scenarios had similarities to the ones presented in the literature, but overall, the expectations of development were far more moderate.

Table 4 Suggested service scenarios

Automation level	Function	Service scenario	No. of scenarios
Full automation	Feeder connection	Fixed point-to-point shuttle line	6
		Flexible point-to-point shuttle line	5
		Bus line	1
	Trunk connection	Bus trunk line	1
		Bus Rapid Transit	1
	Full trip	Door-to-door shuttle	1
Conditional or partial automation	Feeder connection	Bus line	2
	Trunk connection	Bus trunk line	2
	Full trip	Door-to-door taxi	1

While there seemed to be a consensus that CAVs should be used, in the first place, as feeder lines for existing collective transport connections, the opinions diverged regarding where in the city should such service take place. Some participants suggested that CAVs should be used to increase the coverage of collective transport in loosely populated areas of Helsinki. The participants justified this view by stating that when the driver is displaced, the cost-efficiency of operation will significantly increase, and services could be provided in areas where it was not previously possible. Contradictory, some participants argued that operation in loosely populated city parts would not be possible, as there is not enough demand, and the cost-efficiency would remain unsatisfactory; instead, the services should operate in suburbs with a relatively high population density, near high capacity transit where the demand is higher. Some participants regarded both service areas as possible.

Most of the participants did not see significant benefits in implementing the services into the central areas of Helsinki. Participants noted that these areas' collective transport supply had already reached saturation. Therefore, a new service would hardly provide any additional value. The participants also expressed doubt about whether technological development would enable operation in the central areas, where traffic volumes are very high and the separation of modes is relatively light.

Participants also had different views regarding certain characteristics of the service. Five participants expected the services to operate based on demand. That is to say, if no-one requested the service, the service would not operate. The automated on-demand service was associated with flexible routes and a specific area of operation (a geo-fence or an operational design domain) within which the vehicle(s) would travel. One participant suggested that the service could operate on flexible routes based on demand during quieter hours, and during the rush hours, the service could operate on a fixed route. Both virtual and physical stops were suggested for the described services. Some participants viewed flexible routes as an essential way to improve the accessibility of areas currently underserved by public transport. When asked about car-orientation of these areas, they expressed confidence that on-demand services could attract car users and questioned whether fixed-route services could do the same.

Participant 10: *"Personally, if I had to walk to a bus stop four hundred meters away when it's pouring slush (while having the ability to use a private car), I wouldn't do it – a hundred meters maybe."*

Participant 1: *"Well I expect that some people will still use cars but if they had a quick way of transport available at will, it would not be as attractive."*

Seven participants expected that the automated feeder services would operate on fixed routes (two expected both flexible and fixed routes to be viable). Three of them expressed a strict preference for the routes being as straight as possible. Other participants did not state an opinion on the geometry of the routes. The reason for preferring straight routes was the expected requirement for the service level – more precisely, travel time.

Participant 8: *"People choose a mode according to what is comfortable and what is fast… Because this is a feeder service, there's going to be a transfer that is seen as uneasy, not convenient, and it's not fast either – it feels like a long time waiting by a bus stop. Therefore, the service must be able to compete with other modes in travel time… The routes should be a few kilometres or less, a distance that people don't prefer to walk, yet it is too short to implement a (conventional) bus connection… A lot of recent pilots have operated on circular routes but that's not a good service quality-wise as you're often travelling in the wrong direction. There could be vehicles travelling the route both ways, but a straight route is still a better option."*

All the participants, except for one, anticipated that the vehicles used for the feeder services will be, by and large, similar to the automated shuttle buses currently being tested in pilots. The expected capacity varied from approximately six to twenty seats. One participant specifically stated that the routes will be so short, that besides a few seats and a place for a wheelchair, the capacity will consist mainly of standing places. Regarding the average speed of the vehicle, the expectations varied from no advancement to the vehicles being able to operate according to all speed limits. In general, the participant expected that the average speed had to increase at least to match the lowest speed limits of Helsinki (30 km/h) for the services to become viable.

When asked about equal accessibility, a significant divergence of views occurred. Some participants implied that the demand-based CAV-services would enhance the transport opportunities of people with physical disabilities, as the stops would be closer than previously. On the other hand, some participants stated that CAV-services will be problematic for people with physical disabilities and that there should be certain services where a service person would be aboard to help them. Few participants outright stated that replacing an existing collective transport connection with a CAV-service would worsen transport equality and expected that it would be impossible, or extremely difficult, for some social groups with disabilities to use these services.

Almost all participants considered the vehicle's ability to operate in the current infrastructure as a prerequisite for the implementation of the services. Consequently, the participants did not expect major reforms to the physical infrastructure. All participants expected that CAVs will operate in mixed traffic with manually driven vehicles. Though some suggested that separation of CAVs from other traffic could be beneficial in certain areas, it was not regarded as mandatory for the services. Two participants anticipated that enhanced maintenance of the infrastructure in the service areas will be necessary to ensure the safety and quality of the service. Other suggested actions included replacing outdated traffic lights with newer models to enable communication between them and the vehicles as well as enabling communication with other traffic flow altering systems. There were also conflicting views calling for more significant changes in the infrastructure. One participant considered on-street parking to be a major obstacle for the operation of the services.

Participant 10: *"I don't think it made a single successful round the whole testing period without manual intervention (referring to a recent automated shuttle bus pilot) ... The streets (of Helsinki) are overcrowded. I don't see how a new transport mode could be introduced into the scene when even the current ones don't fit in properly... The operation (of CAVs) is possible in mixed traffic, but the on-street parking seems more problematic for the operation. Parking should be moved to designated facilities from the streets (where the service operates)."*

None of the participants expected that there would be an operator or a service person on board the vehicles in the described fully automated services. When asked about how the service would function if a disturbance, for example an obstacle on the road, would appear, almost all of the participants described an operation centre where the vehicles are monitored, and if needed, controlled manually via remote access. To ensure a proper level of cost-efficiency, one operator would simultaneously monitor several vehicles. When asked about social disturbances, the participants almost unanimously stated that the services of a security company would be used similarly to the existing public transport services in Helsinki.

Many of the participants had difficulties imagining policies that should be introduced for the suggested services to work. All participants expected that new policies needed to be implemented, but naming specific policies proved to be difficult. The most often mentioned policy was the standardisation of the services, the vehicles, and the software. Other suggested policies included the previously mentioned restriction of parking, restriction of private vehicles in certain areas, and incentivisation of automated collective transport services.

Participant 2: *"In 2030 the technology is going to be quite ready, and then we need to have the legislation regarding the technology ready, which is not the case at the moment, as we are waiting for policy from UN, UNECE, and EU. We don't have a type-approval system for the vehicles. So, the framework of transport policy and legislation is not complete."*

Participant 8: *"We don't have a standard that defines how automated vehicles should be able to perform in traffic... So here it comes down to the co-operation of public authorities. I believe that, at least within Finland, we could develop safety standards for these vehicles and services."*

The importance of coordination among public authorities was considered vital in implementing new automated collective transport services. Some participants expressed worry regarding new actors entering the field with a lack of understanding or concern for public transport goals. Few participants criticised the current pilots and the "let them do" attitude the city has taken towards the technology. On the other hand, some participants welcomed the possible reform of service provision and called for more ambitious experiments.

Participant 3: *"Transport automation brings many new actors to the field. The first priority for some of these actors is not necessarily the public good. There needs to be strong coordination on how the technology is applied."*

Participant 4: *"It feels almost like the (automated shuttle bus) pilots are a way for tech-developers to outsource their testing. The recent pilots (in the capital region) have had little to do with providing better collective transport services, which may be due to a lack of involvement from the (current transit) operators… The (automation) technology should not be treated as a no-brainer. Right now, it seems that we're implementing these pilots because they are cool, and that's not a good reason. Automation should be applied to collective transport if it enables enhancements in an existing service or provides an opportunity for an entirely new, needed service"*

Participant 10: *"To develop these services, we need innovation, and well, Helsinki is quite open to innovation but most cities, frankly, are not. We should pursue an even greater number of, and more ambitious, pilots."*

4.1.2 Criteria

A total of thirty-three criteria were suggested to measure the performance of the suggested service designs. Most frequently mentioned criteria were the ease of using the service, cost-efficiency, traffic safety, and overall user experience. Approximately half of the participants mentioned ridership, travel time, and service reliability. Criteria such as accessibility, environmental impacts, social safety, perceived safety, connectivity, traffic flow and flexibility were mentioned by only a few participants. These were formulated into six main criteria and twenty-eight subcriteria (table 5). The main criteria, which were compared in the survey, were environmental effects, reliability, resource efficiency, safety, transport system effects, and travel experience.

Three criteria were not included in the survey, as they were not deemed relevant for the scenario evaluation. These criteria were "the effect on the driver's work in conditionally automated services", "the number of privately produced collective transport services compared to the number of services provided by public authorities" and "the number of connected and automated vehicles in traffic compared to the number of manually driven vehicles".

