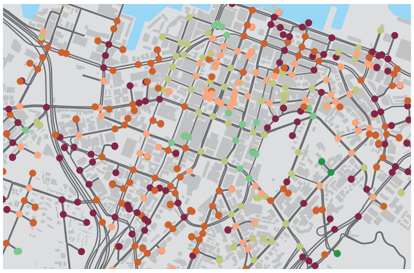
International Transport Forum

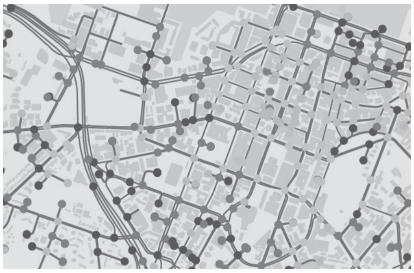
Shared Mobility Simulations for Auckland



Case-Specific Policy Analysis

OECD

Shared Mobility Simulations for Auckland



Case-Specific Policy Analysis

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Case-Specific Policy Analysis Reports

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Executive summary

What we did

Shared mobility refers to optimised transport services that are not individually owned but shared among users. Previous ITF studies have shown that shared mobility services can provide citizens with more flexible, comfortable and easily available alternatives to traditional public transport and encourage the shift from private car use to more sustainable forms of transport.

This report explores how the deployment of shared mobility services could change mobility in Auckland, New Zealand's largest city. The study is based on a simulation model of the more than 4.5 million trips undertaken on an average weekday by 1.3 million inhabitants in the most densely populated part of Auckland region (46% of the area and 90% of the population). The data used in the simulation was provided by New Zealand's Ministry of Transport, Auckland Transport and the Auckland Forecasting Centre.

The model was used to simulate different scenarios in which shared mobility services replaced other forms of travel. The impact of introducing shared mobility was tested using different configurations of these services: Shared Taxis with up to six passengers that provide an on-demand door-to-door service and Taxi-Busses with 8 to 16 seats that offer a street-corner-to-street-corner service and must be booked 30 minutes in advance. In the model, transport supply and demand are matched while detour distances and travel times are minimised. This report provides in-depth analysis for three out of ten scenarios tested for the present (2013 data) and the future (2046). The tested scenarios do not intend to provide an optimal configuration or suggest a pathway to implementation. These scenarios aim to assess the range of outcomes that can be achieved when such a system is implemented.

The simulations provide indicators for the performance of shared modes including service quality, efficiency and cost competitiveness. The model also measures impacts on accessibility, existing public transport, parking space requirements, congestion and emissions. Additionally, the model allows an assessment of the impacts of a driver-based system and a system based on self-driving vehicles. The simulations were complemented by a survey and focus group with citizens of Auckland to investigate the preferences of potential users and identify early adopters, as well as to help tailor shared services and develop strategies for raising awareness and interest in such new services and their benefits.

What we found

If all of today's private car trips were instead provided by shared mobility services, the total distance driven by all vehicles would halve, as would emissions and congestion. Even if only a subset of car users switch to shared mobility services, this can deliver reductions in total kilometres driven and CO_2 emissions of around 15%. CO_2 emissions could be significantly further reduced if the fleet is comprised of electric vehicles.

Shared mobility services could serve as feeders to existing rail, bus rapid transit (BRT) and ferry services in Auckland. Feeding makes the introduction of shared services easier and at the same time increases the use of high-capacity public transport. In the scenario where private cars are fully replaced by shared services, rail ridership grew by a factor of ten compared with 2013 for the same network. In practice, however, an adaptation of the rail station design would be necessary to integrate the specific needs of shared mobility services such as pick-up/drop-off areas for shared vehicles.

Several scenarios tested showed the use of Taxi-Buses with 8 and 16 seats to be inefficient where low density of demand is complemented by slow adoption of shared mobility. Here, these services could be initially provided by a single vehicle type with fewer seats but offering a choice of either street-corner-to-street-corner or door-to-door service with the possibility of real-time booking. As demand grows, the fleet of shared vehicles could be expanded to include 8 and 16 seaters.

The shared mobility scenarios resulted in a drastic improvement in equitable access to opportunities in the Auckland area. A full-scale implementation improved the access to jobs by a factor of more than three. Shared mobility makes jobs and services more easily accessible, especially in areas that currently have a low frequency of public transport services.

The focus group and survey results showed that citizens are not only willing to share vehicles, but favour sharing trips with the highest possible number of people, as long as seating is guaranteed. The potential early adopters of shared mobility services are younger (below 25 years) and older (above 65 years) transport users, as well as citizens who live far from the city centre and are not well served by existing transport services. Cost of the service is the main factor affecting people’s preferences. Shared mobility’s potential role as a feeder to the existing rail, bus rapid transit and ferry services is seen as important.

What we recommend

Consider integrating shared mobility services into Auckland’s existing transport offer

Shared mobility services can provide significant benefits to the Auckland region. On-demand Taxi-Bus and Shared Taxi services could replace private car trips and thus reduce emissions, congestion and the need for parking space. Shared mobility would also result in better access to opportunities for citizens, and make access more equitable for inhabitants of areas not well-connected to public transport. A shift to shared mobility requires the alignment of other policy tools such as pricing, regulation and licensing, concessioning, land-use and infrastructure design.

Use shared services as feeder service for train, ferry and bus rapid transit services to increase use of public transport

Existing public transport can significantly benefit from new shared mobility services if both are properly integrated. Shared mobility services can act as a feeder to high-capacity public transport services and increase passenger numbers for rail, bus rapid transit and ferry services. However, dynamic access policies and improved drop-off/pick-up zones at rail stations and major destinations, such as schools or centres of employment, would be needed. Additional capacity may be required in mass transit modes due to increased frequency, particularly for rail, in order to maintain service levels as ridership increases.

Ensure shared mobility services are provided in a large enough area of Auckland

Reaping the benefits of shared mobility depends on creating the right market conditions and operational frameworks. Specifically, these solutions need to be implemented on a relatively large scale to be effective. Introducing shared mobility services in a small area leads to low vehicle occupancy and high prices. Furthermore, transfers from private cars to shared mobility services or to public transport modes in such scenarios cause high degrees of congestion near the parking lots integrated with public transport stations (park-and-ride stations). Scenarios with fleets of electric vehicles show that larger fleets are required as vehicles need to be more time idle to charge and vehicles with driving range available are not always at the requested location. Moreover, as shared mobility services scale up, the additional fleet requirements compared with combustion engine fleets decrease significantly as the probability of finding a car with sufficient charging level increase in larger fleets.

Target shared mobility services for potential early adopters

Citizens of Auckland under 25 years of age, seniors above 65 years and residents of remote areas have very positive attitudes towards using shared mobility services. An estimated 20% or more of users would likely shift to shared mobility. This share would be sufficient to make the services affordable, supporting their uptake. However, targeted public information campaigns to raise awareness and build acceptance among citizens will be an important success factor.

Integrate land use and transport policies to limit urban sprawl and support the uptake of shared mobility services

Integrated land use and transport policies are a key to the development of the Auckland region. A higher urban density makes the transport system more efficient and supports the adoption of shared mobility by concentrating demand. Auckland’s population density is currently not high enough for efficient use of larger (8- and 16-seat) shared vehicles in scenarios with low adoption. In such cases, a single, smaller shared vehicle type (6-seat) could be tested to offer differentiated services (door-to-door or street-corner-to-street-corner) and real-time booking.

Create a legal and regulatory framework focused on delivering societal benefits from uptake of shared mobility services

Rules for existing taxi or public transport services may not be fully suitable for novel shared mobility services. Innovative regulations may be required, including those related to licensing, minimum service requirements and concessioning. The model for the simulations in this study uses a single dispatcher/operator providing a uniform service and is agnostic with regard to whether the service is supplied by a public or private operator (or operators) under different market rules. In order to provide a stable and predictable market for new shared mobility services, it will be essential to have rules in place that are designed to deliver the desired societal benefits from the new services.

Make sharing of performance data a pre-requisite for licensing shared mobility services

The outcomes described in this study are the result of a plausible but constrained modelling exercise. Real-life introduction of shared mobility services will require continuous monitoring of performance in order to adjust regulations or policies where outcomes diverge from objectives. As a pre-requisite for licensing of shared mobility services, authorities will thus want to ensure that operators provide performance data for agreed metrics.

Introduction

This study examines how optimised sharing of transport services can change the future of mobility in the Auckland region, while promoting public transport integration and preserving non-motorised mobility.

Shared mobility services are at the heart of the sharing economy. The arrival of new types of shared mobility services has gained ground in recent years, especially in urban areas (e.g. Uber, Lyft and Taxify). These services may be precursors to more optimised shared mobility solutions that could deliver a more flexible, comfortable and available public transport (PT) alternative for citizens, encouraging a shift away from private vehicles. The shared modes could fill some market segments or geographical locations where conventional public transport cannot be efficient and avoid dominant private car usage under low occupancy rates and vehicle usage, both in space and time.

New shared modes will likely shape the future of mobility, driven by technological innovations and by authorities' regulations for public space and transport services. However, the conflation of technology with evolving societal trends and new relationships built around the production and consumption of services has been faster than anticipated by many authorities and may outpace the speed of regulatory adjustments. These are real challenges for public authorities and it is likely that the kind of disruptions appearing now only foreshadow even greater ones that may come about in the future. The authorities willing to promote shared modes in an effort to reduce congestion and emissions, improve accessibility, and increase equity may also face a challenge of acceptance of the new transport services by the public, as buyers and voters.

While urban mobility confers a wide range of benefits to society ensuring access to opportunities, it is a source of increasing concern due to its environmental and social impacts, mainly related to the use of private cars (Zegras and Gakenheimer, 2006). The prevalence of private vehicles together with their inefficient use, which is characterised by low occupancy rates, leads to congestion, social exclusion, increase of road accidents, inefficient use of space, and environmental issues such as poor air quality and high carbon dioxide emissions.

The population growth in Auckland has led to increasing urban sprawl and congestion. Auckland is one of the most congested cities in the Australasia region with an average occupancy rate of 1.39 per car trip (Sullivan and O'Fallon, 2003) or in the 2011/2012-2013/2014 Household Travel Survey a value of 1.51 for mean light four-wheeled vehicle occupancy (people/km). The situation is aggravated by a high concentration of commuter trips into the city centre, the existence of low-cost parking, relatively low provision of public transport and the geographical position of Auckland's surrounded by waterways (Austroads, 2016).

The Auckland region has ambitious plans of expanding the public transport network in the coming decades and promoting higher densities in the metropolitan region with more efficient land use (Auckland Transport, 2017a). These plans provide an opportunity to assess how shared mobility services could be integrated into these plans to enhance the efficiency of the regional mobility.

This report assesses the impact of these new services on key performance indicators and may help in guiding the design of the future services and the corresponding regulations to ensure their effective integration into the transport policy. The ITF Shared Mobility Model simulates daily travel for a hypothetical shared mobility system. Previous ITF reports have looked at the potential impacts of new shared urban mobility solutions leveraged by digital connectivity in the city of Lisbon (ITF, 2015; 2017). The results of these simulations, under an assumed large car travel replacement by shared mobility, are extremely promising in terms significantly reducing the required vehicle fleet, emissions and congestion while improving equity of access.

Furthermore, this study assesses how optimised sharing of transport assets can change the future of the city; a combination of qualitative and quantitative approaches is used, which includes a micro-simulation model and a focus group meeting with potential users. Two shared services are proposed: Shared Taxi and Taxi-Bus. They could fully or partially replace current motorised road transport alternatives (car, motorcycle, taxi and bus) and serve as a feeder to the heavy transport modes (rail and ferry). Both kinds of services are on-demand and dynamically dispatched via a centralised dispatching system. Shared Taxi is a door-to-door service provided with a spacious vehicle for up to six people, circulating in real-time, with optimised trajectories, and small detours for boarding and alighting the passengers. Taxi-Bus is a street-corner-to-street-corner service that requires 30-minutes advanced reservation and provides transfer-less trips in a minibus of 8-16 people along dynamically defined routes.

The focus group meeting consisted of a discussion and a stated preference survey, which help to investigate the Auckland transport users' preferences regarding the proposed shared modes compared with the existing urban and sub-urban transport options. It includes identifying and quantifying the most important attributes of the new modes and socio-demographic characteristics of the users that influence mode choice. This, in turn, allows for identifying the potential early adopters of the new services, to design new modes that are more tailored to the potential users' needs to ensure the desired modal shift, and to develop better strategies for raising awareness of the targeted market segments on the new alternatives and their individual and societal benefits.

The micro-simulation model reproduces the daily mobility patterns and the interactions between the users and shared mobility modes in a transport network in an urban context. The agent-based simulation manifests itself in a dynamic optimised matching of demand and supply under minimal detour distances and travel times constraints. The model allows for the exploration of different transport scenarios that preserve the behavioural preferences of the citizens of today. This provides insights for understanding how the potential new modes will perform in terms of quality of service, productive efficiency and cost competitiveness; and their potential impact on mobility, accessibility, environment and public space use in the study area of Auckland.

The scenarios tested include full-adoption and partial-adoption scenarios. In the former, the existing motorised transport alternatives (private car and buses) are completely substituted with new shared mobility services. In partial-adoption scenarios, only certain trips by motorised modes are substituted and conditioned by the origin and destination, time of day, mode, and by the value of the utility of different modes for a given transport user. The partial-adoption scenarios allow for investigating the impact of graduate deployment of the services.

Deployment of shared mobility services is tested both for the current situation (base year 2013) and for the future projection (year 2046). The future scenarios are modelled based on the population and employment projections and on planned changes in the road and public transport networks. The future scenarios provide important insight for the long-term planning on the performance of the transport system with and without shared mobility services.

Modelling framework and shared modes specification

Project outline

The ITF shared mobility modelling framework is developed upon five main building blocks and study stages as presented in Figure 1. The first building block addresses the characterisation of the study area. This characterisation englobes the spatial definition of the study area and its definition in terms of land-use characteristics; the definitions of available transport infrastructure and services (road network and public transport services), and the resulting transport performance by spatial division (grid) origin-destination (OD) pair and transport mode; and the analysis of mobility using the Household Travel Survey (2011/2012-2013/2014). All these elements are discussed in in the section "Characterisation of the study area".

All the data from the first building block is used to estimate a revealed preferences mode choice model as the final input to create a synthetic mobility dataset. The synthetic population and its socio-demographic characteristics are generated based on census data (2013) and the Household Travel Survey (2011/2012-2013/2014), expanded to the total population, by generating synthetic households' compositions with similar mobility profiles to the sampled in the Household Travel Survey. The trip patterns of each representative of the synthetic population and their spatial distribution are obtained based on the travel survey containing revealed preference data. The model generates the mobility of these individuals constrained to their generated residential location, land-use distribution in the study area, and the transportation network performance for the generated transport mode, estimated from the probabilities derived from a estimated revealed transport mode choice model. The development of this stage is described in the section "Modelling current travel demand" (for the present [2013]) and "Modelling transport supply and demand in 2046".