Table 5 The criteria and the subcriteria

Criteria	Subcriteria (no. of mentions)	Description
Environmental effects*	Carbon balance (1)	The amount of produced CO_2 emissions subtracted by the amount of reduced CO_2 emissions

Reliability	No. of malfunctions (3)	The number of malfunctions within a certain time that prevent the service from operating normally
	Punctuality (1)	The service's ability to operate on time
	Response time in malfunctions (1)	The average amount of time that is used to recover from a malfunction back to normal operation
	Service reliability (5)	The service's ability to consistently operate on a predefined level
Resource efficiency	Capacity (4)	The maximum number of passengers transported over a certain time
	Cost-efficiency (7)	The achieved service level in relation to the costs of producing the service
	Number of service users (6)	The number of passengers using the service over a certain time
	Service flexibility (1)	The ease of modifying the service to fit the demand
	Vehicle occupancy (1)	The average number of passengers in a vehicle during the time of operation divided by the passenger capacity of the vehicle

Safety	Social safety (3)	The number of occurred social disturbances in the service over a certain time
	Traffic safety (7)	The number of traffic accidents that the service is a part of over a certain time
	Perceived safety (1)	The level of safety a service user associates with the service
Transport system effects	Accessibility (2)	The ease of reaching destinations
	Modal share (3)	The percentage of travellers using a particular type of transport or the number of trips using said type
	Collective transport coverage (3)	The total area within which collective transport services are accessible
	Collective transport ridership (2)	The number of passenger boardings on collective transport
	Seized benefits (1)	The benefits that are achieved through implementing a collective transport service (e.g. reallocation of street space)
	Traffic flow (1)	The movement of travellers and vehicles and the interactions they make with one another e.g. congestion

	Transport system functionality (1)	How well the transport system fulfils its' purpose
Travel experience	Average speed (3)	The average operational speed of the vehicle
	Connectivity (1)	The ease of chaining a trip with the service to another trip
	Ease of using the service (8)	The ease of physically or digitally accessing and using the service / a user's experience of the ease of using the service
	Service fare (1)	The cost of a single trip with the service
	Travel time (6)	The total time spent waiting for the service and using it to reach a destination
	User acceptance (1)	A potential user's perception of the service's usability in comparison to other available modes of transport
	User experience (7)	The overall satisfaction or dissatisfaction of a service user
	Waiting time (3)	The time spent waiting for the service

* Three participants suggested "environmental effects" as a criterion without specifying what aspects should be considered

4.2 Final scenarios

Based on the interviews, six alternative scenarios were designed. As the participants unanimously agreed that the early implementations of CAVs in the collective transport system should be feeder services or last/first-mile services, the scenarios reflect this view. Additionally, the scenarios reflect two dilemmas that transpired in the interviews.

- Some participants expected that CAV-services would be implemented into densely populated areas, whereas others expected them to serve loosely populated areas.

- Roughly half of the participants suggested that these services should operate on fixed routes according to a timetable, and the other half suggested that they should operate within an area based on demand.

Two neighbourhoods in Helsinki were chosen: one with relatively low population density and one with a relatively high population density. Both neighbourhoods had an existing collective transport connection, a bus line, that connects the areas to high capacity transit connections such as rail rapid transit and light rail transit.

Table 6 The scenarios

Scenario	1.0	1.1	1.2	2.0	2.1	2.2
Population density		Low			High	
Land use		Homogenous			Mixed	
Level of automation	None	Full	Full	None	Full	Full
Route type	Fixed	Fixed	Flexible	Fixed	Fixed	Flexible
Route/Network lenght (km)	2.8	2.9	13.8	2.4	2.4	5.8
Travel time inside the vehicle (min)	7	7	N/A	11	11	N/A
Speed limit (km/h)	40	40	30–40	30–40	30–40	30–40
Service frequency (min)	10–30	5	N/A	15–20	6	N/A
Stop spacing (m)	100–350	100–350	200–300	100–200	100–200	100–200
Separation of pedestrians and cyclists from the carriageway	Structural	Structural	None / Structural	Structural	Structural	Structural

The baseline scenarios 1.0 and 2.0 reflect a status quo situation and serve as a reference point for the other scenarios. In the other four scenarios, the existing bus line is replaced with a connected and automated shuttle line. In scenarios 1.1 and 2.1, the bus line is replaced with a similar fixed-route CAV-service, and in the scenarios 1.2 and 2.2. the line is replaced with a flexible CAV-service that operates based on demand within the area. Table 6 presents some variables of the scenarios. Numerous presumptions had to be made to make the scenarios comparable. These presumptions are listed in appendix 2. Full descriptions and visualisations of the scenarios are presented in the appendices 2–8.

4.3 Survey analysis

4.3.1 Criteria weights

Figure 4 depicts the criteria weights calculated from the survey. Unsurprisingly, the participants held safety as the most important criteria. The weight of safety was over double the weight of the next most important criteria, reliability, and seven times the weight of the least important criteria, environmental effects. Reliability and transport system effects were held almost equally important with a slight incline to reliability. Travel experience and resource efficiency were regarded as equally important.

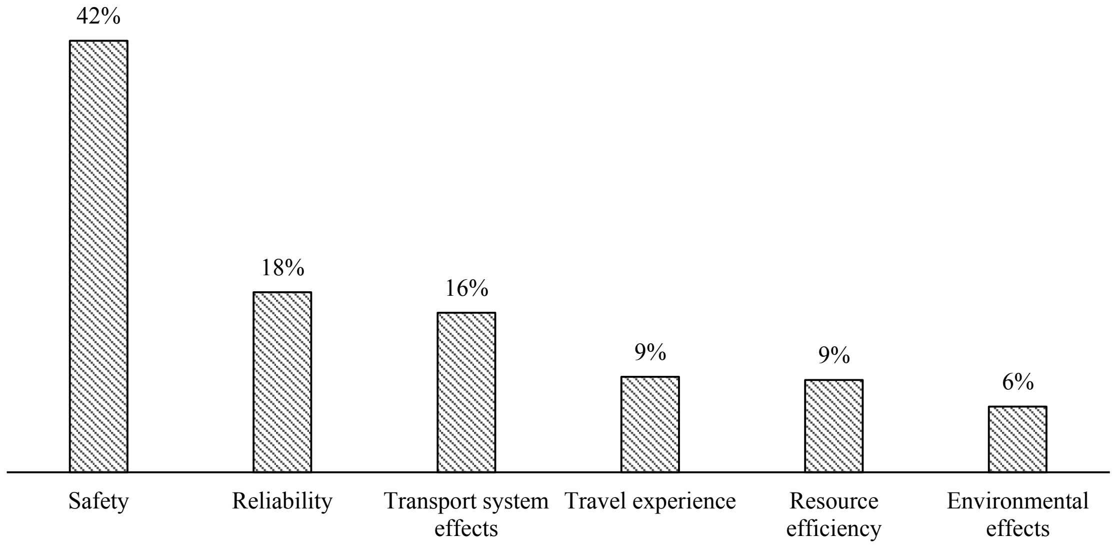

Figure 4 Criteria weights

At the end of the survey, the participants were asked to name missing criteria or subcriteria. All but one regarded the presented criteria as sufficient. One participant suggested that there should be a specific criterion addressing the ability of people with disabilities to use the service. In the feedback section, one participant noted that comparing the importance of the criteria was difficult, as the criteria are interconnected.

4.3.2 Scenario rankings

Table 7 depicts the calculated ranking flows and the ranking of the scenarios. No two scenarios are indifferent, as all outranking flows have different values. As the negative and positive flows do not produce the same ranking, some alternatives are not comparable. By examining the values of table 7, it can be inferred that the incomparability occurs between scenarios 1.1. and 2.2. Since the incomparability occurred between scenarios in different geographic contexts, the scenarios are still comparable within their respective contexts. It would not even be meaningful to compare services in different contexts, as many of the imagined criteria are directly connected to the spatial characteristics of the operation area, such as the number of potential service users and route/network length. Though a service in the loosely populated context might not catch as many users, it does not render it less important. More meaningful observations can be made by examining how the services perform within their spatial contexts.

Table 7 Scenario rankings and flow scores

Rank	Scenario	φ	φ^+	φ^-
1	2.1 Fixed	0,644	0,816	0,172
2	2.2 Flexible	0,244	0,574	0,33
3	1.1 Fixed	0,172	0,586	0,414
4	2.0 Baseline	-0,06	0,428	0,488
5	1.2 Flexible	-0,456	0,272	0,728
6	1.0 Baseline	-0,544	0,228	0,772

The scores reflect that the participants expect that connected and automated services, flexible or fixed, will be an improvement from the current services operated with manually driven vehicles. The expected improvement is more drastic with fixed services. Nevertheless, flexible services too are expected to perform better than the baseline services. It is somewhat surprising that the fixed services outranked the flexible ones so distinctly, as in the interviews half of the participants regarded flexible services as a good way of serving loosely populated neighbourhoods.

Table 8 Aggregated scenario evaluation table

Scenario	1.0	1.1	1.2	2.0	2.1	2.2
Environmental effects	4,29	6,71	6,86	4,71	7,29	7,29
Reliability	7,29	6,71	5,57	7,43	7,00	6,00
Resource efficiency	4,29	5,57	7,00	5,29	6,71	7,71
Safety	7,43	7,86	7,29	7,71	8,00	7,71
Transport system effects	4,57	6,57	7,29	5,43	7,00	7,71
Travel experience	5,71	7,43	7,29	6,43	8,14	7,86

From the aggregated evaluation table (table 8), several interesting observations can be made. First, there are no major differences in the most heavily weighted criteria, safety. This is likely a consequence of the presented presumptions about CAVs' ability to perform in traffic (appendix 2). However, the fixed services are presumed slightly safer than the flexibles ones. Since safety is by far the heaviest criteria, a small difference does affect the ranking flows considerably. Second, the conventional bus lines are viewed as more reliable compared to the automated ones. Third, in both settings, CAV-services on fixed routes are expected to provide the best travel experience. Fourth, on-demand services are expected to benefit the transport system the most, and they are also regarded as the most resource-efficient.

5 Discussion

This study is one of the first that has attempted to systematically identify and critically assess potential near-future collective transport service designs for CAVs and the criteria based on which the performance of these services should be evaluated. At the beginning of this study, it was stated that there is a gap regarding studies examining the near future of transport automation – in general, and even more so with local contexts. The results of this study justify this statement.

Even though the conducted scenario review was not systematically carried out, it highlights that relatively few studies explore the near future of connected and automated transport. Furthermore, the interviews revealed a major divergence of views, not so much among participants, but between the reviewed scientific literature and the participants. The divergence between participants' views and the ones expressed in scenario studies is significant and even greater with impact studies. Many of the latter describe, model, or evaluate independent, connected and automated taxi-systems that serve all demand, including the current public transport demand, whereas the participants viewed CAVs as a way to support the established public transport system. The participants' expectations regarding technological development were also far more moderate than those expressed in the literature.