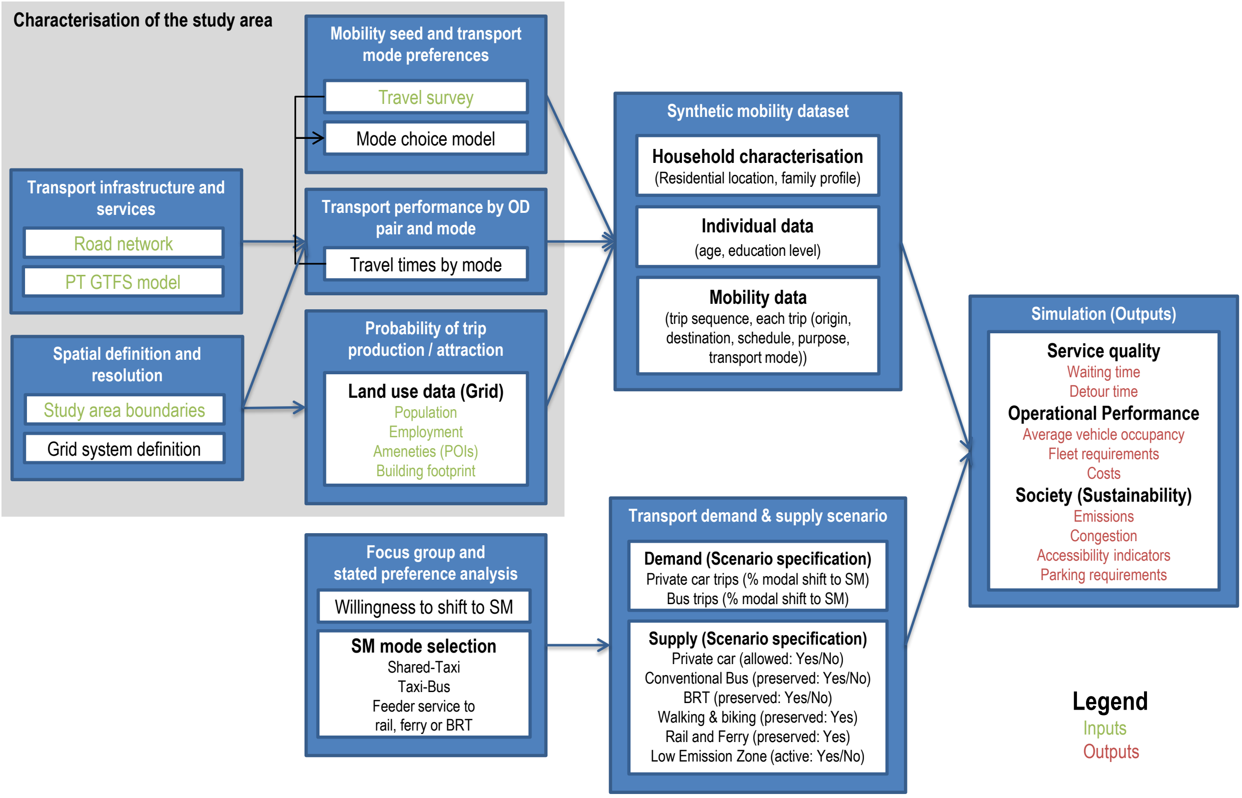
The next stage of the study is the collection of information regarding the city citizens' willingness to adopt shared mobility (described in the section "Potential users of shared mobility"). To identify the local transport users' preferences in the scenarios with presence of the shared modes, ITF and the city partners organised focus groups with potential users. The focus groups included a discussion and a web-based revealed and stated preference survey. It allowed for identifying and quantifying the most important attributes of the shared modes and social-demographic characteristics of the users' influencing mode choice, as well as the calibration of a new mode choice model. Additional survey respondents, who did not participate in the focus group discussions, enabled us to explore how conveying the information regarding the new modes affects mode choice preferences. The collected information is used to identify the market segments of early adopters and rank the willingness of current private motorised transport (car, motorcycle or taxi) and bus users to switch to shared mobility solutions. Furthermore, the results are also used to forecast, in case of adoption of shared modes, the most plausible mode for each trip.

After analysing the focus group results, in dialogue with the Ministry of Transport of New Zealand and Auckland Transport, a set of transport supply scenarios were selected with potentially different adoption levels of private car and bus users (a total of ten scenarios). These scenarios are described in detail in the section "Setting the shared mobility scenarios".

The synthetic mobility dataset and the different transport demand and supply scenarios are then tested in the ITF shared mobility simulation model. The outputs for each tested scenario include measures of the service quality, the operation performance and the sustainability analysis. These results are discussed for the present (2013) and for the future (2046) in the section “Impact of shared mobility”.

This section presents a detailed description of the simulation model and shared modes specifications. For more detailed information on the modelling framework, data sources and other assumptions/parameters, see *Shared Mobility Solutions for Cities: Modelling Framework* (ITF, forthcoming).

Figure 1. **Shared mobility modelling framework**



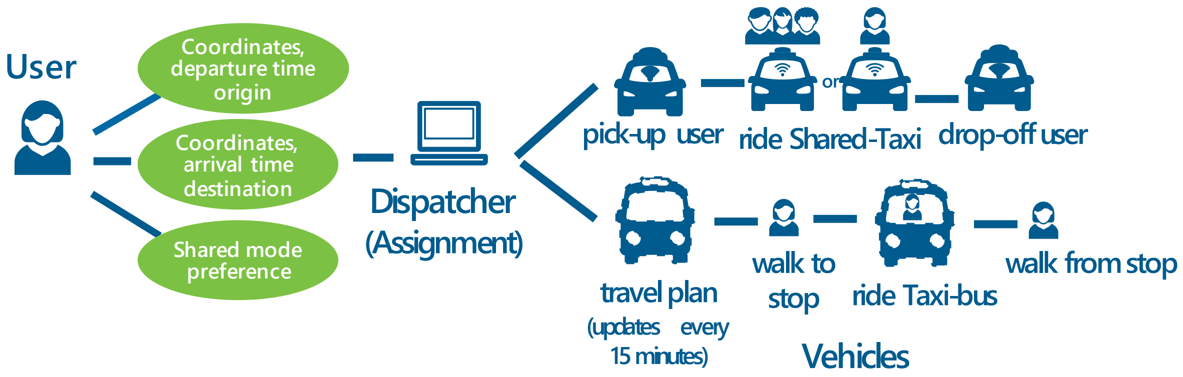
Notes: PT- Public Transport; OD – Origin-Destination; SM – Shared Mobility.

ITF shared mobility simulation model

The core of the modelling framework is an agent-based simulation model. The model has three main agents interacting in a common environment: users, vehicles and a dispatcher (see Figure 2). It reproduces the daily mobility patterns in the study area for the synthetic population, matches demand and supply, and saves the trip logs for the estimation of performance indicators. Two types of shared services are considered: a door-to-door Shared Taxi and an on-demand bus-like system designated Taxi-Bus.

In the simulation environment a trip is generated when a user (or a party of users) requests a service. The mode is then assigned to the user based on the calculated mode choice probabilities. Then a dispatcher matches the demand with the transport supply. If the user prefers a Taxi-Bus, they need to order the service 30 minutes in advance with information about the desired trip (location of origin/destination and desired departure time). In the case of Shared Taxis, the system can generate a new route with the recent demand, or allocate the clients to vehicles already under operation, or re-assign this request to the Shared Taxi service. More specifically, the dispatcher finds the best match in Taxi-Bus service that warrants at least 50% occupancy (at least for some part of the trip) and an average distance-based occupancy rate greater than 25% of the vehicle capacity. If the user requests a Taxi-Bus but there is no designated stop within the acceptable distance and/or there are not enough users to share a bus and meet the minimum occupancy constraints, the user is upgraded to a Shared Taxi (at the price of a Taxi-Bus).

Figure 2. **Relation between agents in the simulation model**



Shared Taxi requests are handled in real time. The dispatcher analyses each request and provides the user with the pick-up time, the vehicle licence plate, how many clients will share the vehicle and if she/he should cross the street to reduce waiting time. The model takes into account a distance-minimisation principle that applies not just to the requesting user but also to those already under way in the same vehicle. The dispatcher runs a local search algorithm that tries to minimise the additional travel distance generated by the new client complying with the users' constraints (waiting time and detour time).The resulting trips have waiting time, detour time and arrival time within the model constraints, which are calculated based on the current trip characteristics with some variations within pre-set tolerances.

The obtained flows are attributed to each link of the road network though a dynamic traffic assignment procedure that updates travel time based on volume-capacity ratio for every five simulated minutes. The study area is divided into a homogeneous grid of 500 metre x 500 metre cells with an additional segmentation of 200 m x 200 m central city area (CCA). The origins and destinations of the generated trips are linked to the closest road network nodes.

The dispatcher defines a set of rules for matching cars to users, centralising all real-time information required to produce and monitor these trips. The choice of which car or minibus to match with a user's request takes into account a time-minimisation principle that applies not just to the requesting user but also to those already under way in the same vehicle. The dispatcher also controls the vehicle movements when idle, ensuring efficient vehicle movements to stations and calculating the additional fleet requirements. Whenever the car is not dispatched to a new trip, it returns to the nearest station (depot) and stays there while idle. Taxi-Buses relocate from the last performed service to a departure stop of the next generated route. The Shared Taxi depots and Taxi-Bus departure stops are set across the city at predefined locations. Positioning of the Taxi-Bus stops is constrained by a minimum distance between stops (400 m) and the selection of the road node with greater connectivity in the neighbouring area, in order to ensure flexible routing for the vehicles, e.g. by avoiding streets with traffic only in one direction or right-turning blocking (as in New Zealand where driving is on the left-hand side of the road).

Once the users' trip is finished, the agent representing the user leaves the simulation system and indicators are generated in a trip log so that they can be used for ex-post system evaluation. The model produces detailed information regarding the origin and destinations of each trip, the party on-board (for members of the same household or people sharing a vehicle), arrival and departure time, waiting and access time, travel time, transfers, and associated costs. The model relies on an app-based wire payment method with no cash transactions, to allow easier, safer and faster pick-up and drop-off of clients.

The simulation allows for testing the system operation either with drivers, constrained by working regulations, or by self-driving vehicles that do not need to relocate to operate the changes of shifts of drivers and different cost estimations.

The simulation model provides detailed outputs from the resulting mobility throughout the day for each mobility scenario tested. These include passenger-kilometres (pkm), vehicle-kilometres (vkm) by mode, operational performance (fleet requirement, routes operated, occupation levels by mode, estimated costs), client satisfaction (travel time, waiting time, detour time, average number of passengers on-board by time of the day and mode) and environmental performance (CO_2 emissions). Adoption of electric fleets and their charging requirements are also included as a parameter in the model.

Shared modes specification

Two shared transport services, Shared Taxi and Taxi-Bus, are used to assess the impact of shared mobility services. The new modes can fully or partially replace current motorised modes and serve as a feeder to the existing bus rapid transit (BRT), ferry and rail lines. Shared Taxi is an on-demand door-to-door service with up to six people sharing the vehicle (see Figure 3). It can be booked in real time and moves along dynamically optimised trajectories with detours and travel times matching the pre-set constraints. Taxi-Bus is a street-corner-to-street-corner service in a mini-bus of up to 8 or 16 people (see Figure 4) with at least 30-minutes advanced reservation time. Taxi-Bus also moves along dynamically optimised routes between designated stops. Both shared services offer either direct transfer-less trips or deliver the user to a heavy public transport station (rail or ferry) if the latter connects to the destination without transfers. Table 1 shows the shared services characteristics, which were designed in order to provide modes more comparable with private car, including more flexibility, comfort and availability compared to the existing public bus system, and more affordable than conventional taxi services. Some of the values presented in Table 1 were used as a starting point for the focus group discussion (presented in the section "Potential users of shared mobility") and were subject to further adjustments based on the focus group results.

The feeder service is specified as a pre-booking system with the booking rules and walk access constraints of Taxi-Bus. The feeder services serve high-capacity public transport trips by BRT, rail and ferry. In the case of BRT and rail, these are trips for which one station is within walking distance from either origin or destination. This means that the entire trip would have one transfer and include two legs: the one by a shared mode serving only one end of the trip and the one by BRT or rail. An origin-destination (OD) pair poorly served at both ends leads to a direct Taxi-Bus or a Shared Taxi service. In the case of ferry, the feeder is allowed on both ends of a trip, trying to get clients that require good public transport connection between Waiheke Island and the rest of the study area.

Table 1. **Specifications for proposed services**

Mode	Booking	Access time	Max. waiting time (depending on distance)	Max. total time loss (depending on distance)	Vehicle type
Shared Taxi	Real time	Door-to-door	5 minutes (≤ 3 km), up to 10 minutes (≥ 12 km)	Detour time + waiting time, from 7 minutes (≤3 km), up to 15 minutes (≥12 km)	Minivan of 8 seats rearranged for 6 seats, with easy entry/exit
Taxi-Bus	30 minutes in advance	Boarding and alighting up to 400 m away from door, at points designated in real time	Tolerance of 10 minutes from preferred boarding time	Minimum linear speed from origin to destination (15 km/h)	Minibuses with 8 and 16 seats. No standing places

Figure 3. **Example of Shared Taxi vehicle**

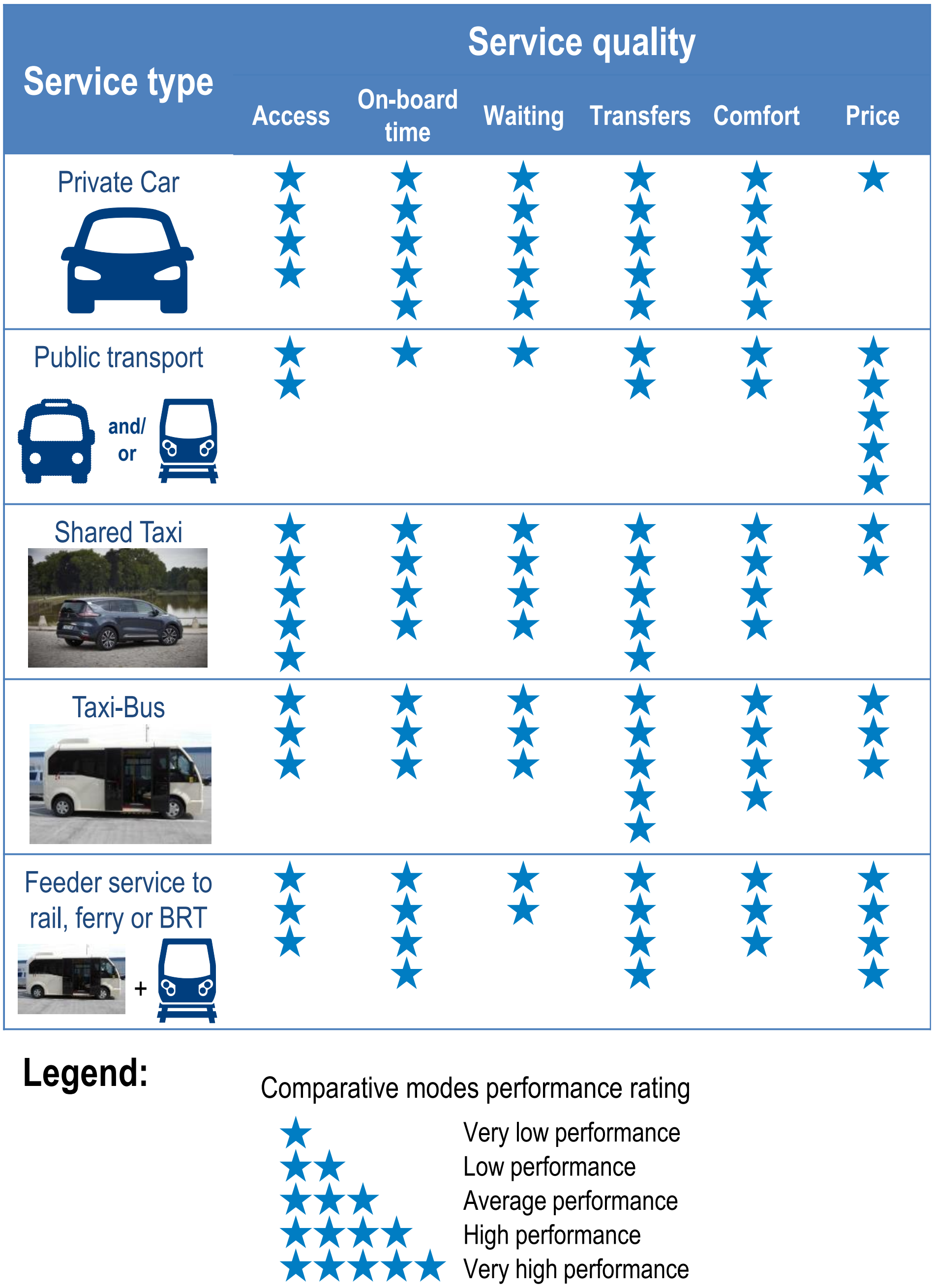
Source: Saud Al-Olayan (2017).

Figure 4. **Example of Taxi-Bus vehicle**

Source: TTC 9701 (2015).

Figure 5 presents a qualitative comparison of the transport modes considered in the simulation; it compares the various performance attributes among the modes, highlighting the differences that will lead to either market segmentation or change of performance when compared with currently available transport services. Shared Taxi clearly presents a performance profile similar to private car, while Taxi-Bus and feeder services try to preserve the good features of current public transport (e.g. price) and enhance the ones that deteriorate the quality of service (e.g. on-board time, waiting time and transfers).

Figure 5. **Qualitative comparison of transport modes**



Service type	Service quality					
	Access	On-board time	Waiting	Transfers	Comfort	Price
Private Car	★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★
Public transport and/or	★★	★	★	★★	★★	★★★★★
Shared Taxi	★★★★★	★★★★	★★★★	★★★★★	★★★★	★★
Taxi-Bus	★★★	★★★	★★★	★★★★★	★★★★	★★★
Feeder service to rail, ferry or BRT +	★★★	★★★★	★★	★★★★	★★★	★★★★

Legend:

Comparative modes performance rating

★	Very low performance
★★	Low performance
★★★	Average performance
★★★★	High performance
★★★★★	Very high performance

The configuration of shared services and their interaction with public transport systems is completely flexible and reconfigurable. The tested solutions do not intend to be prescriptive of what can emerge in the market or is organised by public transport authorities, but assess the potential of such like solutions that have been emerging in the market (Shared Taxi – e.g. UberPOOL and Lyft Line; Taxi-Bus in Kutsuplus, Finland; and BRIDJ in the United States of America).

Characterisation of the study area

The study area covers the Auckland Metropolitan Area and some adjacent areas which are relatively densely populated or are projected to have high population growth in the future. The modelled area has about 2 233 km^2 out of the 4 894 km^2 of the Auckland region, of which 986.32 km^2 have population and/or employment. The current population of the modelled area is 1.3 million inhabitants in 2013 (out of 1.44 of the Auckland region Census 2013 population) with projected growth up to 2.3 million by the year 2046. Figure 6 and Figure 7 show the distribution of current population and employment in this region.

Inside the area around 4.9 million trips take place on an average work day in 2013, 1.39 million (28% of the whole day) take place during the morning peak period (6 am to 10 am) and 1.35 million during the afternoon peak (27% of the whole day). The great majority of the trips are made by a private car (86%), followed by walking (9%) and public transport (4%) (see Table 2). Cycling trips grow annually by 10% (Auckland Council, 2014) but remain insignificant as cycling is not a viable option for many people. In many cases cycling is not viable due to the geography, long commuting distances and the lack of thorough cycleway network to induce demand. This fact may change in coming years (Chowdhury and Costello, 2016).

Table 2. **Mode share distribution based on the total number of trips in the Auckland Metropolitan Area, 2013 (%)**

Walking	Car	Rail	Bus	Ferry	Car + PT	Taxi	Cycling
9.1	85.8	0.3	3.5	0.1	0.4	0.4	0.4

Source: Computed by ITF based on the Household Travel Survey (2011/2012-2013/2014).

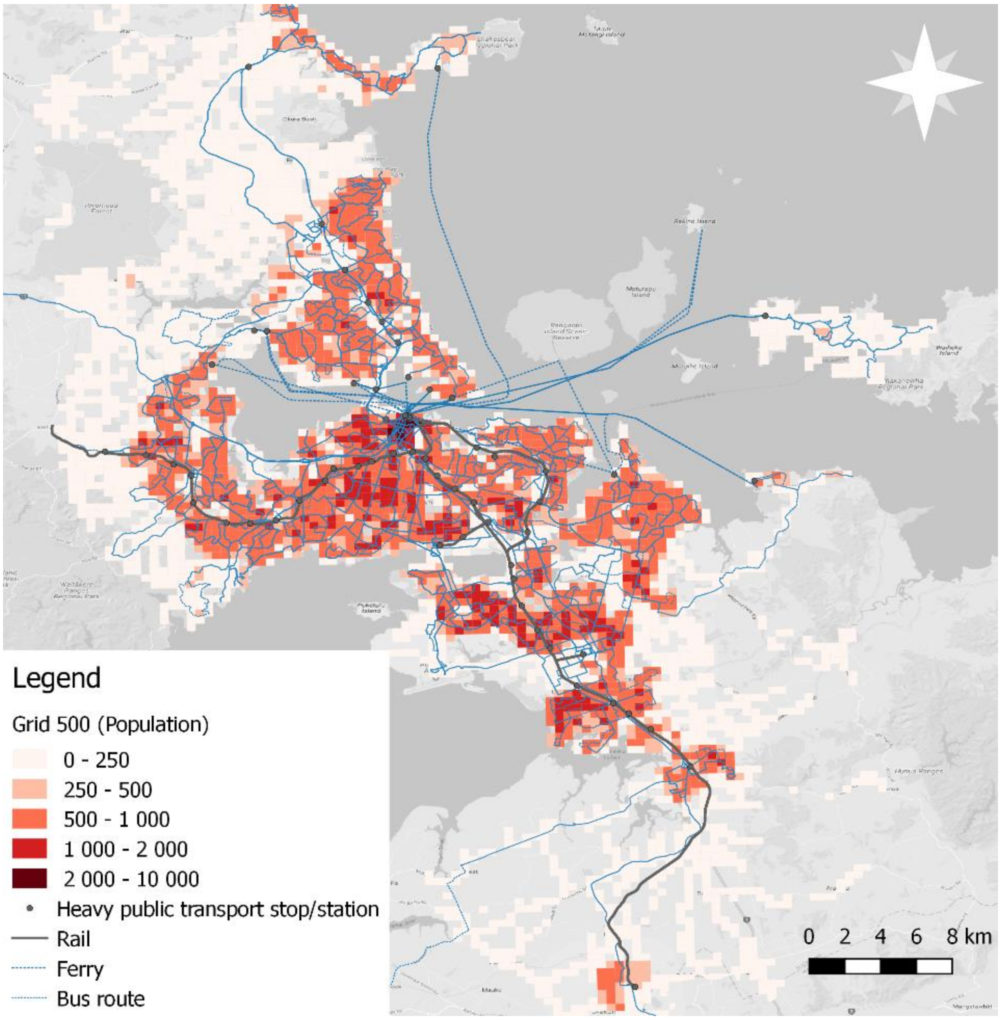
Public transport modes in Auckland include bus (including BRT), rail and ferry. Since Auckland's deregulation of public transport in 1989, privately-owned bus companies contracted by Auckland Transport provide the bus services. Most of the bus-routes are very complex, indirect and radial, aiming to cover the greatest amount of the population and discourage transfers (Imran, 2014). A single high-frequency BRT line has been operating since 2008 along five stations in a direct corridor between the central business district (CBD) and North Auckland, with 2.3 million passengers per year (2013). Part of the route goes along a dedicated busway, while outside buses are subject to road traffic conditions (crossing the Auckland Harbour Bridge). Yet, a trip with BRT takes much less time than car travel along the same corridor.

Rail network covers four suburban lines. The frequency and punctuality of the lines has improved significantly and many stations were upgraded. Also, since 2015 most of the rail infrastructure has been electrified substituting the aging diesel-based fleet. Finally, ferries provide nearly hourly services within the region in the harbour area and the Waiheke Island. Using ferries allows commuters to avoid congested bridges. Ferry services for smaller islands are more focused on leisure trips.

The public transport share is growing: PT boardings grew by 6.9% in 2016 over the previous year in 2015, with an increase in every mode (Auckland Transport, 2017b). Yet, private car remains a dominant mode and the city is the poorest road network performer for its size in the Australasia region, according to a recent report (Austroads, 2016). The report states that the poor performance of the existing transport system includes the highest travel time delay due to congestion and peak hours' unreliability (10-12%). The average speed is 77.6 km/h on motorways, while the lowest speed is measured along the St Lukes Road (22 km/h). Journeys during the peak hour increase travel time by 16.5% on average. The total cost of congestion is estimated between NZD 0.9 – 1.3 billion (New Zealand dollar) (Leung, Destremau, Pambudi, and Bealing, 2017). In order to arrive on time at their destination in 90% of the trips, road users need to budget 45% additional time during the afternoon peak-hours. Road infrastructure has not been growing at the pace of demand growth, and the population and vehicle-kilometres travelled have grown five times faster.

The population distribution of the study area presented in Figure 6 shows that the population is quite evenly distributed throughout the study area, although it presents some stronger concentrations around the CBD and the south-east region. This population distribution results from the land-use patterns and residential predominance of single-family detached housing, which results in low residential densities and some urban sprawl.

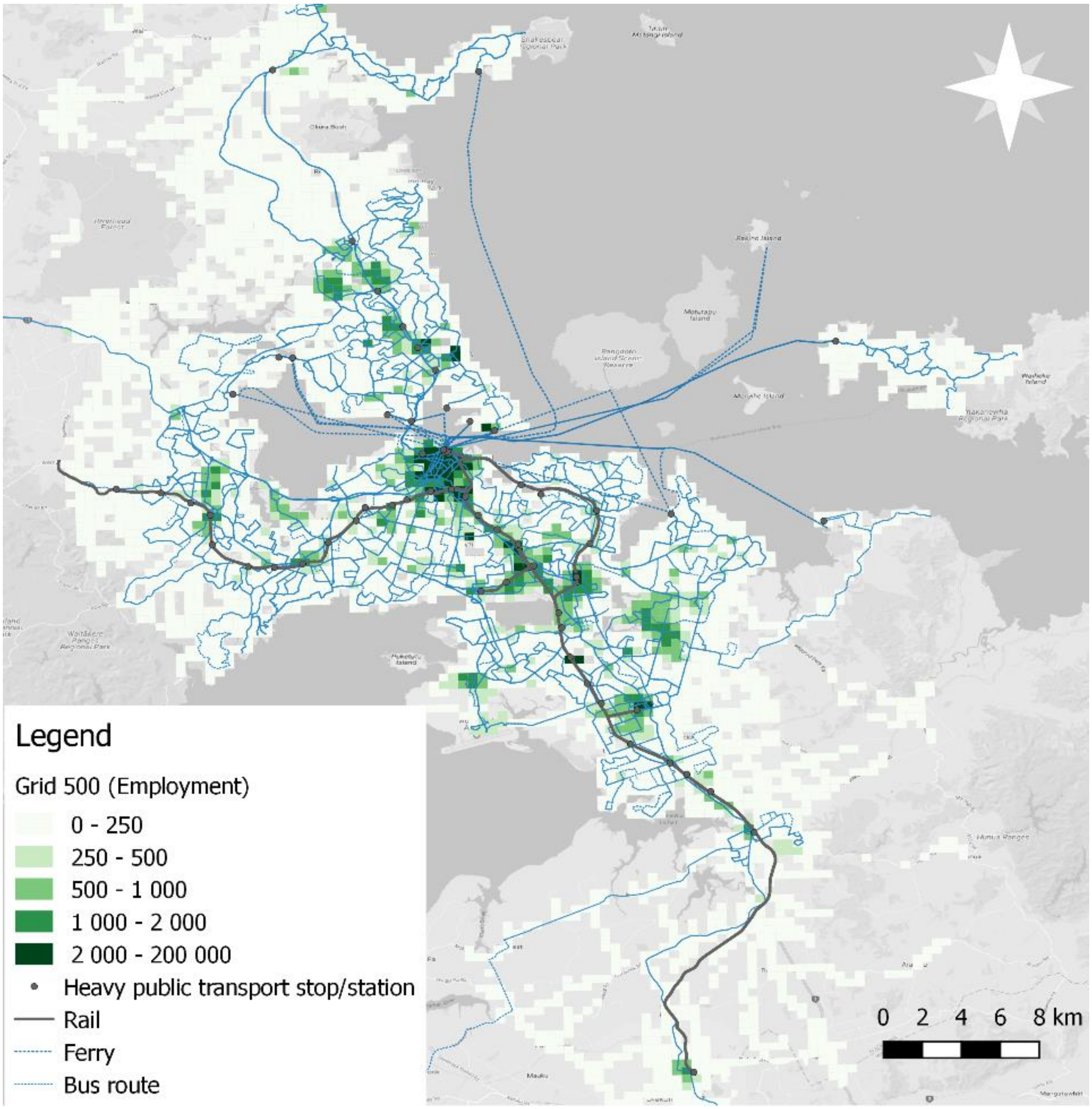
Figure 6. **Population distribution, 2013**



Source: New Zealand Census 2013; ITF, Map tiles by QGIS.

Besides a comparatively low level of public transport, Auckland's geography with its harbours and peninsulas (Devonport/Te Atatu/Whangaparoa), constrains the transport system to narrow corridors along bridges or ferry routes and contributes to the congestion. This is accentuated by many commuters' trips with destination concentrated in the CBD and by motorways often being used for short-distance trips. Additionally, the CBD provides substantial public car parking - a trend started in the 1960s. Availability of cheap and easily accessible parking makes driving a car attractive and impedes overcoming the inertia of using private cars by the citizens (Austroads, 2016). Another relevant factor is the historical existence of multiple dense employment areas in the region as presented in Figure 7, decreasing the public transport provision efficiency, enlarging commuting distances and favouring private car use.

Figure 7. **Employment distribution, 2013**



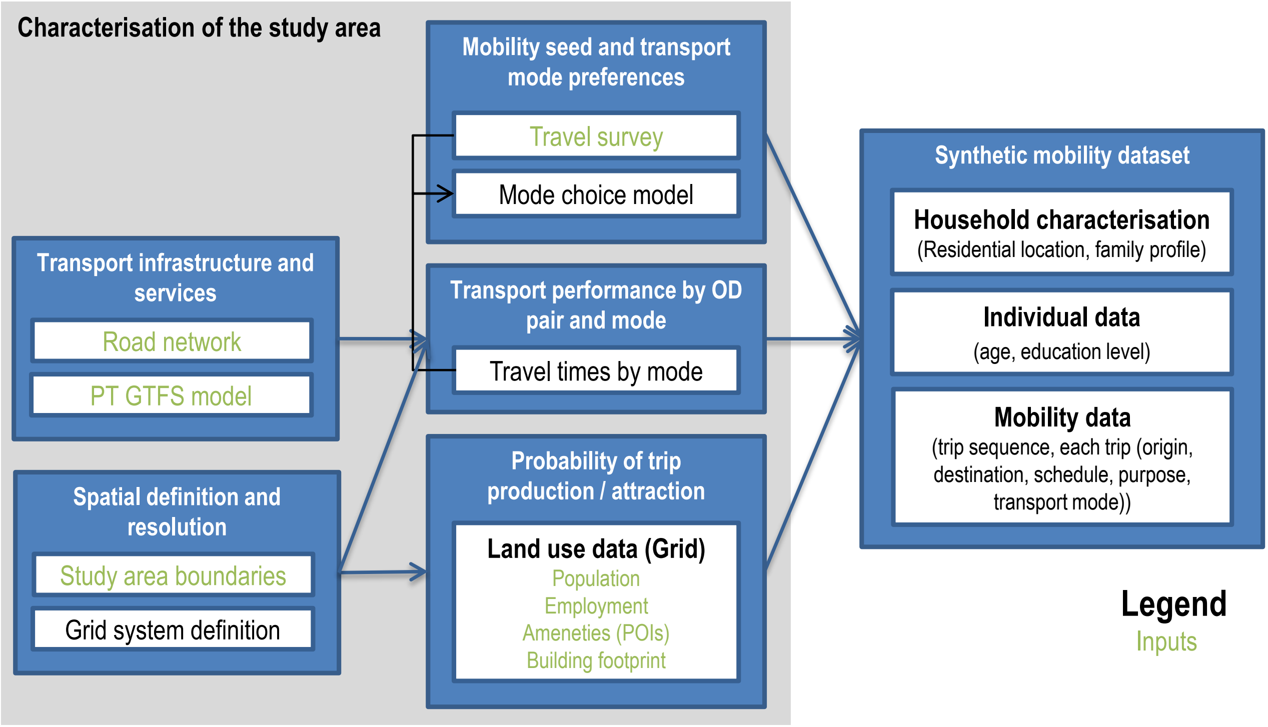
Source: New Zealand Census 2013; ITF, Map tiles by QGIS.