This discrepancy of views can be partly explained by the context of studies. The participants of this study examined the phenomenon through their cultural and geographic context, Finland and Helsinki. It is not surprising that they see CAVs as a possibility to enhance feeder connections, as the HSL-region (area operated by inter-municipal PTA) is a well developed trunk-feeder public transport system (Weckström et al. 2019). On the other hand, researchers, planners, and decision-makers based in cities that are more heavily dependant on the private car could see CAVs as an extension of their prevailing transport system. As many of the cited studies originate from such cities, it is not surprising that they seem to examine the matter bilaterally: either CAVs penetrate the market as a shared service, resembling current ride or car-sharing schemes, or as a private utility. A business-as-usual scenario sometimes accompanies these two perspectives. This research underlines the possibility that the near-future implementations may not resemble car or ride-sharing schemes, nor private transport, but public transport instead – at least in cities where the preconditions for these implementations exist. In section 5.1 the alternative service designs and the implications of organising such services in Helsinki are discussed. In section 5.2 the imagined criteria and their sufficiency are discussed, and in section 5.3 the author addresses the limitations of this study.

5.1 Near-future implementations of connected and automated services

Even though some contradictions about the service designs, the associated opportunities and threats, the expected rate of technological development, and the vehicle features appeared in the interviews, the participants had rather similar views about the future of CAVs in Helsinki's transport system. The biggest contradictions related to the expected rate in which the technology could be implemented. Some participants expected that much of the current collective transport system could be automatised in fifteen years, whereas some did not anticipate major reforms to become possible. Nevertheless, all expected that fully automated services would be implemented and that they would be feeder connections. Two service designs were mentioned frequently in the interviews: more than half of the participants anticipated that fixed-route services and half of the participants anticipated that flexible-route services would be implemented to complement the public transport system. Flexible services were mostly associated with low demand areas and fixed-route services with dense suburban settings. Though the literature about transport automation has not yet formulated an opinion on the matter, it can be said that this line of thought is somewhat consistent with previous research on non-automated DRT (Daniels & Mulley 2012; Mageean & Nelson 2003; Velaga et al. 2012). The participants did not see CAVs providing additional value to central areas' transport supply, as these areas' demand was thought to be saturated as it is. Furthermore, they had doubts about whether CAVs could perform on a required level in such an environment. Participants had similar views about the characteristics of the vehicles that will be used, as most described connected and automated shuttles that were very similar to the ones currently used in pilots. The participants did not expect major changes to the infrastructure as a consequence of implementing CAV-services and noted that for the services to become truly viable, they have to be able to operate in the current infrastructure. Hence, the two major dilemmas that transpired in the interviews can be expressed as follows:

1. Should CAV-services operate on fixed routes according to a timetable or flexible routes based on demand?
2. Should these services be organised in loosely populated areas or densely populated areas?

The participants were fairly consistent in terms of the views expressed in the interviews and the survey answers. None of the participants seemed to alter their opinion about the services significantly during the process. The ones who talked about flexible services also ranked them higher than the baseline and fixed services on almost all criteria. The ones who talked about fixed services rated the flexible ones higher mainly in resource efficiency and transport system effects. However, this is most likely a result of the presumption, presented in the survey background, that the flexible services are technologically applicable, not "a change of heart".

Both fixed and flexible routes have their pros and cons. Fixed route services provide faster travel, whereas flexibility eases the access to the service. It seems intuitive that fixed-route services would operate in more densely populated areas and flexible services in more loosely populated areas. The analysis of the survey responses indicates that matching the optimal service with the optimal area is not as straightforward. In both settings, the fixed service ranked better than the one operating on flexible routes. Although the margin was significant, this is not a definitive answer to the question which is better, and it can be fairly confidently stated that their performance could be ranked differently in different settings or if other criteria were incorporated into the process. The survey results also indicate that some participants had difficulties in distinguishing how the alternative geographic contexts would affect the services' performance. Moreover, the used method gives only a very rough estimate of the expected performance based on expert opinions. However, from the results, it can be interpreted that the participants view both service designs as plausible and expect them to enhance the situation from the status quo – providing that the technology will be mature. Future studies should aim to investigate these two designs more thoroughly and critically assess their performance and implications in a variety of settings. The author proceeds now to highlight some aspects that should be considered.

The essential questions in organising any transport service are “what is the need?” and “to whom will it cater?” Many participants viewed CAV-services as a good way of establishing a better connection between loosely populated areas and the “core” public transport system. To organise a functional CAV-service into a loosely populated area, the service needs to able to compete with other modes of transport, first and foremost, the private car, as it is the main mean of transport in many loosely populated suburbs in Helsinki. The participants emphasised the importance of travel time and service accessibility in attracting car users. Here, a puzzle occurs. The speed of the vehicle cannot be increased, as the traffic environment of loosely populated suburbs does not support high speeds; therefore, a fleet of multiple vehicles is required to achieve a compelling level of service. The number of required vehicles is most likely higher with demand-based services, but in turn, service accessibility could be distance-wise significantly worse with fixed-route services. The problem could be examined relatively easily with conventional transport models. However, such models cannot answer how attractive the new mode of transport is in comparison to the private car.

The question of service level inevitably leads to the question of costs. Though recent literature has highlighted that increased capital costs, resulting mainly from new technology, vehicles of lower capacity, and consequently a larger fleet, are expected to be compensated by reduced operational costs, resulting mainly from displaced labour (Hatzenbühler et al. 2020; Tirachini & Antoniou 2020), this is unlikely to be the case with early implementations in loosely populated areas. In Helsinki, these areas are often served by radial routes, stretching from the city centre or other important nodes, which simultaneously act as feeder lines for higher capacity transit. Therefore, if a CAV-service would be organised in such a suburb, it would most likely displace only a fraction of the previous service or exist alongside it. Contradictory to the expected cost savings, the total costs could increase significantly. This, in turn, leads to a question of social equity. As the new services would serve only one neighbourhood or postal code area, unlike most of the existing services, all capital and operative investment would be made into that area. Considering that the average income of the dwellers of loosely populated suburbs in Helsinki is often greater than of those living in densely populated suburbs, and most likely they already have sufficient means of transport (often one or more private cars), making capital-heavy investments into these areas may be seen as unjust, especially if the service fails to catalyse a modal shift. This problem is evident and should be considered especially in the early stages of transport automation when the technology is still expensive compared to conventional collective transport vehicles.

It should also be noted that the service’s ability to attract car users is not only a matter of operational characteristics such as fleet, route and speed. Experiences with a recent non-automated DRT service pilot in Helsinki have illustrated the importance of pricing, ease of use, and service image in attracting car users and extending the service access to different social groups (Jokinen et al. 2019; Weckström et al. 2018). Moreover, regardless of the characteristics of the new automated feeder service, the users would still be dependant on the existing public transport system for the rest of their trip. If the system does not properly cater to their needs or they view it as an unpleasant, unreliable, unsafe, or otherwise worse option than the available private car, it is unlikely that they will make the modal shift. For these reasons, the alternative service designs’ ability to attract car users must be investigated before implementation. While some valuable information can be discovered by examining the service itself, the matter must be also examined holistically from a system point of view.

The complexities in organising a CAV-service into a more densely populated area are not necessarily fewer in number. Many participants described a shuttle system that acts as a feeder service for high capacity transport such as the metro. Considering that the number of travellers disembarking the metro on certain stops could be as high as a hundred, the required vehicle fleet could be very large as well as space-demanding. Using the vehicle capacity of the scenarios (10+6+1), seven shuttles would be required at the metro station to serve the demand generated by one metro (running in two-minute intervals) immediately – and those are just the vehicles at the metro station. Otherwise, the service level during peak hours could be significantly worse in certain areas than it currently is. Organising such a service would get even trickier if flexible routes were incorporated, as placing people in the right vehicles to optimise routes would require a sophisticated, easy-to-use system. Consequently, guaranteeing a sufficient level of reliability and attractive travel times could prove to be very difficult.

The answers to the two presented questions are not necessarily either-or. The services could be mixed and matched with each other and other transport services to comprehensively serve the demand of a certain area. Above all, organising the first CAV-services will be a question of technical capabilities and available resources. It can be stated fairly confidently that suitable areas, where technical capabilities, demand, and available resources match, can and will be found. Whether these service designs can be scaled to more difficult environments and larger demand, and whether they prove to be financially sustainable in the next ten to fifteen years, is at this time a matter of belief. In this study, the question of resources was touched upon only lightly due to the prevailing uncertainties. Nevertheless, previous experiences with innovative transport service pilots have highlighted that the importance of cost-efficiency, sustainable funding, and sustainable business model cannot be ignored (Jokinen et al. 2019; Daniels & Mulley 2012). Furthermore, certain policy issues are still to be solved for the technology to transcend the pilot stage. All these aspects still require addressing in the scientific literature.

These hypothetical speculations illustrate how important it is to evaluate a service's performance with the essential criteria. The decision about implementation should be based on these criteria and their relative importance. Although using a MCDA-method may not be practical or possible in all decision-making situations, the decision-makers should at least have a clear idea of the criteria to consider and their priorities. In this study, experts and stakeholders were used for identifying the criteria and determining their weights, as they should have sufficient knowledge about the matter and the ability to holistically examine it from multiple perspectives.

5.2 Essential evaluation criteria

Thirty-three essential criteria were identified and then grouped into six main categories: environmental effects, reliability, resource efficiency, safety, transport system effects, and travel experience. Safety was deemed to most important criteria, followed by reliability, transport system effects, resource efficiency tied with travel experience, and finally environmental effects. The ranking of the criteria reflects their interconnectivity. For example, a service cannot provide a satisfactory travel experience if it is not safe or reliable, and a service will not have a positive environmental effect if it will not attract users. Most of the identified criteria and subcriteria can be seen as very conventional, and it is reasonable to question whether they are sufficient for making just decisions about implementing a potentially disruptive technology into the transport system. For example, socio-spatial criteria addressing the distribution of benefits and burdens are missing almost completely, and the criteria are rather user and service provider-oriented, while the viewpoint of the people who are not users but have to interact with the service is neglected.