Modelling current travel demand

In order to accurately assess the impacts delivered by the new shared modes, it is first necessary to model, in the most detailed manner possible, the current mobility for the area. To do this, "synthetic mobility sets" are generated (also designated as "synthetic population"). These sets reproduce the entire personal mobility for an average work day in the region. The synthetic population is represented by the socio-demographic characteristics of each individual, household composition and by their travel patterns based on the travel survey containing revealed preference data, and expanded to the total population. The modes used for the trips are defined based on the probabilities derived from an estimated mode choice model.

This section presents the major steps of modelling the current travel demand, which include preparation of the inputs, the mode choice model assumptions and results estimated from the revealed preferences of the Household Travel Survey, and the application to the generation of the synthetic population. The section also compares the results with the travel survey data. Figure 8 presents a connection between the different data sources and the final travel demand.

Figure 8. **Procedures to model travel demand (current and future)**



Notes: PT- Public Transport; OD – Origin-Destination; SM – Shared Mobility.

Model inputs

The preparation of the inputs for the mode choice model and for the generation of the synthetic population included the following steps:

- spatial division of the area and assigning of the travel survey, census and land-use data to the spatial units
- defining the travel survey respondents to represent the population and the travel modes to be included in the model
- defining available travel modes for each respondent; calculation of the attributes of each available mode (travel time, travel cost etc.), and computation of the shortest path for each mode based on the total travel time.

To accommodate the spatial distribution of the trips in the model, the study area was divided into a homogeneous grid of 500 m x 500 m cells with an additional segmentation of 200 m x 200 m for the central city area (CCA). As a result, the study area is covered with 3 949 cells of 500 m x 500 m while the CCA is covered with 3 107 cells of 200 m x 200 m. The obtained grids were used to link the residential and the employment data, and the origins and destinations of the trips of the synthetic population.

For modelling the current mobility situation in Auckland, available travel survey data were used for years 2011/2012-2013/2014. Some responses were excluded from the data used for the mode choice model calibration in order not to bias the model results. After the exclusion, 25 375 responses (out of the initial 32 864) were kept and used in the mode choice model calibration. Answers from certain respondents were excluded:

- Respondents younger than 18 and older than 65, who are assumed not to be decision-makers for the mode choice. These respondents are included into the synthetic population but not to the choice model calibration since their travel patterns and mode choices could depend on other members of the same household, or not have car as an alternative mode.
- Car passengers were excluded from the mode choice model as they are not faced with the cost trade-off. These respondents are preserved in the synthetic population trips. People who did not chose driving car for the trips reported in the survey and/or had missing information about their driving license have been excluded as well.
- Respondents residing outside of the study area were excluded from both the synthetic population and the choice model input data.
- The trips which started and/or ended outside of the study area have been excluded from both the synthetic population and the choice model input data (2 078 trips).
- The trips whereby the reported mode choice violated the choice availability constraints presented below.

The list of the modes considered for representation of the current mobility includes the soft modes (walking and cycling), private car, taxi and public transport modes (bus, ferry and rail). Multimodal trips are aggregated into a single trip for which a rule-based main mode is defined depending on the constituting trip legs in the following way:

- walking (if all the trip legs are walking)
- cycling (if all the trip legs are cycling)
- private car (car/motorcycle driver or passenger, if there are no public transport [PT] trip legs)

- train (if train was used and no private car trip legs)
- ferry (if ferry was used and no train or private car trip legs)
- bus (if only bus was used for PT trip legs and no private car trip legs)
- car + PT (if both private transport and PT heavy modes (rail and ferry) were used during the trip)
- taxi (if only taxi was used or if the distance by taxi was longer in a combination of taxi and car).

Trips containing trip legs by plane and “other” modes have been dismissed. External sources through traffic and visitors were not accounted as model demand. Walking to/from a public transport stop represents “access” and “egress” correspondingly. Private car is also an option for access, and the return trip is assumed to be symmetric.

The General Transit Feed Specification (GTFS) files for the study area are the main inputs for defining the mode choice sets (that is, the available modes), and calculation of the modes’ attributes. For each trip the mode choice set was formed based on the following rules:

- Walking is available if distance between the origin and the destination is not more than 2 km.
- Cycling is available for distances not more than 6 km.
- Taxi is available for distances above 0.5 km.
- The private car mode is not available for those who do not have a driving license.
- The PT modes are available if a route was found such that the person does not have to walk more than 1 000 m to the first PT stop, more than 1 000 m from the last PT stop and more than 250 m between the transfer stops.
- Car + PT is only available if the person has a driving license and for the trips which meet the following criteria: the PT modes are either rail or ferry; the PT distance is not shorter than 1.5 km; the PT part of the trip is without transfers; the walking distance from the PT stop to the destination is less than 1 km.

The shares of respondents for which certain modes are available are presented in the Table 3.

Table 3. **Availability of modes (% of respondents)**

Walking	Cycling	Private car	Taxi	Bus	Ferry	Train	Car + PT
25.9	57.7	93.2	99.3	66.6	1.0	16.7	31.1

Based on the GTFS data and the origin and destination of the trip of each respondent, given the availability of the mode, the shortest path (in terms of total travel time) has been calculated for each mode. With this information, the mode attributes for each trip could be calculated.

For trips with use of a PT mode, aggregated (across the trip legs) characteristics were calculated such as total travel time, in-vehicle travel time, total access and egress time, total travel cost (prices in 2013) and number of transfers. The walking and waiting time were penalised based on data from Balcombe (2004). Each transfer was penalised with additional 12 minutes based on average literature data (Papaioannou, 2017).

For car travel, the shortest paths measured in travel time are calculated between all of the cells in the grid. The speeds of the network used for this calculation resulted from an average congestion level of the network of 50% (resulting from volume divided by hourly capacity for each link). The road network contains information on each link and is the basis for these calculations. The road network has been validated ensuring that all the nodes are connected.

Mode choice model results

A multinomial logit discrete mode choice model was estimated based on the data described above. The model allows for identifying the drivers for the mode choice, including trip attributes and socio-demographic characteristics of individuals that condition their decisions. Table 4 presents the model specification and the estimated results. The variables used aggregate a common model coefficient for in-vehicle travel time and different coefficients for the same variable in other modes. The model fit is very high (rho-squared of 0.813) resulting from the significantly skewed mode selection towards car, which provides a relevant role to the alternative specific constant (ASC).

Table 4. **Estimated model parameters**

Parameter name	Walk	Private car	Train	Bus	Ferry	Car + PT	Taxi	Cycle
Alternative specific constant	2.4500*	4.5300*	0.5330*	0.5870*	2.3900*	-0.61600*	0	-2.2500*
Travel cost (NZD)	-	-0.2240*	-0.2240*	-0.2240*	-0.2240*	-0.2240*	-0.2240*	-
In-vehicle time (min)	-0.0175**	-0.0290*	-0.0175*	-0.0175*	-0.0175*	-0.0175*	-0.0291**	-0.0193**
Access time (min)	-	-	-0.0491*	-0.0491*	-0.0491*	-0.0491*	-	-
Waiting time (min)	-	-	-0.0109*	-0.0109*	-0.0109*	-0.0161*	-	-
Number of transfers	-	-	-0.2040	-0.2040	-0.2040	-0.2040	-	-

- not applicable, * significant at the 95% level; ** significant at the 90% level.

The model calibration results give a value of time for private cars around NZD 7.8 and NZD 4.7 for public transport. These values are aligned with recent studies performed for Auckland, for the general population, normally being significantly higher for commuting trips (Douglas, 2016; Wallis, Rupp, and Alban, 2015). An additional transfer in a public transport connection penalises additional 12 minutes on-board. Public transport users value the access/egress time 2.8 times greater than in-vehicle travel time.

The values of time for Auckland are comparable with Lisbon (EUR 6.05 for private car, EUR 3.26 for public transport and a transfer time penalty of 12.14 minutes) (Martinez and Viegas, 2017).

The model results were validated by comparing the estimated mode choice options with the input survey data used to estimate the model. The results are summarised in Table 5, which presents both the number of people travelling (pax) and the corresponding shares in percent.

The results show a good fit of the model estimates to the data available, both in terms of the pkm and the mode shares. Thus, the model reproduces the current mode choice behaviour with a high level of accuracy, even for the modes with low shares. The model slightly overestimates bus usage and underestimates walking. It should be noted that the figures do not include trips by car passengers and other records excluded from the survey.

Table 5. **Mode share comparison with calibration data**

Model	Walk	Private car	Train	Bus	Ferry	Car + PT	Taxi	Cycle
Estimated mode choice (pax)	2 055	21 817	132	1 055	33	117	75	91
(%)	8.10	85.98	0.52	4.16	0.13	0.46	0.29	0.36
Household Travel Survey choice (pax)	2 179	22 039	100	741	23	113	82	97
(%)	8.59	86.86	0.39	2.92	0.09	0.45	0.32	0.38

Note: Subset of the Household Travel Survey.

Synthetic population generation

The synthetic population model generates information on the household composition, the activity of each individual member and his or her daily mobility pattern taking into account the connections within the household and private vehicle ownership. The model relies on:

- Census data (population and employment, spatially distributed). The census data were available for meshblocks. A meshblock is both the smallest geographic unit and a classification used by Statistics New Zealand. The area of the meshblocks varies in size from part of a city block to large areas of rural land. The meshblocks data were intersected with the grid, meaning that the corresponding values of population and employment were computed for each grid cell based on proportions of its area belonging to meshblocks.

- Travel survey with mobility patterns, depending on the socio-demographic characteristics a mode choice model estimated based on these data. The mobility patterns include the trip purpose, departure and arrival time, and if the trip is homebased. The mode choice model produces coefficients of the utility functions of each mode, which are used to compute the probability of choosing each mode.

- Land-use data, based on the location of amenities (grouped in nine types) in each grid cell of the study area for different types of activities (grouped in 14 categories based on the activities reported in the travel survey). The groups of amenities include: offices, restaurants and bars, commerce and stores, hotels, shopping centres, hospitals, education centres, housing, recreational. The activities are: returning home, work – main job, work – other job, work - employers business, education, shopping, social welfare, personal business/services, medical/dental, social visits/entertainment, recreational, accompany someone else, overnight lodgings, others. The activities were aggregated into nine groups to be linked with the amenities.

Each of the individuals from the travel survey is replicated in accordance to the expansion coefficient. For each individual, the agent-based model generates the structural activity representing the habitual trips (work, school, etc.), and discretionary trips (shopping, recreational trips, social visits, etc.) in the time of the day attributed to each kind of activity. The activity pattern of each individual from the synthetic population is kept the same as of the “seed” individual from the survey. The trips’ attributes, including origin/destination, start time, duration, and mode are based on the original seed but have a probabilistic component that incorporates stochasticity.

The synthetic population model generates 1 295 495 persons that reside inside the modelled area, with 4 920 488 trips for an average weekday of 2013.This value leads to a high trip production rate of 3.8 trips per inhabitant. This value is high but comparable with the city's high income levels (a highly correlated variable reported in the literature (Litman, 2008) - similar to Phoenix, Arizona (3.76), Geneva (3.4), Oslo (3.4) or Munich (3.4) in 2012 (UITP, 2015). The synthetic population does not include non-residents or visitors to the study area, though traffic and visitors were not accounted as model demand. This component, while small (for example, for Greater London it is accounted as 4% of visitors and 8% of non-resident commuters [Transport for London, 2014], meaning that for a smaller city like Auckland it should be even less), can lead to underestimation of congestion in the simulation. Yet, any bias is inserted as the model for the baseline comparison scenario is also run endogenously in the ITF shared mobility simulation model.

The simulated population nicely matches the mobility survey responses. Table 6 displays how the probabilistic trip mode of a synthetic person matches the corresponding trip mode of the seed person (a person from the survey based on which a synthetic person was generated using the expansion factors provided by the survey). The diagonal of the table presents the correct predictions, which are quite high for the most used modes (walking and private car) and are lower for other modes. Since the final mode shares and the pkm of the synthetic population and the travel survey are very similar, the disparities do not create a problem but accommodate the stochastic nature of the synthetic population model. Table 7 presents the aggregated results for the entire population as distinct from the mode shares presented in Table 5, which were calculated just for the survey sample.

Table 6. **Synthetic population mode shares (vertical) versus the seed mode shares (horizontal) (%)**

Modes	Walk	Private car	Train	Bus	Ferry	Car + PT	Taxi	Cycle
Walk	92.23	4.35	0.19	1.87	0.14	0.25	0.22	0.75
Private car	0.91	98.97	0.01	0.07	0.00	0.01	0.01	0.02
Train	2.64	47.83	20.23	15.79	0.46	9.87	1.09	2.09
Bus	10.17	40.24	4.84	32.07	1.59	4.55	1.53	5.01
Ferry	5.05	55.50	1.14	20.73	11.30	2.88	0.32	3.08
Car + PT	4.86	41.20	15.74	22.19	2.70	9.66	1.61	2.03
Taxi	26.18	37.86	5.64	21.03	0.47	2.83	2.10	3.89
Cycle	6.18	54.70	3.89	22.48	0.00	3.09	0.73	8.94
Mode share	**13.56**	**81.62**	**0.41**	**2.59**	**0.11**	**0.31**	**0.10**	**0.30**

Table 7 further provides characteristics of an average trip generated for the synthetic population. As the table shows, residents of the study area use public transport mostly if no transfers are required and if the stops are within, on average, six minutes walking distance from the origin or the destination. The frequency provided by the existing public transport is relatively low, resulting in a relatively long waiting time. That leads to a large total travel time, three times exceeding the travel time by car, even given the lower average travel distance associated with a trip by PT.