The author acknowledges that this may be partly a result of the used methodology. Further discussion on the matter is provided in the next section. However, this can also be partly explained by the sample group of the study. As the aim was to simultaneously identify possible service designs, the group of selected professionals was skewed towards transport planning. Consequently, the imagined criteria reflect the state of the practice. Regardless, some completely new criteria and ones previously given little emphasis in collective transport planning were identified. These include carbon balance, service flexibility, social safety, perceived safety, seized benefits and user acceptance.

To identify a wider range of criteria, future studies should aim to include a more diverse group of experts. The need for diversity is further illustrated by the observation that there was some discrepancy between the frequency of criteria mentions and the criteria weights. For example, every participant ranked safety as the most or the second most important criterion, but three participants did not mention any aspect of safety in the interviews. Ease of use was the most frequently mentioned criterion, but travel experience had the second-lowest weight tied with resource efficiency. This indicates that some participants could not name the criteria that they held as important. It is possible that a larger group, consisting of a heterogeneous sample of professionals from different fields or potential users, could identify very important criteria that are left unimagined by a too small, homogenous sample group.

It does not come as a surprise that safety was deemed as the most important criteria. This finding is in line with previous studies that have identified the importance of safety (Innamaa & Kuisma 2018; Kim et al. 2019; König & Neumayr 2017). However, all safety is not equal. The issues of social and perceived safety were mentioned only in few interviews, and the survey results support the finding that participants either do not associate CAV-services with social and perceived safety issues or expect them to be solved with surveillance, security services, and simply by users becoming gradually accustomed to the services. A few participants mentioned the same analogy, “self-driving vehicles are like horizontal elevators”, through which they expressed that people would become accustomed to travelling in a self-operating machine, as it has happened before. While it could be argued that this analogy is very flawed for many reasons, such as elevators being independent systems in which travel time is usually less than one minute, it is most likely true for some, or even for the majority of users. On the other hand, some social groups are not as receptive to new services, as previous studies have highlighted (König & Neumayr 2017; Bennett et al. 2019a), and the question of whether these services are even usable for some of these groups is open.

Interestingly, the often-mentioned safety aspects of hacking and data use were not associated with the services. The reasons for this could be numerous. For example, only a few participants expected that institutional reform in transport service provision would occur due to the new services. Consequently, as public authorities in Finland generally enjoy a high trust and do not advance a commercial interest, data misuse issues are not expected to occur. Other explanation could be that the imagined services resembled more existing public transit than the more futuristic door-to-door systems that are widely present in the literature. Users could operate the imagined services relatively anonymously without supplying the service provider with a lot of personal information. It is more difficult to answer why the issue of system security was not addressed in the interviews. However, the author argues that these are essential safety criteria that should not be neglected.

It is somewhat surprising that the participants weighted travel experience relatively lightly. As mentioned, the ease of using the service was the most frequently mentioned criterion, and the participants seemed very conscious about the possible threat of unequal mobility, some going as far as stating that it would be extremely difficult to ensure usability for some social groups – mostly referring to people with physical disabilities. In the scenario presumptions (appendix 2), it was stated that the shuttles would be equipped with the same utilities as the newer city buses: a ramp, braille, and audiovisual notifications. Yet, the participants expected that CAV-services would provide a better travel experience than conventional bus lines. It seems unlikely that this will be the case for people with physical disabilities unless actions are made to develop the service accessibility from the current state of the practice.

Furthermore, the multidimensional nature of accessibility should be understood; equipping a shuttle with a wheelchair ramp, braille and audio-visual notifications does not necessarily make the service equally accessible. Besides the barriers inside the vehicle, other physical barriers, such as high kerbs, difficult surfaces, lack of benches or handrails, and stairs may complicate the use of the services for many (Stjernborg 2019). Informational and technological barriers may complicate the use of service especially for the elderly, as has been observed (Weckström et al. 2018). Some social groups that are seemingly able to operate the service without help, such as children, people with mental disabilities, people with low-income, or genders, might suffer from exclusion from transport for various reasons unrelated to their physical abilities (Hine 2011). Moreover, the wider picture should be acknowledged. Since the first CAV-services will be, according to the participants, feeder services, the traveller is dependant on the rest of the public transport system for the rest of their trip. Although developing innovative accessibility solutions for the CAV-services would be a good start, it should be noted that all public transport services are not necessarily up to par. Hence, implying that CAVs could break certain social groups from mobility disadvantage any time soon is – if not misinformed – gratuitously optimistic.

This should not be mistaken for criticism of the concept of connected and automated services, as the purpose was merely to illustrate how important it is to examine different social perspectives and to examine the emerging services from a holistic point-of-view to ensure an equal, safe, and functional transport service. Certain criteria such as travel time, waiting time, average speed, traffic flow, and to some degree even more complex criteria such as cost-efficiency could be examined with conventional transport models. This is not the case with social criteria such as perceived safety, ease of use or user acceptance – or even certain traditional criteria such as the effect on the modal share – that have a pivotal effect on the services' performance. Service pilots, currently organised all over the world, offer a great platform for studying these criteria. However, as some participants argued, this opportunity has not been utilised properly in the capital region.

A counterargument could be made that the pilots so far have aimed to test and display the vehicles ability to operate in a variety of settings. While this may be true, it should be noted that for example technical accessibility solutions, that have not been systematically tested in the pilots, are very much an integral part of the operation. Should these services enhance equal mobility, the functionalities that advance this goal have to be an intrinsic part of vehicle and service development, not an additional feature that is incorporated when the service is otherwise ready. The pilots shape the narrative through which we view these vehicles, their technical features, and their relation to other modes of transport and the transport system as a whole; they create mental images of what the technology is supposed to be, and these images have been shown to enter policymaking (Haugland & Skjølsvold 2020). Therefore, expressing the concern that pilots may act as a slippery slope to unjust mobility for some is not unfair.

Hence, a suggestion for action is made here: future CAV-service pilots should aim to simulate real transport services more effectively, and the possible implications should be studied more extensively. If CAVs should eventually provide new feeder options for transit or replace services such as subsidised taxis or bus lines that have low cost-efficiency, they should simulate replacing them. Transport demand should be analysed, and pilot routes should be designed accordingly. Tech suppliers should be heavily incentivised to design solutions for equal usability, and their success should be tested in the pilots. Stakeholders, special interest groups, and the public should be more involved in piloting and eventually service planning.

5.3 Limitations and notes on the methodology

The utilised methodology and its' execution withhold some limitations that should be noted. Retrospectively evaluating the interview protocol, it can be said that it worked well but not perfectly. The goal of the interview was achieved with every participant; however, the process was more heavily focused on identifying the service designs, and as the conversation generally revolved around the operation of these services, the imagined criteria are mostly related to the operation. Some essential criteria might relate to the planning and organization phase of the services, for example, the socio-spatial criteria that are not apparent in the operation but need to be considered in the planning, or by latest in the decision-making phase. Some criteria may relate to the opportunities of participating in the planning and decision-making. Some criteria should look far beyond the operation of a single service to prevent undesirable implications in the long term. Thus, focusing solely on the operation is incomprehensive. Another problem in identifying the essential criteria was already highlighted in the previous section. The sample group of experts was relatively homogenous and skewed towards the transport-related professions, which may be reflected in the imagined criteria. Further studies should aim to incorporate a more diverse group of experts as well as members of the public and special interest groups, together or separated. Though this study specifically aimed to include key-actors in the field, it can be said that a larger sample has its' benefits even though the expertise could vary more heavily.

No conclusive interpretations should be made about the ranking of the criteria. As the survey and participation process were very demanding, some participants failed to submit survey answers in time dropping the response rate of the survey to seventy per cent. Moreover, while it can be fairly confidently said that safety is the most important criterion, it is possible that if the criteria groups were deconstructed and all subcriteria were compared pairwise, the ranking would be different. However, as thirty-three criteria would accumulate to over five hundred pairwise comparisons, this approach was not applicable to the chosen methodology. Another well-known problem with the AHP ranking method is the rank reversal problem. If new criteria were added, it could change the relative ranking of the other criteria. Also, the consistency of the pairwise comparisons was not tested.

As the main contribution of this study was made by interviewing people from various organisations, the aspect of rhetorical discourse should not be ignored. Although the experts had rather similar expectations of the general characteristics of the near-future services, there were also some discrepancies, and their narratives could reflect their backgrounds. People representing academic or research expertise expressed more moderate views and expectations than their counterparts. When answering questions, some referred to the recent scientific literature, including their own work. In general, they addressed the subject pragmatically and viewed the emergence of the technology as a controllable phenomenon. This mindset was indicated by remarks about the technological development being unable to override the policymaking and ethical principles of the society. Contradictory, some people coming from commercial or innovation-related positions seemed to have more deterministic and nebulous views of the emerging technology. This was illustrated by comments about the technology being inevitable and the near future being almost impossible to predict. Some of them viewed the emergence of the technology as a niche for the private sector companies to enter the mobility market or for Helsinki to promote itself as a leading technology innovator. Although there were also more moderate expectations, the most progressive views came from this segment of participants. Participants representing public authorities had the most ambivalent views of the technology. While this segment was mostly optimistic about the prospect of CAV-services, they were also the ones most concerned about the implications. Even though there were no blatant incongruities between actors, for example the private sector and public authorities, these observations highlight the danger of leaning on a narrative of too few agents.

Lastly, when designing the scenarios, numerous presumptions had to be made to make them comparable. These presumptions may not be realised in the next fifteen years. Alternatively, technological development could exceed the generalised expectations of the participants. Additionally, many essential variables such as approximate demand, operative costs, investment costs, and cost-efficiency were not available for the participants. Therefore, definitive conclusions cannot be made about the superiority or inferiority of CAV or conventional collective transport services. Summa summarum, the main purpose of this study was to identify possible service designs as well as criteria that should be used for evaluating their performance; though additional results were simultaneously obtained, the activities were conducted solely for supporting these two aims. These results should be interpreted cautiously.