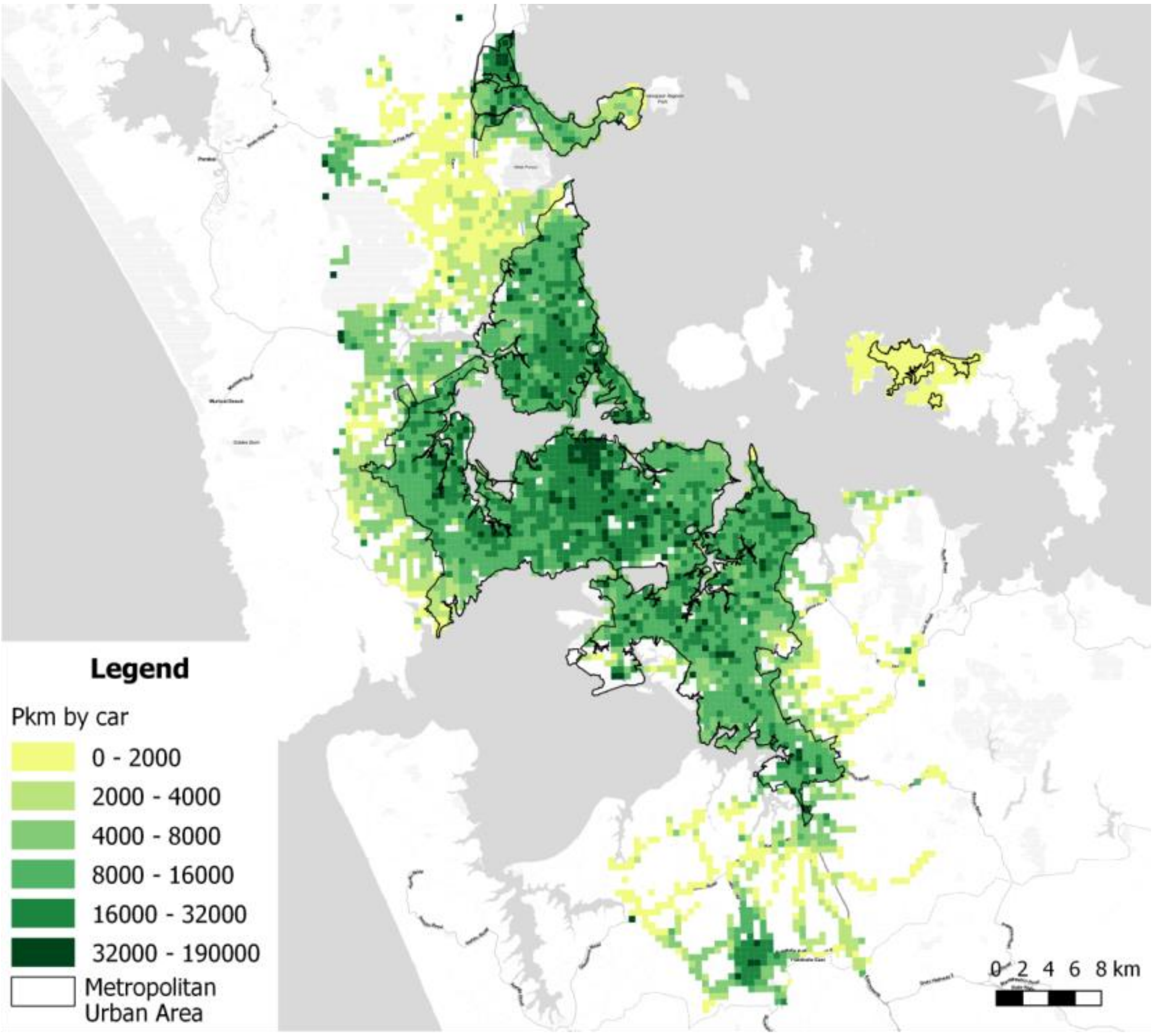
Table 7. **Average characteristics of a trip (within the study area)**

Travel mode	Total travel time (min)	Travel distance (km)	Number of transfers	Access + egress time (min)	Waiting time (min)
Public transport	47.03	7.81	0.86	11.97	18.02
Private car	17.77	10.71	-	-	-

The synthetic population allows the analysis of the current mobility distribution in time and space. Figure 9 displays the pkm by car produced by trips originating in each grid cell, and Figure 10 the pkm per capita. The scale is divided into classes with approximately same number of observations in each class (quantiles). The MUA produces most pkm per grid cell, due to the density of its population. The majority of the cells produce pkm within range of 4-16 000. The area outside of the MUA produces most pkm per resident, which is a result of travellers taking longer trips. Also non-residential areas in the CBD and some other areas with high density of jobs produce large pkm per capita since they generate return commuting trips. The figure is presented only for private cars as they accommodate most of the pkm, while the pkm generated in each grid cell by public transport fall into range 0 – 2 000 for the majority of the cells (with exception of seven cells, which constitute less than 0.2% of the entire grid).

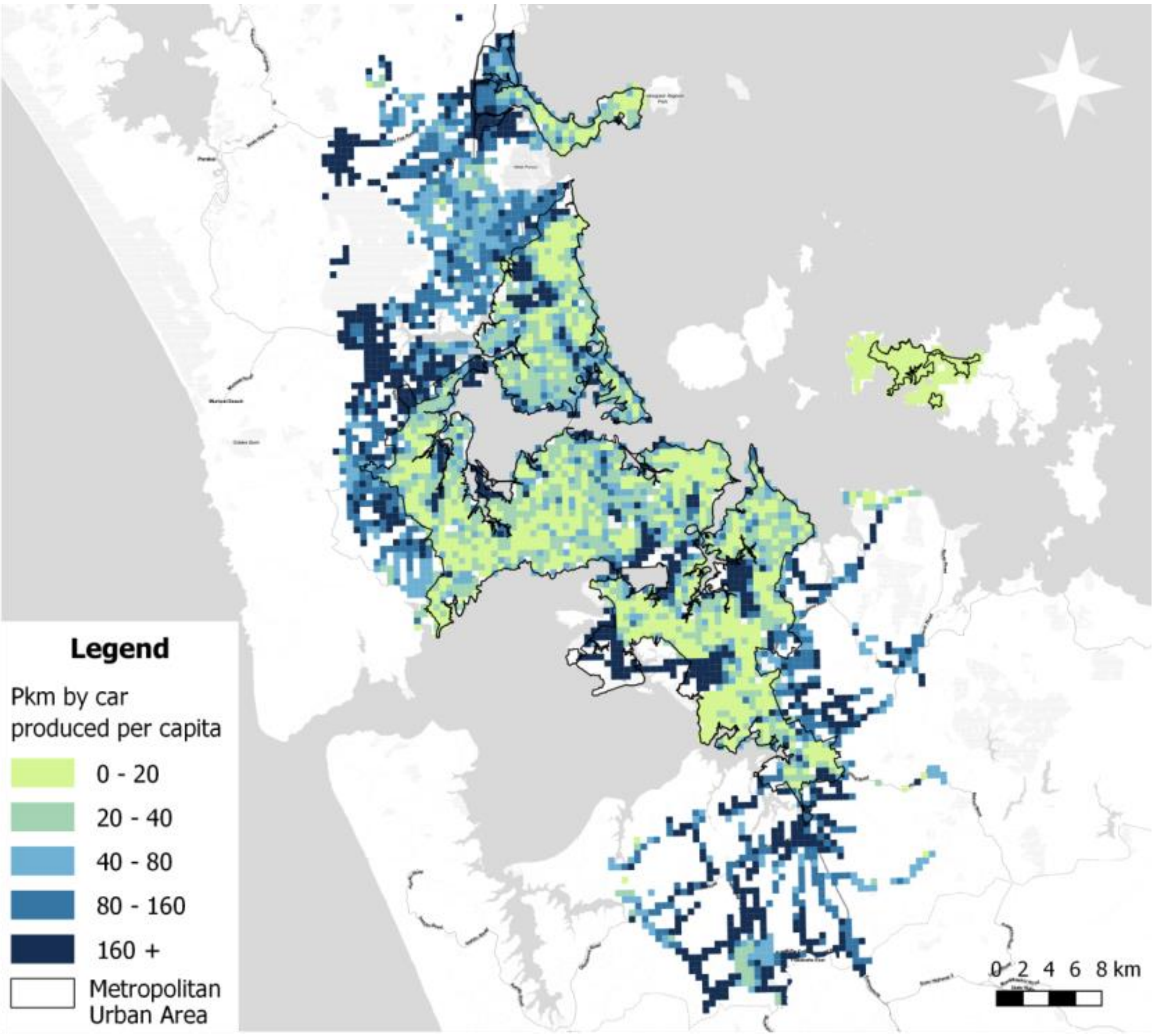
Assigning synthetic population trips to cars shows that congestion along some road network links in the study area is quite high. Figure 11 displays the congestion per each road network in the evening peak. The congestion is represented by the volume-to-capacity ratio. While for most of the links the congestion level is quite low (the volume to capacity ratio is below 0.25), for the main roads it is substantial (volume-to-capacity ratio above 0.9).

Figure 9. **Passenger-kilometres by car, total, current mobility**



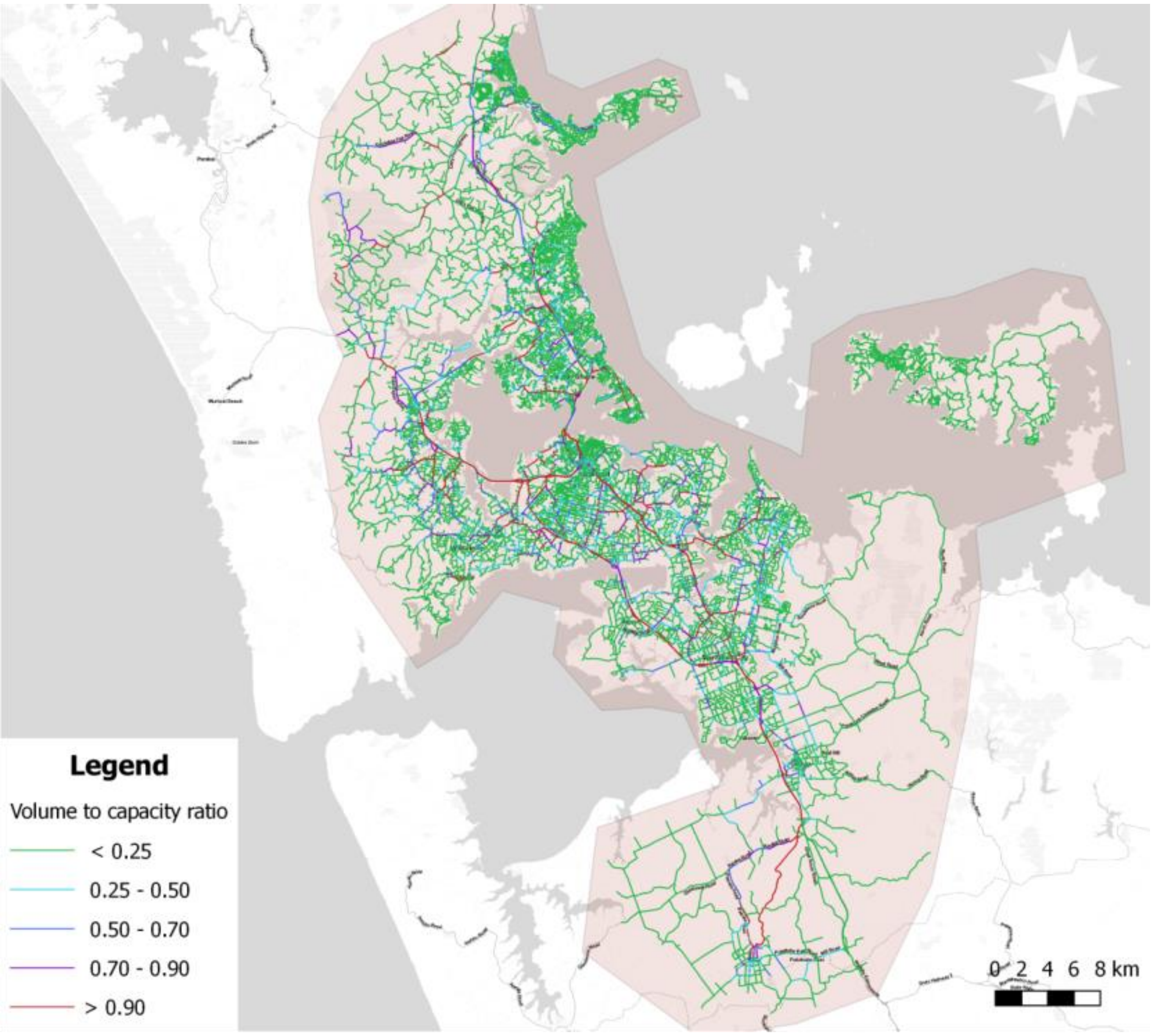
Source: ITF, Map tiles by QGIS.

Figure 10. **Passenger-kilometres by car, per capita, current mobility**



Source: ITF, Map tiles by QGIS.

Figure 11. **Congestion for each road network link (evening peak)**



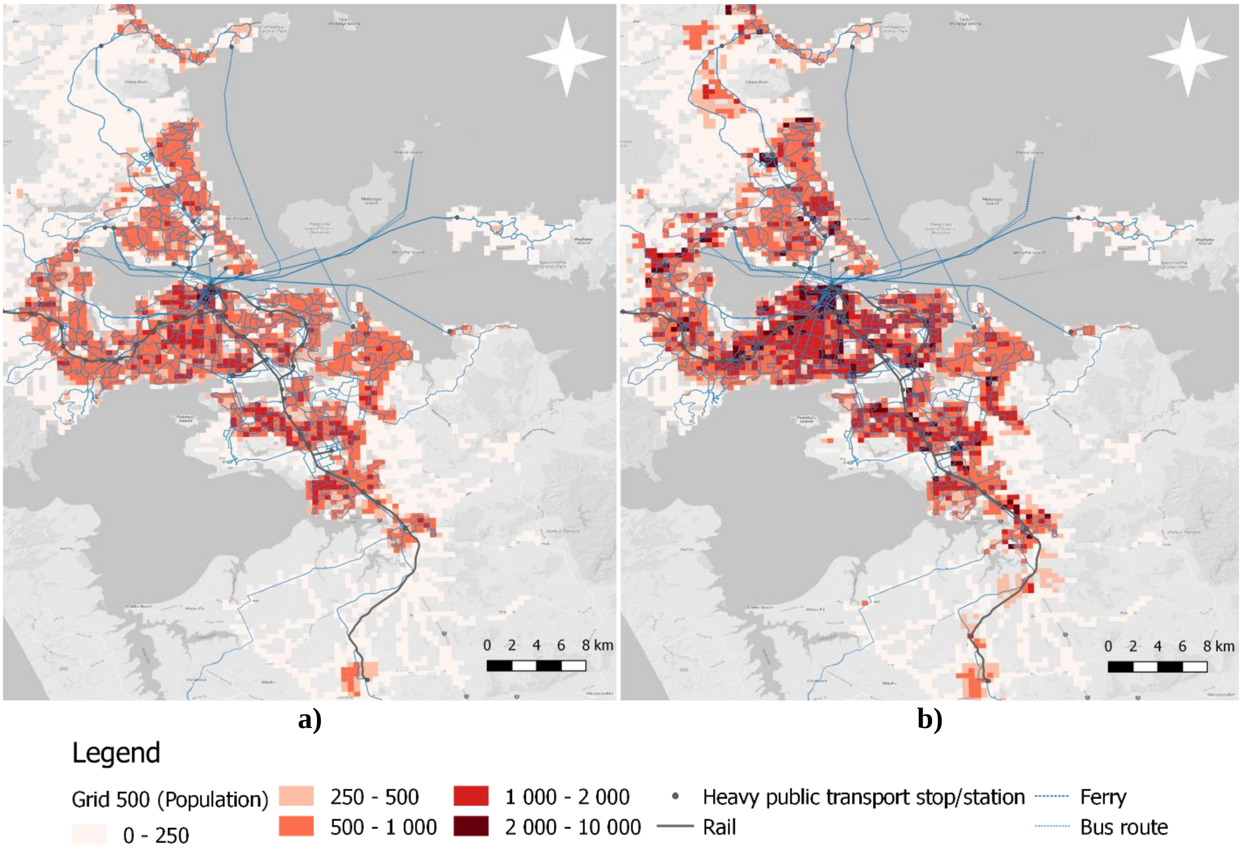
Source: ITF, Map tiles by QGIS.

The observations based on the synthetic population show that the currently available public transport implies quite a high travel time (mostly due to low frequency) and the majority of the population tend to use private car, especially travellers living outside of the MUA. At the same time the capacity of many main roads is not sufficient enough to provide congestion-free movement of motorised vehicles. Therefore, the possibility to divert users from car to more sustainable modes with higher occupancy rates is of special concern to the study area.

Modelling transport supply and demand in 2046

One of the challenges of this study was the development of an assessment of the impacts of shared mobility in a future mobility context. The year 2046 was selected as a horizon year and this required setting long-term assumptions regarding the development of the study area. These comprise the population of the area and its geographical distribution, as well as regional employment. In addition, the development of transport infrastructure and services, the mobility profile of persons and transport costs had to be estimated.

Figure 12. **Population spatial distribution in the 2013 (a) and in 2046 (b)**

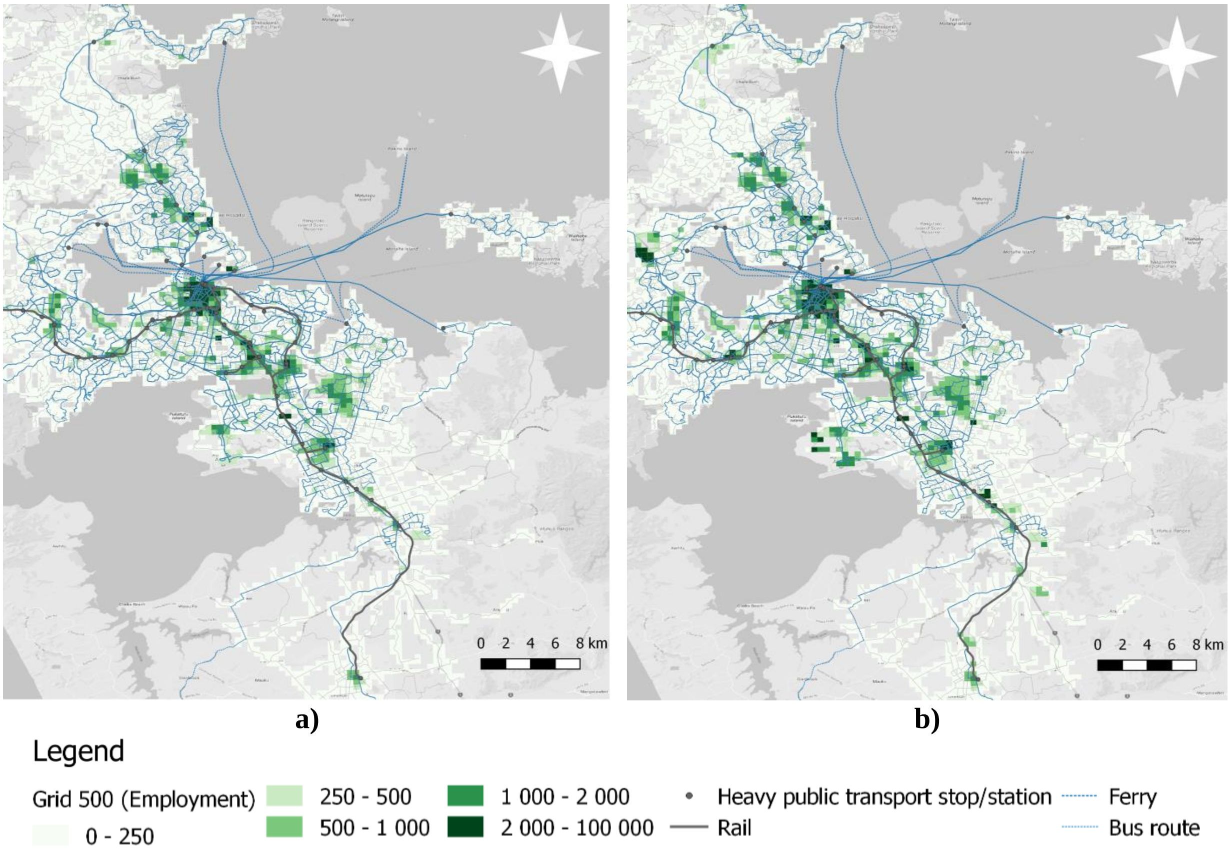


a) b)

Source: ITF, Map tiles by QGIS.

Most of the assumptions used in this forecasting exercise were provided by previous studies by Statistics New Zealand and Auckland Transport, with the Auckland Regional Transport (ART3) model. This model estimates population growth based on Statistics New Zealand latest medium-growth population forecast model. This forecast is spatially divided into 557 zones for the Auckland ration. The new public transport infrastructure plans were also compiled into a new GTFS system for the future with approximate stops located. Road network was also expanded in order to accommodate the increase in population following a hierarchical rule-based procedure. The mobility profile of users in the future was considered to be constant. The current travel survey was again used as a mobility seed but corrected with trip expansion coefficients. Other relevant factors and transport costs and modal preferences (mode choice model) were considered to be the same as today.

Figure 13. **Employment spatial distribution in the 2013 (a) and in 2046 (b)**



a) **b)**

Source: ITF, Map tiles by QGIS.

All these assumptions together with some model adaptions allowed for estimating a synthetic population of trips for 2046.

The synthetic population model generates information on the household composition, the activity of each individual member and his or her daily mobility pattern taking into account the connections within the household and private vehicle ownership.

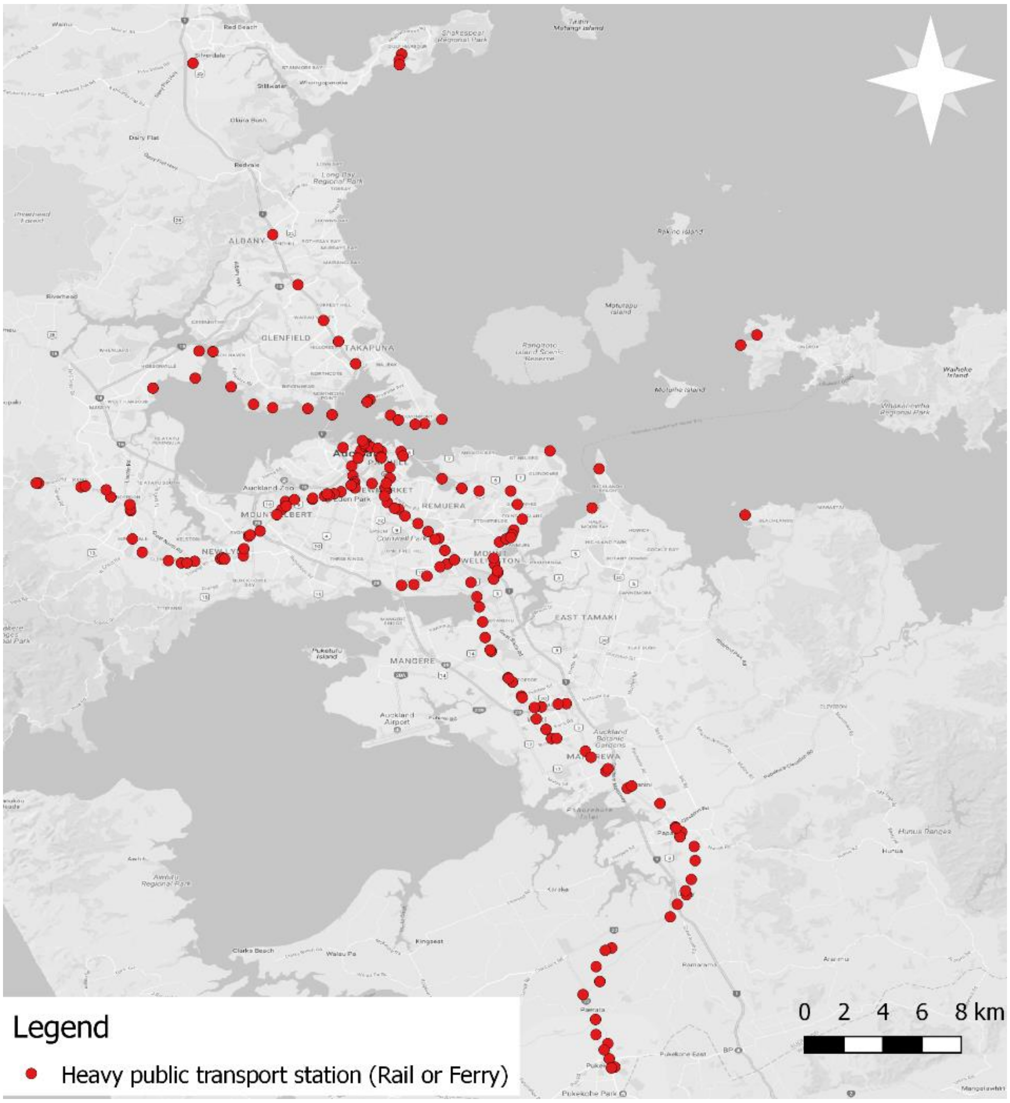
For the estimation for the year of 2046, the population and employment data provided at the level of the 557 zones was converted into the grid used in the present case with the 3 949 cells by considering that each grid cell would grow in population the same percentage of the ART3 zone that contains it (Figure 12 and Figure 13). The estimated 2.28 million inhabitants and 0.9 million employments were then distributed into the grid cells following this procedure.

The current travel survey is used as a basis ("seed") for future urban mobility and an estimated expansion factor of each respondent was used proportional to the increase of population of the respondent residential location. This correction produced 7.5 million trips per day for the year 2046. The mode choice procedure calculated for the current mobility was considered valid for the future to run the synthetic mobility set.

Land-use data for each travel purpose was corrected linking each trip purpose either to the estimated population or employment data as growth rate from the present.

The travel time between all pairs of grids was re-estimated based on the GTFS system for the future public transport network. The public transport attributes for each original-destination (OD) pair were obtained by the calculation of the shortest path by public transport mode for the future public transport network provided in the GTFS system. The rail network is planned to be expanded (Figure 14); the bus and the ferry networks are also planned to be reconfigured, which changes the mode choice sets for the travellers and the corresponding travel times.

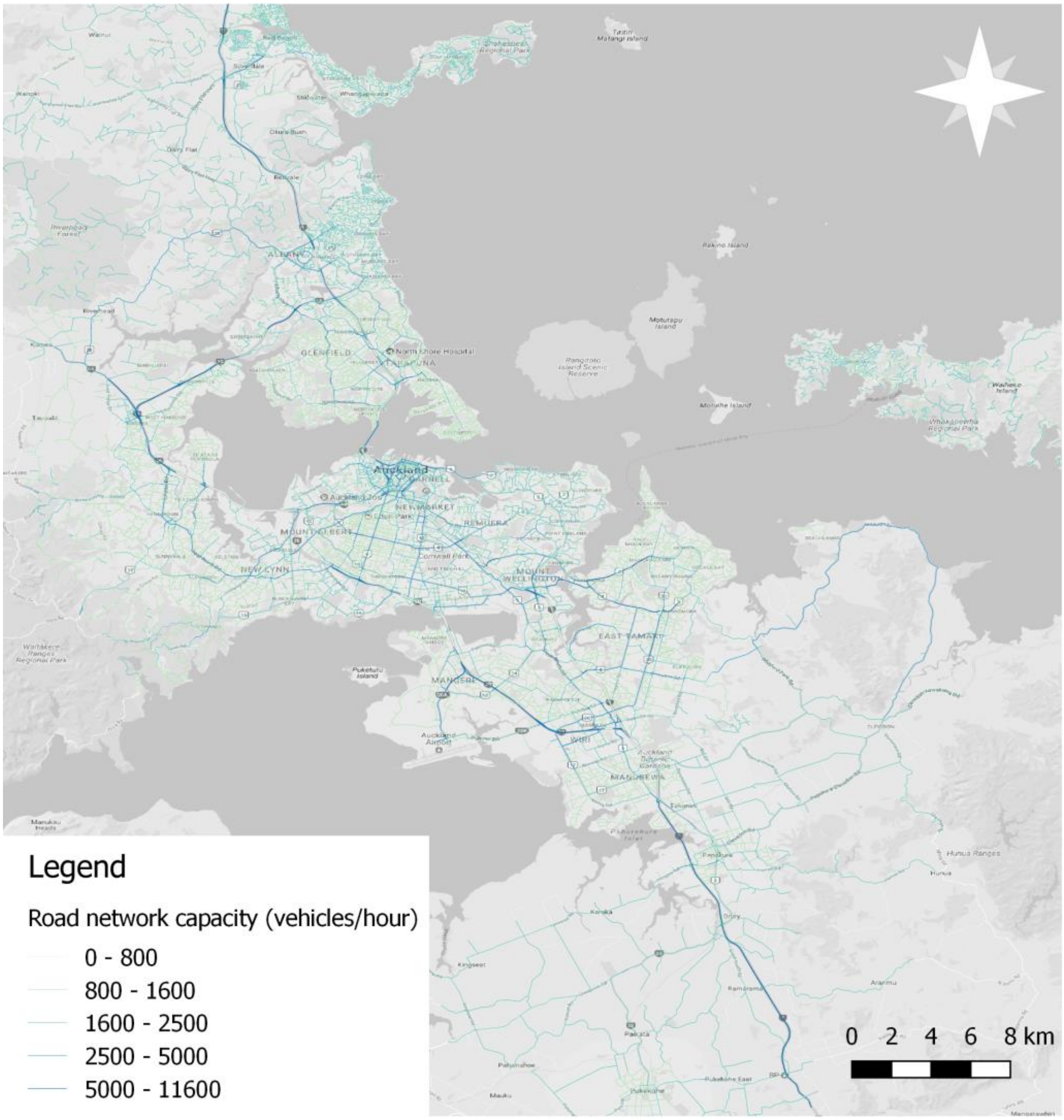
Figure 14. **Plans for expansion of heavy transport network, 2046**



Source: ITF, Map tiles by QGIS.

The future road network (Figure 15) was modelled by adapting the capacity of the road network and free flow speed. For this purpose a step function was used considering that higher hierarchy links increase their capacity at a maximum of doubling capacity. New shortest paths between grid OD pairs were also computed.

Figure 15. **One-way road network capacity, 2046**



Source: ITF, Map tiles by QGIS.

Each individual in the travel survey is replicated in accordance to the corrected expansion coefficient, following the same procedures discussed above for the present case. The synthetic population model generates 2 246 223 persons (+ 73% compared with today) with 7 516 269 trips (+ 53%), that is, 3.5 trips per inhabitant. The synthetic population does not include non-residents or visitors to the study area. The simulated population and the mobility survey responses match well. Table 8 displays how the probabilistic trip mode of a synthetic person matches the corresponding trip mode of the seed person (a person from the survey based on which a synthetic person was generated using the expansion factors provided by the survey). The diagonal of the table presents the correct predictions, which are quite high for most of the used modes (walking and private car) and are lower for other modes. Since the final mode shares and the pkm of the synthetic population and the travel survey are very similar, the disparities do not create a problem but rather accommodate the stochastic nature of the synthetic population model.

Table 8. **Synthetic population mode shares (vertical) versus the seed mode shares (horizontal), estimation for 2046, (%)**

Modes	Walk	Private car	Train	Bus	Ferry	Car + PT	Taxi	Cycle
Walk	42.26	45.70	0.10	0.62	0.01	0.47	0.00	10.84
Private car	6.17	86.21	0.89	3.78	0.01	1.98	0.96	0.00
Train	1.29	73.11	8.10	6.15	0.00	2.40	0.84	8.11
Bus	7.24	56.68	1.36	14.41	0.01	3.49	2.86	13.94
Ferry	2.40	70.04	0.62	6.87	1.29	10.61	0.28	7.89
Car + PT	3.24	66.64	3.79	7.44	0.12	9.20	4.91	4.68
Taxi	9.26	64.50	0.95	2.40	0.00	1.46	6.34	15.09
Cycle	9.95	65.49	0.00	0.00	0.00	0.09	0.00	24.47
Mode share	**11.03**	**79.54**	**0.87**	**3.72**	**0.01**	**1.89**	**0.92**	**2.02**

Table 9 provides characteristics of an average trip generated for the synthetic population in 2046. Similarly to the current case, residents of the study area use PT mostly if no transfers are required and if the stops are within, on average, a six-minute walk from the origin or to the destination. The frequency provided by the existing public transport is quite low, resulting in a relatively long waiting time.

Table 9. **Average characteristics of a trip (within the study area), estimation for 2046**

Travel mode	Total travel time (min)	Travel distance (km)	Number of transfers	Access + egress time (min)	Waiting time (min)
Public transport	68.06	13.26	1.22	11.94	12.86
Private car	13.95	8.95	-	-	-

The estimated synthetic mobility for 2046 suggests an increase of 36% in the total pkm in the metropolitan area. This is significantly lower than the population and mobility increase, suggesting an increase in the efficiency of mobility. This efficiency stems from two sources: the increased densification of the region and the expected decrease of the average distance travelled to arrive to the employment or other type of activities; and the expansion of the public transport network and the envisaged expansion in capacity of the road network.

Potential users of shared mobility

Focus groups were conducted with potential users from Auckland to investigate their preferences in relation to the two proposed shared modes. The analysis includes identifying and quantifying the most important attributes of the new modes and social-demographic characteristics of the users influencing mode choice. The focus group discussion regarding the current user preferences and the proposed new modes was followed by a stated preference (SP) survey to estimate a mode choice model.

In addition to the focus group participants, other residents of the Auckland study area also answered the SP survey; combined, these surveys allow us to explore how conveying the information about new modes affects mode choice preferences. The findings help to identify market segments with potential early adopters of shared services, design new modes more tailored to the potential users' needs to ensure the desired modal shift from private car, and to develop better strategies for raising awareness of the targeted market segments on the new alternatives and their individual and societal benefits.