6 Conclusion

Implementing emerging, possibly disruptive, technologies into the transport system is a complex and demanding process. As the tech-developer race to the finish and activists and enthusiasts alike cheer on, cities and public authorities should remain calm and analytic. Numerous possible implications of CAVs have been identified, but just like decision-makers failed to anticipate the consequences of early automobile technologies, a myriad of implications could remain hidden. Nevertheless, one prediction can be made with extreme confidence: these implications are highly dependant on the service designs that are implemented. Hence, the contribution this study made in identifying possible near-future implementations of CAV-services and the essential criteria to evaluate them is significant.

A few lessons can be learned from the results as well as the whole research process. First, different service designs may be applicable in different contexts, and their performance and effects should be thoroughly examined before implementation. Different countries, cities, and neighbourhoods have different characteristics in terms of the culture, transport supply, land-use, socio-demographics among other things that heavily affect the applicability of the services, and therefore it is difficult to achieve universally interpretable conclusions from a holistic evaluation based on a certain geographic context. This study focused on the City of Helsinki, and the results should be interpreted accordingly. Vice-versa, results from studies with no geographic focus may not be applicable in all local contexts. Therefore, the need for studies examining the phenomenon from specific local perspectives is imminent.

Second, planners, public authorities and stakeholders alike should not believe that all essential criteria for evaluating CAV-services have been identified. CAVs hold great opportunities but may also act as a pitfall for unequal mobility as well as other unidentified negative externalities. This study highlights that some obvious problems related to the social equality of CAV-services remain unsolved. As public authorities have increasingly started to emphasise social equality in their agenda, the needs of the few should not be overlooked anymore.

Third, there is a major gap regarding near-future implementations and implications of CAV-services in the scientific literature. Future studies should more thoroughly investigate the matter with a wider range of participants and methods. It is important to look far ahead in the future, to anticipate the far-stretching societal implications, but it is equally important to thoroughly investigate the first steps that are taken as these are the ones that take us on a path from which it may be difficult to break out. It should be noted that the process of implementing CAVs into the transport system has already begun. Pilots shape the narrative through which we view these vehicles, and the actors involved in testing hold a significant power to shape the future of the technology. Hence, as a concluding remark, the author states that the available platform should be more extensively used to study possible service designs and their performance with the essential criteria.

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Appendix

Appendix 1. The interview protocol

Introductions (5 min)

Explaining the study and the methodology (10 min)

This interview is carried out as a part of research relating to the Sohjoa Baltic Project. The purpose of the research is threefold:

1. To identify alternative near-future scenarios of self-driving vehicles operating in the collective transport system of Helsinki.
2. To identify different criteria based on which the viability of the implementation of the vehicles should be evaluated.
3. To Identify divergence between expectations and opinions of experts and stakeholders regarding the matter.

Ask whether the participant understands the goals

The participation process is two-parted. The first part is a face to face a semi-structured interview. This interview will last about 1 hour and will be voice-recorded with the participant's permission. The second part is a survey that will be sent to the participant via email. The participants will not be directly identifiable from the answers they give. The interviewer, Janne Olin, is the only person to process the data retrieved from this interview and the survey.

The anonymity of the participant is agreed upon now.

Choose one:

1. The participant will remain fully anonymous. Neither the organization he/she belongs to or his/her name will be mentioned in the publication. The participant is referred to as "a participant/ an expert/ a stakeholder".
2. The participant is referred to with a generic description of her/his position or expertise. For example: "private sector project manager"

This interview can be voice-recorded:

1. Yes
2. No

If accepted, start recording now.

As mentioned, this research has 3 main goals. From these, the first 2 are discussed in the interview.

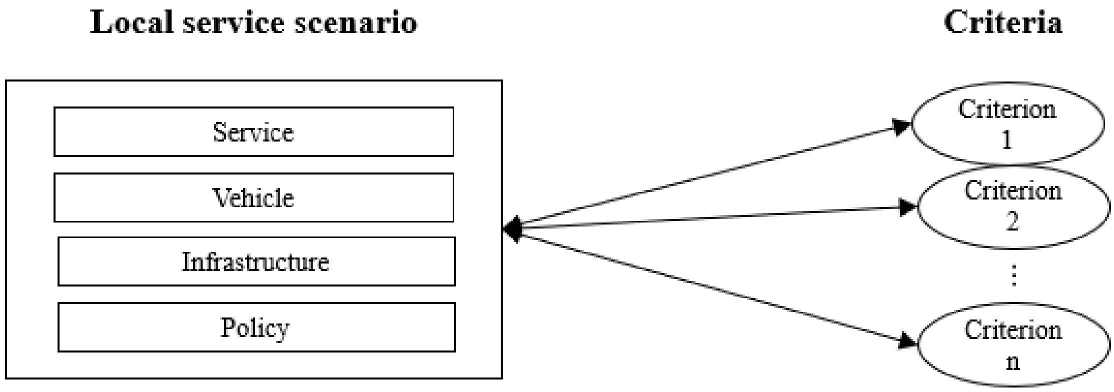
1. To find alternative near-future scenarios of self-driving vehicles operating in the collective transport system of Helsinki.

We're especially interested in local service scenarios I.e. what kind of service can be produced with these vehicles in the transport system of Helsinki, as well as operational design domains, I.e. where, when, and in what kind of infra can these vehicles operate.

Subsequently, we're interested in the different types of vehicles that can be used for providing collective transport services and what policies are required to ensure the proper functioning of these services.

2. To identify different criteria based on which the success of the implementation of the vehicles should be evaluated.

This question can be best answered by imagining how one could measure the success of implementing these vehicles into the collective transport system of Helsinki.



Show this picture.

The information gathered from the interviews will be assembled into a survey, which will be sent to the participants. The participants are asked to evaluate the importance of each criterion in relation to the other criteria. Then, each alternative is evaluated in relation to the other alternatives according to how well they perform with each criterion. This process is referred to as a pairwise comparison. The results will be used for a mathematical method called the Analytic Hierarchy Process. The output of this method will be the ranking of the different alternatives and the criteria.

Ask the participant whether he/she has any questions about the study.

The interview method is a semi-structured interview. I will ask you questions and make notes. Preferably, the discussion will bounce back and forth between the alternatives and the criteria.

The goal is that after the interview, we have identified one or more hypothetical local service scenarios for rubber tire, self-driving vehicles in the collective transport system of Helsinki in the next 10–15 years and different evaluation criteria directly connected to the scenarios. I will assemble the output of this interview into graphs and send them to you for verification. Feel free to correct me or add new information at that stage.

You should answer the questions based on your individual views and expertise. You are not expected to provide comprehensive answers – the aim is to simultaneously work at understanding the phenomenon, underline uncertainties, and to come up with alternative solutions.

Interview (35 min)

SDVs are discussed exclusively in the context of rubber tire public transport in Helsinki in 10–15 years.

- Describe freely how self-driving vehicles are present in the public transport system of Helsinki in 10–15 years?
- In what environment do you expect self-driving vehicles to operate?
- Does the current physical infrastructure require development to enable the functional operation of the vehicles?
- Describe the different vehicle types you expect to see operating.
- What type of human involvement do you think will be required?
- What policies are required to guarantee the successful operation of self-driving vehicles?
- How would you measure the success of implementing self-driving vehicles into the collective transport system of Helsinki?

Sum up (10 min)

Complete alternatives and/or components
Criteria

Appendix 2. Scenario background information

The following applies to all scenarios except the baseline scenarios 1.0 and 2.0.

- The scenarios take place in 15 years.

- The shuttles are connected, automated, and powered by electricity. It is given that the required battery charging does not affect service frequency.

- The passenger capacity of a shuttle is 16 passengers (10 seats + 6 standing + 1 wheelchair).

- Each shuttle has a wheelchair ramp, proper components for safe wheelchair travel, and braille in stop buttons. Additionally, the shuttles have audible and visual notifications about the stops.

- The shuttles operate according to the speed limit.

- The examined areas have low traffic volumes.

- The service is provided by a public transport authority.

- All connected and automated vehicles (including software), used in the collective transport of Helsinki, are standardised by law. It is given that a shuttle is able to operate on all routes marked in the maps and it will not make errors by itself. However, a shuttle cannot anticipate all possible traffic situations, for example, another road-user not respecting the rules of the road. The shuttle can operate in the same weather conditions as a regular city bus.

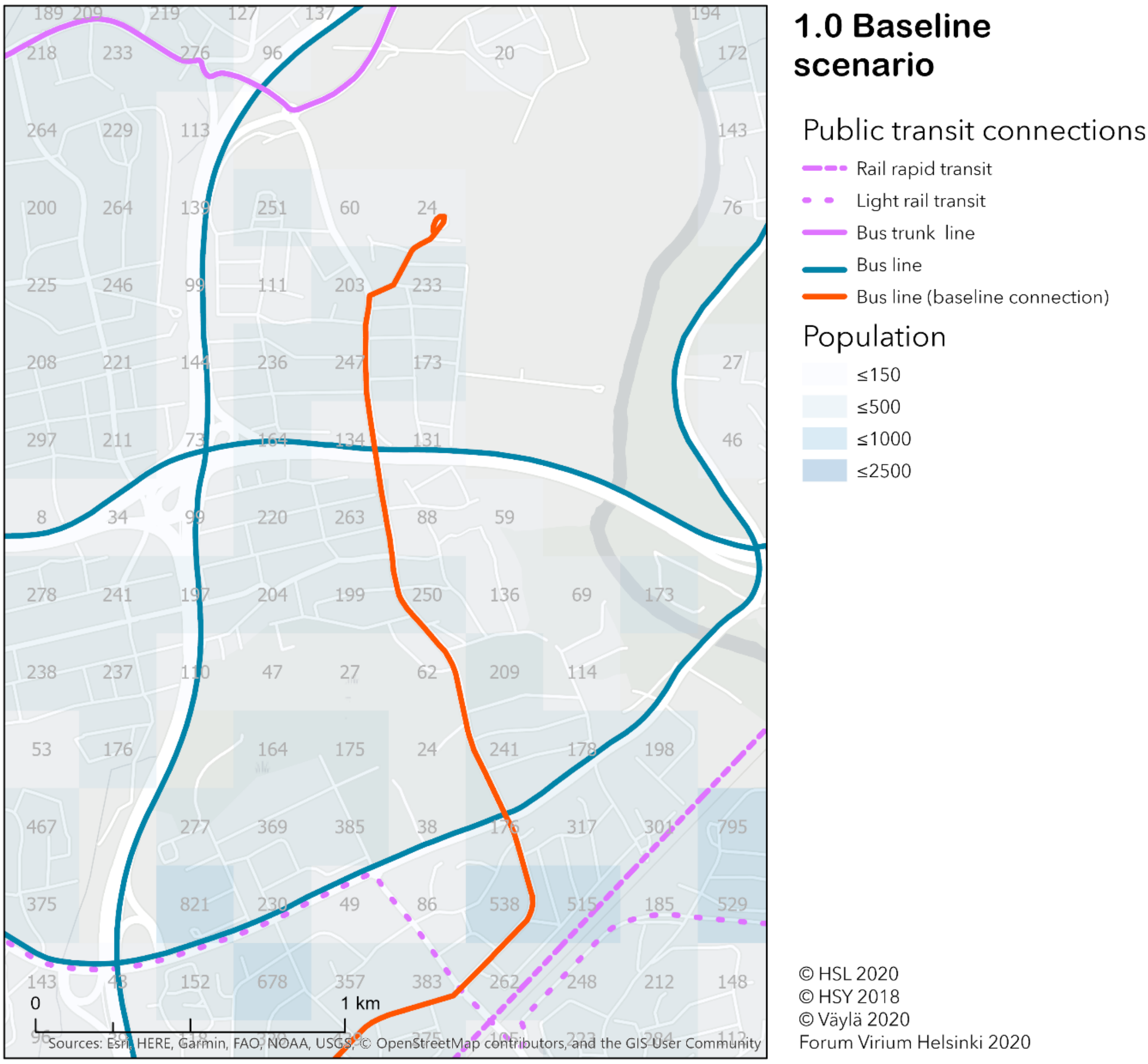
- No major changes have been made to the current infrastructure. It is given that roadside parking, by default, is not a problem for a shuttle even if the cars are parked carelessly. A more detailed description of the traffic environment is presented in each scenario.

- The shuttles are fully automated. They do not have an operator or a service person aboard. The shuttles are monitored constantly from an operation centre. One controller (a person who is paid to supervise the operation of the vehicles) monitors all shuttles simultaneously in each scenario. If a shuttle encounters an obstacle that it cannot bypass, the controller may steer the shuttle manually via remote access. The controller has a voice connection to the shuttle, which enables her/him to inform the passengers about the deviation from the regular operation.

- If a shuttle breaks down or encounters a problem that the controller cannot solve, a dispatch team (one or more people) is sent to the shuttle. The dispatch team will either make the required actions on-site, to enable the resumption of the service, or tow the vehicle to the depot where it will be fixed.

- If a social disturbance occurs in a shuttle, the controller alerts security guards (from a private security company) to handle the situation. In the case of a severe disturbance, the police are alerted.

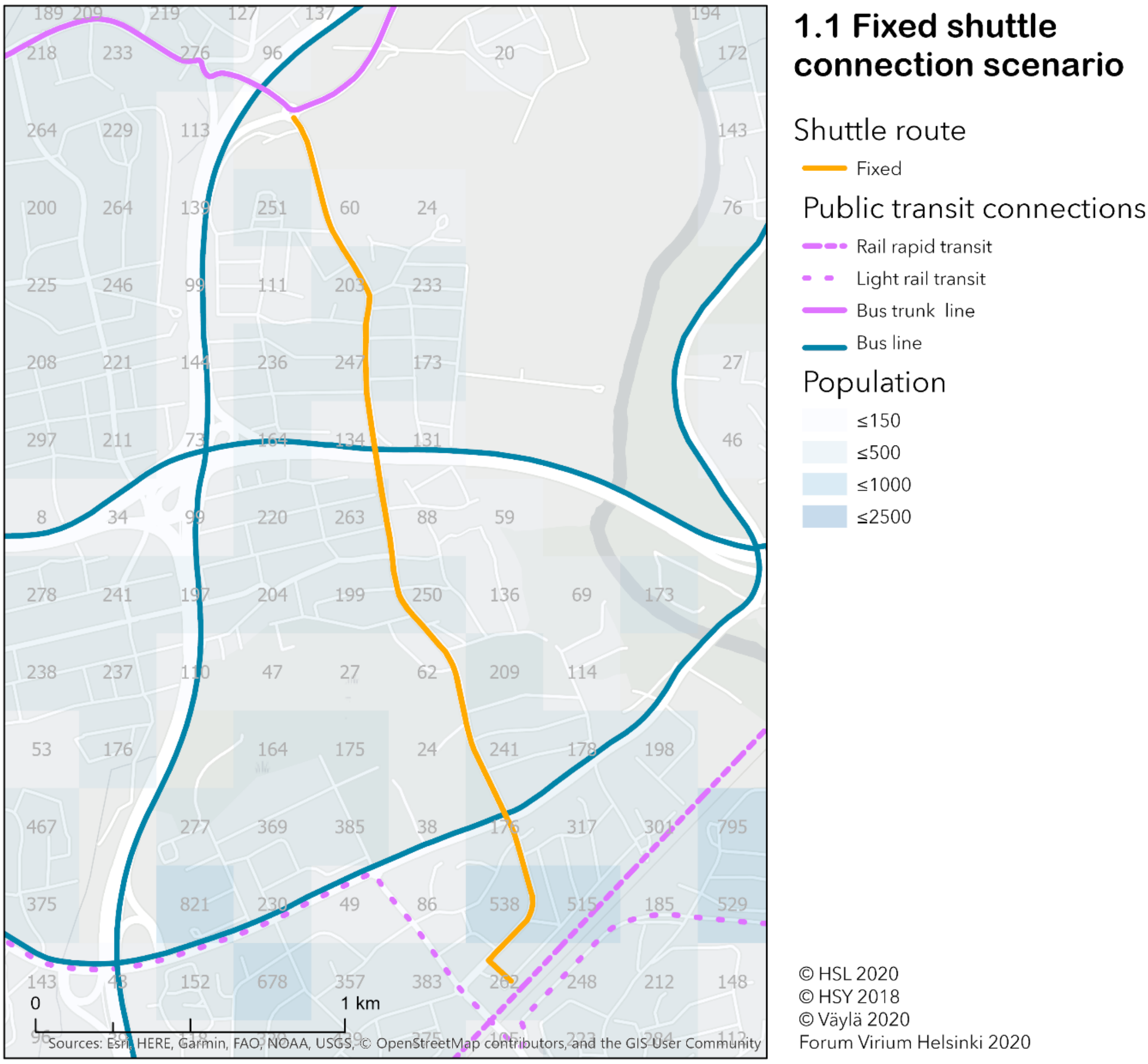
Appendix 3. 1.0 Baseline scenario



A regular (non-automated) city bus line operates on the orange route. The bus line connects a loosely populated suburb, consisting mainly of detached and semi-detached houses, to a train connection, light rail connection, bus trunk line, and multiple regular bus lines. The land use of the area consists predominantly of housing.

- The service frequency is approximately ~10–30 min.
- The line length is 2,8 km (from the end to the intersection of the rail connections)
- The line travel time is ~7 min.
- The speed limit is 40 km/h throughout.
- The space between stops is approximately ~150–350 m.
- Pedestrians and cyclists are structurally separated from the carriageway with a basic kerb in all parts of the route.

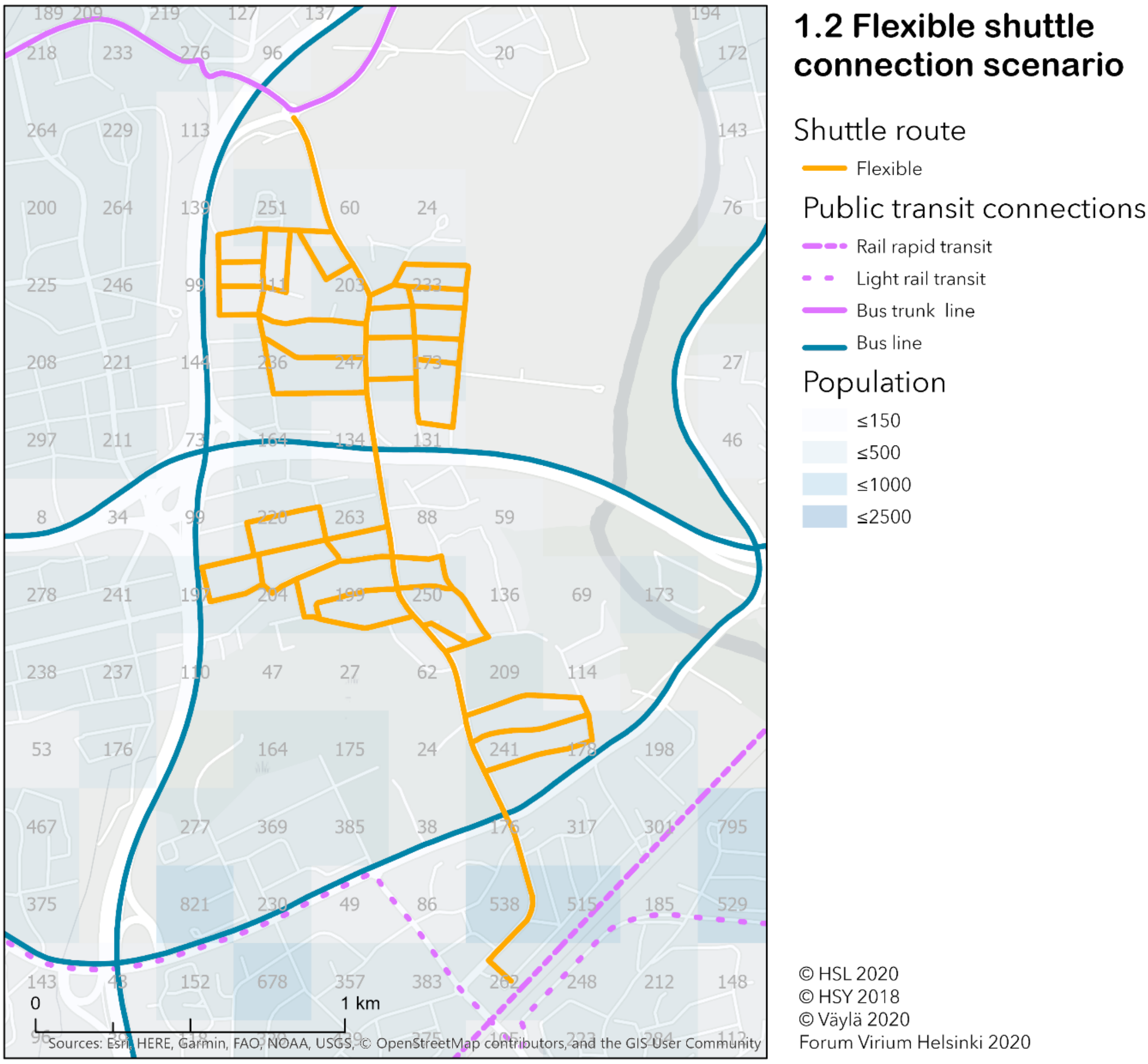
Appendix 4. 1.1 Fixed shuttle connection scenario



The regular bus line is replaced with a shuttle line (yellow), which is operated with four shuttles. A shuttle can be requested to stop with a mobile app, or it can be simply waved down from a bus stop. The shuttle does not stop if it is not requested to do so.