Design of the focus group meetings

The focus group is a commonly applied qualitative research method which fits well for the purpose of the study. Focus groups can provide more personal disclosure and allow more topics to emerge (due to the larger number of participants discussing the matter) compared with individual interviews (Guest et al., 2017). Also, focus groups can mimic better, real decision-making environments where people are exposed to peer opinions and, possibly, are influenced by them.

The ITF shared mobility focus group was designed for groups between seven and 20 people, with sessions lasting between 90 to 120 minutes. All the focus group materials and terminology were adapted to the local language and local, most widespread nomenclature to aid the understanding of the participants.

In Auckland, the study was conducted in three meetings of seven participants with a heterogeneous profile. The introduction was provided by a seven-minute video narrated by a professional and scripted by the authors of this report. This was followed by additional clarifications by a professional facilitator. The facilitator conducted the discussion section for 75 minutes. At the end, participants were given a link to a dedicated survey for Auckland, which was to be answered within the following 24 hours. The completion of the survey was mandatory in order to receive a reward from the city partner. The meetings were conducted during the weekend to ensure heterogeneity of the participants.

The meetings were structured into three main components:

- Introduction providing participants with information about the mobility development plans for the city, followed by a presentation of the shared mobility concept and details on its potential integration into the local transport strategy. The presentation included a description of the services (with photos of the vehicles). This information section was carried out by a pre-recorded video.
- Discussion with participants following a structured script to ensure consistency and comparability between experiments. The discussion included questions to identify the personal

context of each respondent (residential location within the metropolitan area, age, gender, work profile and workplace location, and daily travel patterns including the principal mode of transport). This was followed by questions to understand the main reasons for current modal choice. These are important determinants to be integrated in new shared services as the lack of them would deter respondents from using the services. Respondents' views on conditions under which they would be willing to sell their household's cars were sought after as well. Most of the questions targeted all participants, while some were asked only to certain users (private car, bus, rail/ferry). The latter included questions on trade-offs between the proposed shared services and the currently used mode. The discussion concluded with the participants sharing their opinions about the most preferred shared mode (out of the two), reasons for choosing one service over another and the number of people they would be willing to share the vehicles with.

- Stated preferences survey (taking 10-15 minutes) to understand the respondents' final perceptions of shared mobility and their potential impact on car ownership.

Results of the discussion

The factors driving mode choice in Auckland are: flexibility, convenience, cost and reliability. The sample is representative in terms of socio-demographic characteristics and includes respondents using different transport modes. Table 10 summarises the respondents' profiles and the main findings of the focus group, aggregated around the main discussion questions.

Most focus group participants do at least two trips per day, commuting to and from work, and often combining those trips with other activities such as school drop-off and getting groceries. About 25% of the participants do more trips, mostly for leisure and family visits.

Car users prefer driving their cars for the freedom and convenience it offers them. The focus group participants who use public transport have a good PT service near their key locations (home and work), which makes it a convenient and cheap option for them. Factors that would make the car user change to PT include increased accessibility to PT stops, improved connectivity and higher frequency (especially of buses).

For car users, shared services are perceived as potentially very convenient but may not lead to significant modal changes if conditions of access to the city centre remain similar. All PT users showed a high willingness to migrate to shared mobility solutions conditioned by their affordability and reliability. All respondents stated that cost is the most important factor that would affect the choice. Most of the PT respondents stated that they would accept a slight fare increase compared with the current PT costs (which is also reflected in the survey answers, as the following section shows). Other important attributes were waiting time and in-vehicle time.

The existence of feeder services is valued mainly for residents in suburban areas located somewhat close to rail stations but not close enough to walk.

Higher number of passengers on board the same vehicle is not perceived as a negative issue. On the contrary, the respondents stated that sharing a vehicle with a small party is less preferable since it may require social interaction with other riders while this can be avoided when sharing with larger groups.

The respondents are evenly divided about the favourite shared mobility option (out of the two), with a slight bias towards Shared Taxi. Though for commuting trips most respondents prefer Taxi-Bus, mainly due to it having a lower cost than Shared Taxi.

Table 10. **Summary of the focus groups answers**

Type of questions		Auckland answers
Respondents background	Respondent profile (residential location within metropolitan area, age, gender, occupation, car ownership and PT usage).	21 people total, 9 female, 12 male. Majority are working full time, 4 students. 4 live in the city centre, 1 outside the metro area, everyone else outside the city centre but within the metropolitan area. 10 are PT users, 11 are not, and almost everyone has a car (3 do not).
	Mobility background.	Group split between people who prefer to use their car for the freedom and convenience it gives to them, and people who prefer to use PT (rail - bus).
	Daily travel pattern, including the main mode used.	Main trip purpose for most is work/study related. Most people do at least 2 trips per day, commuting to work and often combining that with other activities. About 25% do more trips, mostly for leisure or family purposes. Most drive a car.
	Main drivers for the mode choice.	PT users mostly have good PT service near their key locations (home - work), which makes PT a convenient and cheap option. Some car users stated that poor PT coverage prohibits them from using PT, but the majority select car for its convenience, flexibility, freedom and low cost.
	Factors that would make the respondent to change from car to PT.	Responses are split between those that need increased accessibility to PT, and those who want improved connectivity for their trips, with fewer trips and/or seamless transfers. Reliability is also mentioned, especially for bus trips (low frequency).
	If the respondent would be willing to move from non-PT (car/taxi) options to the shared services (car users).	The majority would switch to the new services, if they were cheap. In-vehicle travel time is a concern for some (3-4) people, as is safety (3-4). One would use if child seats were available, while 3 would not use, due to their trips complexity and concerns about riding with other people.
Modal preferences and triggers to modal choice	If the respondent would prefer to use the flexible services. Increase in price which the respondent would accept (bus users).	Everyone would switch to the new services. One would only if they could use their "HOP card" (existing smart card). Everyone who commented about cost would accept a small increase, as long as there is a trade-off in speed and directness. Acceptable increases range from 10% to 50% for bus services, while for Shared Taxi, it would have to be cheaper than private car or UBER. Ability to book multiple days in advance is a concern.
	If the respondent would use a feeder service to arrive to the PT stop (rail/ferry users).	Besides the respondents who already live close to train stations, everyone else would be open to using shared modes as a feeder service.
	If the proposed shared services would be suitable for trips the respondent currently does with a car. If the respondent would think of selling the car/cars if these services were available.	Even if the shared services are convenient for car users, almost everyone would prefer to keep their car, for some specific trips or travelling.
	The most important characteristics of the shared modes that would make the respondent shift from private modes (car or taxi).	Cost is the most important factor; about 80% mentioned it, followed by waiting time 60% (mainly car users) and in-vehicle travel time 40%. A few had safety concerns, and one had environmental concerns.
Shared mobility market segmentation	Acceptable number of passengers when sharing a Shared Taxi.	Almost none would object sharing with the maximum number of passengers (to avoid need for conversation). A few would want a free space for comfort reasons.
	Acceptable number of passengers to share with in a Taxi-Bus.	Same as for Shared Taxi.
	Which of the two shared services the respondent would prefer and why.	75% prefer shared bus for commuting trips and Shared Taxi for non-repetitive trips. The remaining 25% prefer Shared Taxi because of the more direct service and speed. One would select Shared Taxi because they do not see much distinction between Taxi-Bus and the existing bus. Cost is a main driver for people who prefer Taxi-Bus.

Stated preference survey

Survey structure and deployment

An online survey devoted to this project was developed and adapted to the local language of Auckland, local terminology and context, including PT modes available, costs of the alternatives.

The survey was organised into four different sections:

1. **Respondent’s profile**. Questions regarding socio-demographic characterisation of the respondent, residential location and level of acquaintance with smartphones and applications.
2. **Stated preferences.** Respondent make a choice among four stated preferences experiments where four type of modes were available to perform the same trip. The modes were grouped into: private car modes (car), PT (bus or rail/ferry), non-motorised alternatives (walking or cycling) and a shared mobility alternative. Each experiment presented attributes relevant to each mode. In the case of shared mobility, access time, on-board time, detour time, cost and maximum number of passengers boarding the vehicle were considered the most relevant parameters. The other four stated preferences experiments given to the respondents were to choose between Shared Taxi and Taxi-Bus given their attributes for the same trip. Orthogonal design was used to generate the choice scenarios, resulting in 64 scenarios split into eight blocks, so that each respondent would face one block with eight mode choice situations. Annex 1 shows an example of the stated preference survey question, as the respondent would see it on the screen.
3. **Mobility background**. Respondents daily trip patterns, the frequency, distance and typical mode choice by trip purpose. The respondents were also asked to characterise themselves into one of four groups: regular car user, regular bus user, regular heavy PT user (rail or ferry) or regular non-motorised traveller.
4. **Attitudes towards shared mobility attributes.** Main features of the proposed shared mobility solutions compared with their current usual mode and acceptable values of the shared modes attributes. For most of the attributes the total acceptable value in a suggested range was asked (i.e. cost, waiting time and number of passengers on board), and for other attributes a degree of their importance (i.e. ability to use the shared modes as feeder services to heavy PT modes), from “not relevant” to “highly important”. At the end, the respondents were asked about the household’s car ownership, parking preferences and willingness to sell some of these vehicles in the presence of shared modes on a large scale.

Assessment of the impact of information campaigns and informative sessions has been reported in the literature as very relevant when introducing new disruptive solutions in the market (Chorus, Molin, and Van Wee, 2006; Steg, Vlek, and Rooijers, 1995; Tertoolen, Van Kreveld, and Verstraten, 1998; Thøgersen, 2006). For this reason, we tried assessing how people that did not attend to the focus group meeting would respond to the same stated preferences survey. With the help of the New Zealand Ministry of Transport we were able to collect an additional 97 respondents from Ministry’s Household Travel Survey panel. These answers were used to test how relevant information campaigns are for the introduction of disruptive transport solutions, but also complement the sample for the stated preference choice experiment. In the next sections, a statistical characterisation of the entire group is presented (16 focus group responses), followed by the analysis of the main indicators that differ for both respondent groups.

Respondents' profiles and mobility background

The first section of the survey included questions regarding socio-demographic characteristics of the respondents, their familiarity with the related technologies, and the current mobility patterns. Annex 2 contains the tables with the detailed results.

The spatial distributions of the respondents are skewed towards the option "close to the city centre" with very few from "the city centre". It may be that respondents' assessment of the city centre is narrow. Age composition presents some balance but is slightly dominated by younger people. The survey was undertaken by 55 males and 58 females. The occupation profile of the respondents is mostly "full-time employee", followed by "student".

Most of the respondents (more than 90%) use a smart phone; around three-quarters use a tablet and around half of them are familiar with using apps; and around half of the respondents even use these devices to request transport services. Some of the respondents who do not own a smartphone are above age of 65. The others are among the younger respondents, which is somewhat surprising. Yet, this question was not obligatory and some may have overlooked it.

The current mobility stated in the survey is in compliance with what was reported during the focus group discussion. The respondents take on average 18.9 trips a week (weekdays) and 2.61 trips a day, with commuting being the main trip purpose (36%). Travel time for commuting and social activities are the largest ones (30 minutes on average), followed by leisure (20 minutes on average). The respondents characterise themselves mainly as car users, followed by bus (young and middle-aged users) and rail (some middle-aged users). Only one young respondent characterises himself as a non-motorised user. Panel respondents also characterise themselves mainly as car users, followed by bus (young and middle-aged users) and active (walk and cycling) modes (younger and older users).

Attitudes towards shared mobility attributes

The survey includes a section regarding the attitudes towards attributes of the shared modes compared with the currently used mode. The section contains questions for all respondents regarding fare, access time, lost time due to detours to pick and drop other passengers, transfers, possibility to use shared mobility modes as feeder services to rail and ferry stations. The car users are also asked a question regarding the number of passengers they are willing to share a vehicle with. The bus and rail users are asked about the importance of ride comfort and seat availability. The number of bus and rail users is fairly limited among the respondents. Annex 3 shows the detailed answers for each of the two respondents' groups (focus and panel).

First, the respondents were asked about the fares of the proposed shared modes. For comparison the calculation of the current cost per trip by car or by a public transport mode was suggested depending on the respondent's profile.

Car users were reminded of the total cost of using a private car. For 15 000 km driven per year (on average 60 km per day) the cost starts at NZD 20 per day; this includes NZD 10 in fuel/energy, NZD 10 for the purchase price of the car, insurance, licensing, Warrant of Fitness and maintenance. By adding tolls and parking costs, the total cost of private car use amounts to more than NZD 25-30 per day. After this narrative the car users were asked how much they would be willing to pay for a trip by a shared mobility mode, using the following scale: 10 - the current value and 1 - half the current cost (around NZD 12 per day).

Bus users were given a scenario in which the user has a HOP card and a daily trip costs NZD 3, which is the average value for Auckland. Then the bus users were asked how much they would be willing to pay for a trip by a shared mobility mode, using the following scale: 0 - not willing to pay, 5 - willing to pay as much as public transport ticket (NZD 3), and 10 - willing to pay double the price (NZD 6).

For the rail users the question suggested they consider a daily trip by a public transport mode that costs NZD 5 one way. Then they were asked how much they would be willing to pay for a trip by a shared mobility mode, using the following scale: 0 - not willing to pay, 5 - willing to pay as much as public transport ticket (NZD 5), 10 - willing to pay double the price (NZD 10).

Car users were quite evenly divided in relation to the potential cost of shared mobility. While some users would never consider using shared mobility, some were willing to pay close to current private car cost for the use. Most of the bus and rail users would be willing to pay a fare similar to the price of the current public transport for shared mobility services. None of the public transport users would accept a ticket increase of two times the cost and none of them would be completely uninterested in paying for shared mobility options.

Both car users and PT users were asked how many minutes they would be willing to walk to a transport stop for a shared mobility mode. Most car users would be willing to walk five minutes to the stop. Most of the bus users accept walking up to 10 minutes to access a shared mobility stop, which is double the car users’ time. Rail users are divided regarding the walking time to stop (between 5 and 10 minutes).

All the respondents were asked how many minutes they would be willing wait for transport plus a detour to pick up and drop off other passengers, while using a shared mobility mode. The car users are quite divided in their attitudes towards detours of shared modes. Many would be willing to lose 10 minutes. Female and older participants seem to accept longer detour times. Many would be willing to lose five minutes, on average, and more than 10% of the users would not accept any detours. Most of the focus group PT users would accept a 5-10 minutes detour.

All the survey respondents were asked to rate the availability of a shared mobility mode to take them to a train or ferry stop bearing in mind that, once on the train or ferry, they will not need to transfer. Integration with rail would allow for more affordable and efficient travel to the city centre. The car users are also very divided, with around 20% of the respondents considering feeder services not relevant. The bus users are divided regarding the presence of feeder services. Around one-fifth stated that shared modes used as feeder services would be highly relevant for them, while a quarter stated that this would not be relevant for them at all. Rail users highly value feeder services, except for one rail user, for whom it was not relevant. The division of opinions in the case of the bus users may be caused by the fact that many of them do not normally use heavy public transport, while in the case of the rail users, feeder services might be not relevant if the main origin and destination of the user are located close to rail stations.

Car drivers were also asked how many people they are willing to share the trip with. The majority of the respondents would prefer sharing with 3-4 people, while around a quarter would be willing to share with 10 or more passengers.

PT users were asked about the degree of importance of the comfort on-board shared services and of seat availability. Some bus users highly valued the seat availability in shared mobility services while one of the respondents did not mind standing if required. All the rail users agree on the relevance of having good ride comfort and seat availability.

All the respondents were asked about the importance of having no transfers. Most of the respondents, including car drivers and PT users, value highly direct services.

At the end of the survey, the respondents were asked about the household's car ownership, parking preferences and willingness to sell some of these vehicles in the presence of shared modes on a large scale. All the respondents have a car in the household and 25% of them have three or more cars, which is considerably high in international comparison. Around 90% of the respondents park their car at home (in a private parking facility or their garage) with no additional cost. The majority of respondents (70%) prefer to keep their car even in the presence of shared transport services. Yet, a few indicate willingness to sell one or more of their cars.