- The service frequency is approximately ~5 min.
- The line length is 2,9 km
- The line travel time is ~7 min.
- The speed limit is 40 km/h throughout.
- The space between stops is approximately ~150–350 m.
- Pedestrians and cyclists are structurally separated from the carriageway with a basic kerb in all parts of the route.

Appendix 5. 1.2 Flexible shuttle connection scenario



The regular bus line is replaced with a flexible shuttle connection (yellow). Four shuttles operate the network at all times according to the demand.

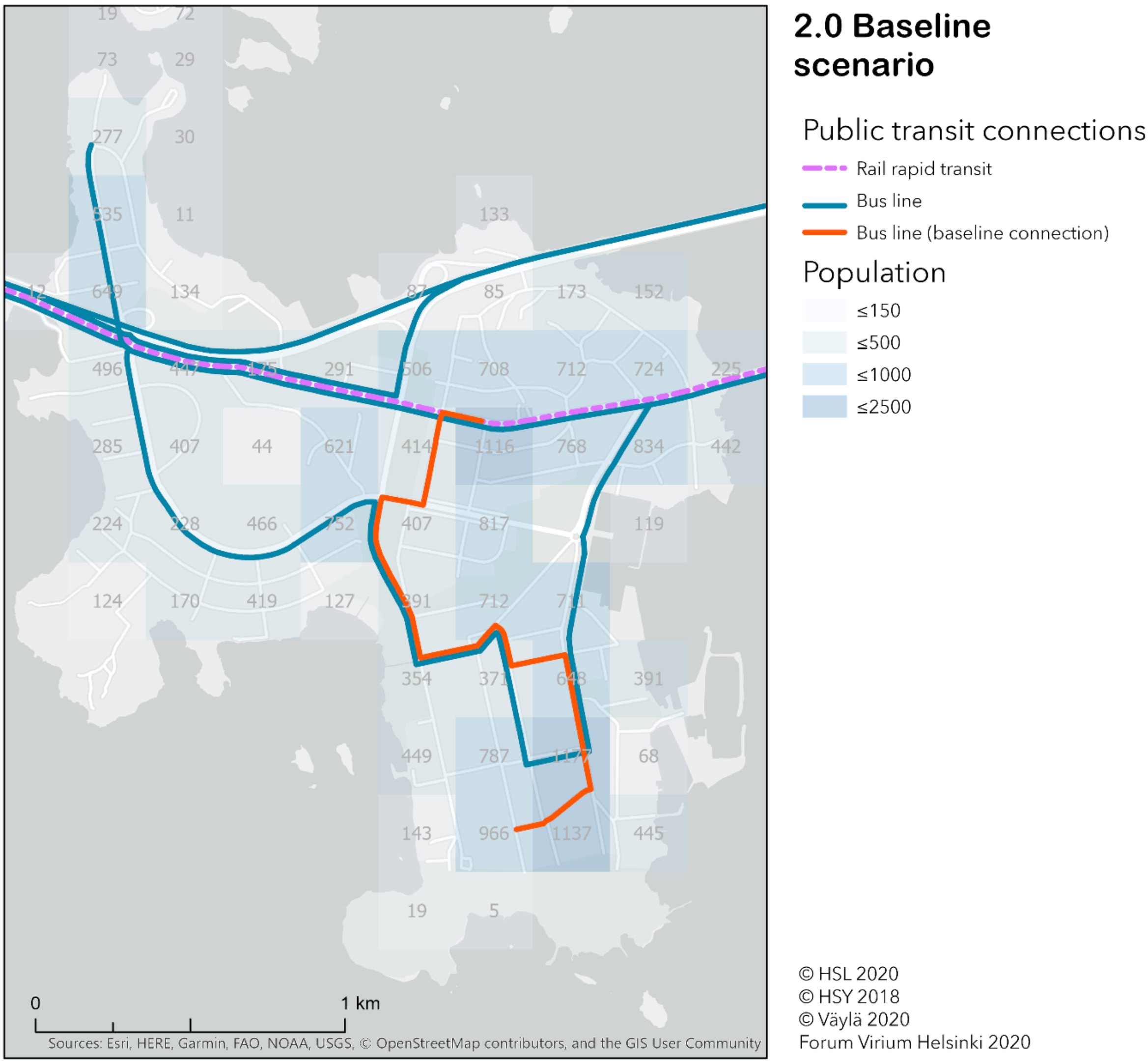
The shuttles do not have a predetermined route or a regular timetable. A shuttle can be requested to a virtual stop with a mobile application. The service does not have physical stops. The application software constantly processes received requests and optimizes a route from one end of the operational area to the other. While in operation, the shuttles will always travel towards one of these ends. They can alter their route sideways, but they will never make a U-turn or travel backward to pick up a passenger. When the full capacity of the service is not required, the shuttles will park themselves or recharge.

The service has virtual stops that are visible in the mobile application.

- The length of the route network is 13,8 km.
- The speed limit varies between 30–40 km/h.
- The space between stops is approximately ~200–300 m.

- Pedestrians and cyclists are not separated from motor vehicle traffic in all parts of the network.

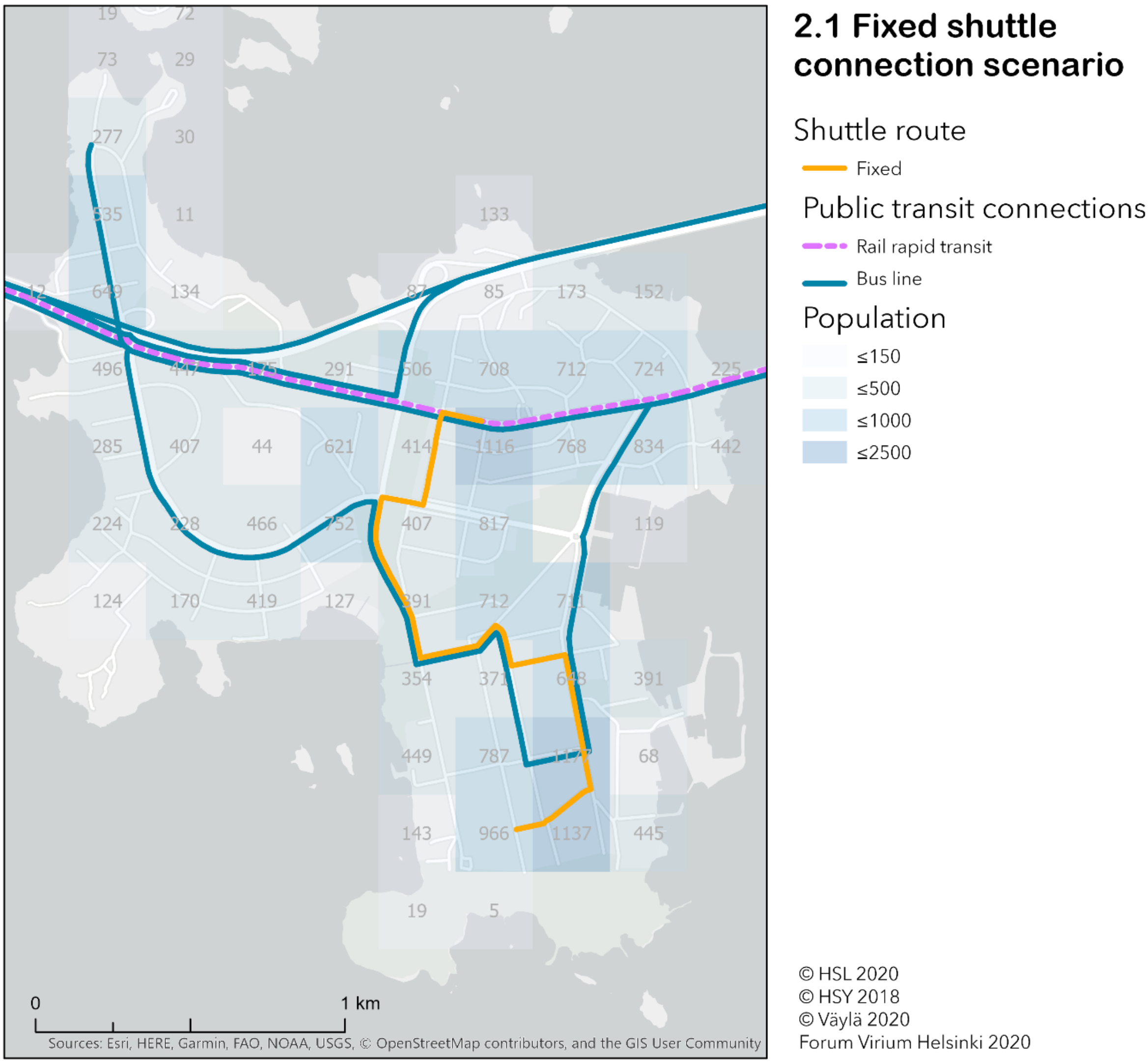
Appendix 6. 2.0 Baseline scenario



A regular (non-automated) city bus line operates on the orange route. The bus line connects a densely populated suburb to the metro and multiple regular bus lines. The land use of the area is diverse and mixed. The area contains housing, retail, brick and mortar shops, restaurants and bars, services, and offices.

- The service frequency is approximately ~15–20 min.
- The line length is 2,4 km.
- The line travel time is ~11 min.
- The speed limit varies between 30–40 km/h.
- The space between stops is approximately ~100–200 m.
- Pedestrians and cyclists are structurally separated from the carriageway with a basic kerb in all parts of the route.

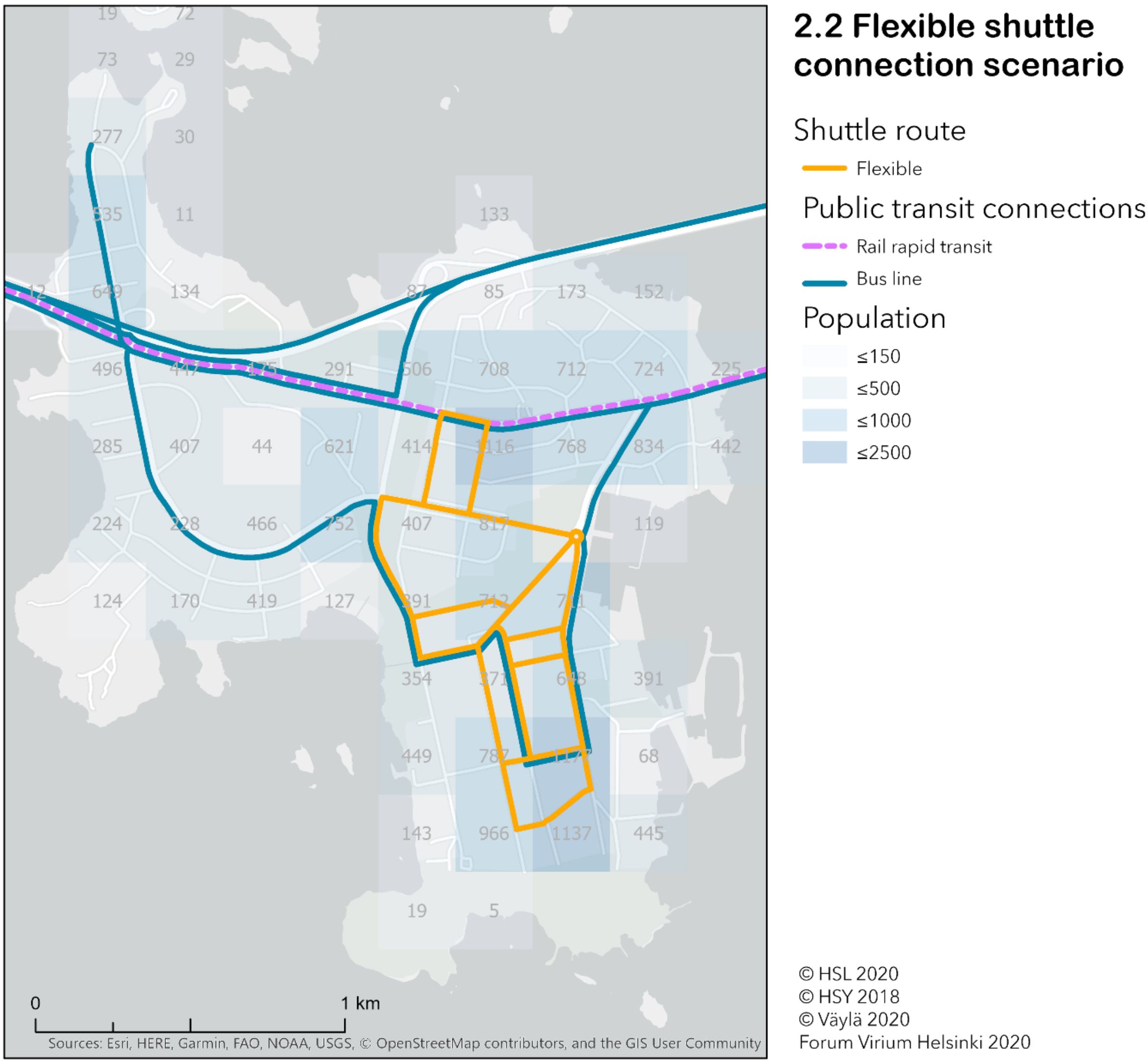
Appendix 7. 2.1 Fixed shuttle connection scenario



The regular bus line is replaced with a shuttle line (yellow), which is operated with four shuttles. A shuttle can be requested to stop with a mobile app, or it can be simply waved down from a bus stop. The shuttle does not stop if it is not requested to do so.

- The service frequency is approximately ~6 min.
- The line length is 2,4 km.
- The line travel time is ~11 min.
- The speed limit varies between 30–40 km/h.
- The space between stops is approximately ~100–200 m.
- Pedestrians and cyclists are structurally separated from the carriageway with a basic kerb in all parts of the route.

Appendix 8. 2.2 Flexible shuttle connection scenario



The regular bus line is replaced with a flexible shuttle connection (yellow). Four shuttles operate the network at all times according to the demand.

The shuttles do not have a predetermined route or a regular timetable. A shuttle can be requested to a virtual stop with a mobile application. The service does not have physical stops. The application software constantly processes received requests and optimizes a route from one end of the operational area to the other. While in operation, the shuttles will always travel towards one of these ends. They can alter their route sideways, but they will never make a U-turn or travel backward to pick up a passenger. When the full capacity of the service is not required, the shuttles will park themselves or recharge.

The service has virtual stops that are visible in the mobile application.

- The length of the route network is 5,8 km.
- The speed limit varies between 30–40 km/h.
- The space between stops is approximately ~100–200 m.

- Pedestrians and cyclists are structurally separated from the carriageway with a basic kerb in all parts of the route.

Appendix 9. Survey

Survey

Welcome to the survey. Please familiarize yourself with the instructions first (attached to the email). If you have trouble answering the survey or understanding the instructions, feel free to call me or to send me an email.

Participants cannot be connected to the answers they give. Individual survey answers are not addressed in the publication. The survey constructor, Janne Olin, is the only person with access to the survey responses. The survey responses will be deleted after the research is completed.

1. Write your first name in the field. This is asked for the purpose of monitoring the responses. *

First name

Pairwise comparison

Choose the value that depicts how important a criterion is compared to the other criterion.

9 = Extreme importance over the other criterion
7 = Very strong importance over the other criterion
5 = Strong importance over the other criterion
3 = Moderate importance over the other criterion
1 = The criteria are equally important

2. Pairwise comparison *

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Environmental effects	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Reliability
Environmental effects	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Resource efficiency
Environmental effects	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Safety
Environmental effects	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Transport system effects
Environmental effects	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Travel experience

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Reliability	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Resource efficiency
Reliability	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Safety
Reliability	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Transport system effects
Reliability	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Travel experience
Resource efficiency	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Safety
Resource efficiency	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Transport system effects
Resource efficiency	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Travel experience
Safety	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Transport system effects
Safety	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Travel experience
Transport system effects	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Travel experience

Scenario evaluation

Score every scenario according to how well it performs with a criterion. Give the scores in relation to the other scenarios. Aim for consistency. It may be helpful to start by scoring a baseline scenario and then using it as a reference point for the other scenarios. The scale is 1–10, where 1 is the worst possible score, and 10 is the best possible score.

3. Environmental effects *

	1	2	3	4	5	6	7	8	9	10
1.0 Baseline	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
1.1 Fixed	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
1.2 Flexible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

	1	2	3	4	5	6	7	8	9	10
2.0 Baseline	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.1 Fixed	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.2. Flexible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

4. Reliability *

	1	2	3	4	5	6	7	8	9	10
1.0 Baseline	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
1.1 Fixed	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
1.2 Flexible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.0 Baseline	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.1 Fixed	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.2. Flexible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

5. Resource efficiency *

	1	2	3	4	5	6	7	8	9	10
1.0 Baseline	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
1.1 Fixed	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
1.2 Flexible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.0 Baseline	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.1 Fixed	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.2. Flexible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

6. Safety *

	1	2	3	4	5	6	7	8	9	10
1.0 Baseline	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
1.1 Fixed	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
1.2 Flexible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2.0 Baseline	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

	1	2	3	4	5	6	7	8	9	10
2.1 Fixed	○	○	○	○	○	○	○	○	○	○
2.2. Flexible	○	○	○	○	○	○	○	○	○	○

7. Transport system effects *

	1	2	3	4	5	6	7	8	9	10
1.0 Baseline	○	○	○	○	○	○	○	○	○	○
1.1 Fixed	○	○	○	○	○	○	○	○	○	○
1.2 Flexible	○	○	○	○	○	○	○	○	○	○
2.0 Baseline	○	○	○	○	○	○	○	○	○	○
2.1 Fixed	○	○	○	○	○	○	○	○	○	○
2.2. Flexible	○	○	○	○	○	○	○	○	○	○

8. Travel experience *

	1	2	3	4	5	6	7	8	9	10
1.0 Baseline	○	○	○	○	○	○	○	○	○	○
1.1 Fixed	○	○	○	○	○	○	○	○	○	○
1.2 Flexible	○	○	○	○	○	○	○	○	○	○
2.0 Baseline	○	○	○	○	○	○	○	○	○	○
2.1 Fixed	○	○	○	○	○	○	○	○	○	○
2.2. Flexible	○	○	○	○	○	○	○	○	○	○

9. What other criteria or subcriteria should a decision-maker consider in order to make a justifiable decision about implementing an automated collective transport service? Leave blank if you think the presented criteria are sufficient.

10. Give feedback about the survey, the interview or the participation process of the research (optional).