Stated preference choice experiments

The survey included a set of stated preferences questions concerning the respondents' final perceptions of shared mobility and their potential impact on the mode choice. Annex 1 show an example of a choice game which a respondent would face in this part of the survey. The modes included in the scenarios were: walking, cycling, bus, rail, car, shared mobility generic, Taxi-Bus and Shared Taxi. Each respondent answered eight choice games: four with choices among three existing modes (one non-motorised mode, one PT mode, and car) and a generic shared mode; and four with choices between the two shared modes.

Model calibration and results

A discrete choice model was estimated using the obtained stated preference data. Table 11 presents the results. For the estimation the car alternative-specific constant was normalised to zero. The coefficients which were found to be significantly different from zero (at the confidence level of 90%) were kept in the model. Few coefficients which did not meet that criterion but usually strongly affect the mode choice (such as alternative-specific constants or coefficients related to level of service of the modes) were kept. The rest of the coefficients were set equal to zero. Different specifications were tested, including nested logit. Introducing the nests did not improve the model fit and the estimated nests scale parameters were not statistically significant (compared with one).

The value of time (VOT) for car users is higher than reported in other studies for general travel, while for the PT users it is slightly lower (Douglas, 2016; Wallis et al., 2015). The obtained value is more aligned to the values in the literature for commuting trips, as respondents identified the mode choice question as a home-work trip (Douglas, 2016; Wallis et al., 2015). The VOT related to the shared modes is close but slightly lower than the car. An extremely low coefficient for the number of PT transfers in Auckland reflects the reality observed and reported by the city experts whereby the residents of the study area hardly accept any transfers and use PT only if it is direct. It is also in compliance with the average number of transfers by PT measured for the trips of the synthetic population, which is quite low (Table 7).

As expected, alternative-specific constants show, all the rest remaining constant, that there is a preference in the choice of car with respect to most of other currently available modes. The shared mobility modes are more attractive than any other modes currently available in each city. In Auckland car users prefer Shared Taxi over Taxi-Bus. Preferences for Shared Taxi for bus users were tested but were not found to be statistically significant.

Table 11. **Model calibration results**

Parameter	Estimated value
Alternative specific constant, cycle	-
Alternative specific constant, bus	-1.82
Alternative specific constant, rail	-1.65
Alternative specific constant, car	0
Alternative specific constant, walk	-
Alternative specific constant, shared taxi	0.973
Alternative specific constant, non-motorised modes	-1.95*
Alternative specific constant, PT	-
Shared mode being Taxi-Bus, for car users	-0.425*
Access time, PT	-0.0851**
Access time, shared mobility	-0.106*
Access time, generic (PT and shared mobility)	-
Being a car user, shared mobility	0
Travel cost, car	-0.196*
Travel cost, PT	-0.260
Travel cost, shared mobility	-0.246
Being female, shared mobility	0
Lost time, shared mobility	-0.0539*
Number of transfers, PT	-0.523**
Number of passengers, Shared Taxi	0
Riding alone, Shared Taxi	0.291
Travel time, car	-0.0729*
Travel time, non-motorised modes	-0.0803*
Travel time, PT	-0.0175
Travel time, shared mobility	-0.0910*
Waiting time, PT	-0.0192
Living far from the city centre, shared mobility	-0.948*
Living close to the city centre, shared mobility	0
Living close to the city centre, PT	0
Being below 25 years old, shared mobility	0
Being above 60 years old, bus	1.82*
Being below 25 years old, bus	0.968*
Being below 25 years old, cycle	1.07*
Adjusted rho-squared	0.29
Number of observations	896
Value of time (NZD per hour), car	22.32
Value of time (NZD per hour), PT	4.04
Value of time (NZD per hour), shared mobility	22.20
Correctly predicted choices (full sample), %	59
Value of riding alone (NZD), Shared Taxi	1.18

Note: - not available, * significant at the 95% level; ** significant at the 90% level.

The respondents exhibited some preferences for being alone in a Shared Taxi but would not be willing to pay much more the option (estimated as 1.18 NZD per trip). During the focus group discussion the respondents stated that sharing with more people is even more preferable, however, the preferences for number of passengers for both Shared Taxi and Taxi-Bus were not found to be statistically significant.

Mode choice preference differences depending on socio-demographic characteristics were analysed. Residents living far away from the city centre tend to choose shared modes less often. This can be explained by New Zealanders' very strong attachment to the private car, possibly resulting in their willingness to keep using cars for longer trips and accepting new shared modes mostly for shorter trips and in the city centre. Young respondents in Auckland choose bus, walking and cycling more often than the others. Respondents above 60 years old would choose bus more often.

Impact of focus group meetings on the perception of shared mobility

Both the results of the attitudes section of the survey and the stated preference mode choice experiment show quite a noticeable difference between the focus group and panel respondents, with the focus group respondents more willing to accept the shared modes. The difference is especially remarkable in the case of car users.

In the attitudes section, as Annex 3 shows, responses of the focus group participants regarding acceptance of fare, walking and detour time of shared mobility services are closer to normal distribution. For the other respondents the responses on the extremes of the answer scales are also very common. The majority of the focus group car users would accept sharing with more than 10 people, while the car respondents of the panel sample are divided into two major groups consisting either of people who prefer sharing with 4 or with 10 people.

The regular bus users of the focus group show more acceptance of a higher price of the shared mobility services than the bus users of the panel group. The walking time of 10 minutes is accepted by the bus users of the two samples, while the detour time of 10 minutes is accepted by all the bus users of the focus group but not by all the bus users of the panel group.

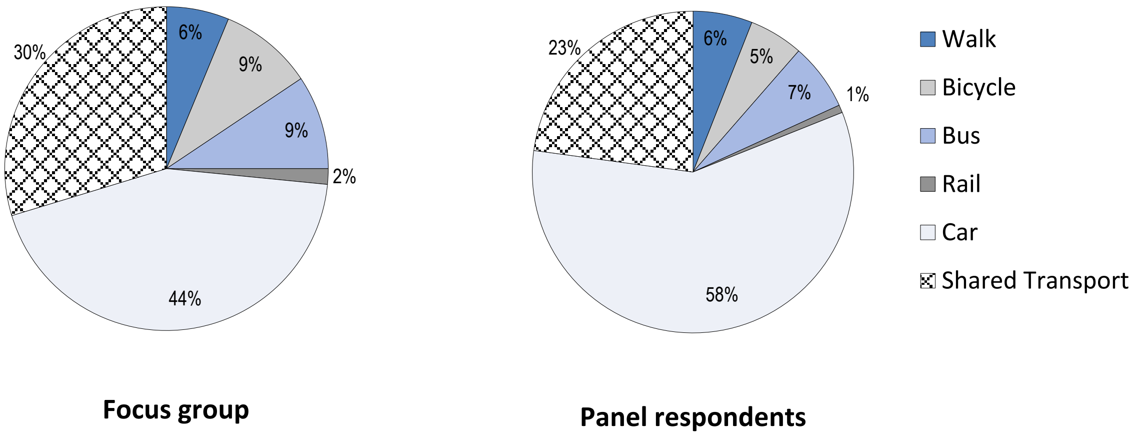
The number of regular rail users is very small in both samples (only two people in each of them). The focus group rail users show more similarities in their answers while the two rail users from the panel group have quite opposite opinions.

All in all, many of the respondents of the panel group show either very high acceptance or complete rejection of shared mobility, while the focus group participants are more "balanced", showing more acceptance on average, and being less "strict" to the attributes of the shared modes.

Both samples are fairly well distributed in terms of socio-demographic characteristics, while the focus group sample was selected to include users of different transport modes and be less skewed towards car users as a random sample would be, and as the panel sample is. However, the observed difference between the attitudes of the respondents from the two samples cannot be explained by their distinct mode shares composition, since the results were aggregated across each user group depending on his or her most preferred current mode. Therefore, the observed differences are most likely due to the participation in the focus group before taking the survey. This hypothesis has been tested based on the stated preference survey data and the results are presented below.

In the stated preference part the focus group participants also chose shared modes more often: 30% versus 23%, as Figure 16 shows. However, this difference might be due the different composition of the current mode shares between the two samples. Therefore, the statistical analysis to identify if there is a difference between the two groups of respondents was also carried out: a test of an assumption that the two data sets have different variance of the error term and a test including a binary variable representing participation in the focus group into the shared mobility utility function of the choice model.

Figure 16. **Mode choices in stated preference survey**



The assumption that the two data sets of the same city have different variance of the error term can be tested by comparing the standard deviations σ as $\sigma^{focus\ group\ data} = \alpha\sigma^{Panel\ group\ data}$, where α is a scale term between the two data sets (e.g. Morikawa, Ben-Akiva, and Yamada [1991]). The scale term represents the difference in the levels of random noise for the two data sets. First, the scale term was calculated combining two full data sets, for the model specification presented in Table 11. The estimated value is less than one, however, it is not statistically significantly different from one.

In order to compare the variance of the two data sets of the same size, a bootstrapping test was performed whereby a model would be estimated for a data set consisting of the full focus group data set and of a random subset of the panel data set with the size of this subset equal to the size of the focus group data set (16 people). The model specification includes only the alternative-specific constants and a dummy variable representing the car-user in the shared mobility utility function. The car-user dummy variable was introduced to accommodate the difference between the responses due to different mode share composition (the currently used mode) between the two samples. The two data sets were combined using the scale parameter. After 500 runs the mean of the estimated value of the scale parameter and the mean of the absolute value of the corresponding t-stats were calculated. Again, the mean of the scale was found to be 0.6 - i.e., less than 1 - which means that the focus group data has larger variance. The results are statistically significant: the means of the absolute values of the t-stats is 2.52 across the bootstrapping runs.

Finally, a binary variable taking value 1 if the respondent participated in the focus group and 0 otherwise was included into the utility function of shared mobility, keeping the rest of the specification as in Table 11. The results showed that the respondents in Auckland who participated in the focus group tended to choose shared modes more often (at 90% level of confidence, with the estimated coefficient of 0.527).

The panel group respondents replied more homogenously, choosing mostly car rather than other alternatives which resulted in the lower variance of the panel group data of Auckland compared with the focus group. Participation in the focus group changed the perception of the shared mobility in favour of the shared modes, which is an important finding for the implementation stage of shared mobility.

Conclusions and implications of the focus group analysis

The focus group study provides an insight into preferences of the current transport users of the study area, their opinions towards the shared mobility modes and their attributes (fare, waiting time, detour time, walking time to a stop, number of passengers), and special concerns (safety, availability of seats for children, etc.). The experiment includes the discussion part and an online survey with a set of stated preference choice games, therefore relying on both qualitative and quantitative methods. The findings *per se* support the decision-making on the assessment, design and deployment stages of shared mobility introduction in the study area. Additionally, the quantitative results (based on the stated preference survey) provide basis for the mode choice in the scenarios tested by the agent-based simulation model.

The participants articulated mostly positive attitudes towards shared mobility modes during the discussion and in the answers to the survey questions. The vast majority of the participants are familiar with technologies (smartphones, tablets, mobile applications) essential to the use of the suggested on-demand transport services. The respondents are willing to share vehicles with more travellers, rather than fewer, though some would be willing to pay slightly more for being alone in a vehicle. PT users, younger people and women are the most likely earlier adopters of shared services. The PT users expressed strong willingness to use the shared modes and expectations that they can greatly improve their mobility. Many PT users stated that having a possibility to use shared modes as feeder services to rail and ferry would be of a great interest to them.

The cost is the most important attribute and the majority of the respondents expect it to be not higher than that of current PT modes (for Taxi-Bus) and cheaper than of conventional taxi or private car (for Shared Taxi). With the lower price of a Taxi-Bus ticket compared with the Shared Taxi, one would compensate longer total travel time, mostly due to waiting, access and detour travel time components.

Shared mobility brings benefits to cities on the conditions that some car users shift to shared modes of transport. As the previous studies highlighted, the larger the shift, the more improvements of mobility in terms of congestion, emissions and equity can be achieved. The desired mode shift requires acceptance of the new modes by car users, as buyers and as voters. Therefore, at the assessment and design stages, it is fundamental to understand car users' attitudes and concerns, together with the factors affecting their preferences. As it was shown in the previous sections, private car users are the majority of the population in the Auckland study area. That means that even higher potential for benefits are associated with shared mobility implementation but, at the same time, it creates more barriers due to transport behaviour inertia, whereby the past behaviour reduces the importance of the modes' characteristics, and which is particularly specific to private car users (Thøgersen, 2006).

The focus group results show that while shared mobility modes are quite positively perceived, many car-using participants are neither willing to substitute their car trips with shared mobility services or to reduce their private car ownership. Moreover, car users tend to perceive the travel cost only as the out-of-pocket cost of the fuel, while valuing car for flexibility and convenience. This perception can be considered as a factor impeding a possible shift of such users to shared mobility, and should be taken into account when setting the fare of the new services, related policies and informational campaigns. The latter is of special importance, as differences between responses of focus group participants and the panel group respondents showed that in order to achieve better acceptance, there is a need to provide more potential users with information regarding the new services. This is especially true in cities with very high shares of private car, such as Auckland; the organisation of focus groups in local communities may allow residents to better understand the attributes of these new transport options and reduce their protective behaviour on preserving current transport choices. Also, choices of the respondents are likely to be affected by opinions and choices of their peers, which should be considered in the introduction phase of shared services.

Finally, the responses obtained from the survey were used to estimate a mode choice model. The model allows for quantifying preferences and trade-offs of potential users and calculating probabilities of mode choices in simulations of different scenarios for the cities. This includes identifying potential early adopters of the shared services depending on socio-demographic characteristics, which is especially useful for scenarios with partial adoption of shared mobility. The cost, as expected, and in compliance with the discussion results, was found to be the most important attribute, followed by access and travel time, while the time lost due to detours is less important. The VOT of new modes was found to be very close to the one of private car.

Identifying the potential users' preferences and the factors influencing them provides rules for mode shift in different mobility scenarios, accommodating various sets of constraints on the present modes and assumptions on the extent of the mode shift. The next section details how the scenarios were developed.

Setting the shared mobility scenarios

The previous section explored potential users' preferences regarding the shared modes. The findings show clear interest and willingness to use the new modes among the travellers of the study area. However, the public's acceptance of shared mobility, as well enthusiasm to pursue the new transport system among policymakers and industry (and consequently, the successful uptake and financial viability of the project) will strongly depend on the performance of the transport system in the presence of the new modes. The performance, in turn, will be conditional on the configuration of the transport system, including new shared and remaining "conventional" modes and their attributes, on restrictions of car use and their degree and extent in space and time, and on new modal split of the users. As different transport system configurations are possible, various scenarios can be set and tested to help decision-makers design a new transport system.

This section presents the set of scenarios for Auckland for modelling the current situation given the present population, employment, road and public transport networks; and for year 2046 based on the corresponding projections. The scenarios include the baseline scenario modelling the present situation with no shared modes. The baseline scenario provides a reference for comparison with the hypothetical scenarios. The rest of the developed mobility scenarios represent the evolution from the current or "business as usual" situation to a fully adopted shared mobility solution with different degrees of market penetration of the new shared services.

All the scenarios include the two shared modes: Shared Taxis and Taxi-Buses, and the feeder services as described in the section "Proposed share services and modelling framework". The shared vehicles can be set as self-driving or operated by a professional driver with regular shift constraints. Usage of the existing PT modes and private car vary across the scenarios with full or partial retaining of certain modes and links. Walking and cycling is preserved in all scenarios, being just very long trips (greater than 3 km for walking and 7 km for cycling) transferred to Taxi-Bus in the full replacement scenario, and preserved as the estimated mode in other configurations. Some of the scenarios include low emission zones (LEZ) of different configurations with restrictions on car usage during the entire day or only during peak hours. The design of LEZ boundaries aimed to maximise the potential of park and ride in the study area.

The scenario with full replacement of motorised modes allows for assessing the potential of shared mobility for the study area; this was tested in the ITF shared mobility studies for the cities of Auckland, Dublin, Helsinki, and Lisbon. The rest of the scenarios are intermediate ones with different degrees of shared mobility adoption. The scenarios were selected in agreement with the Auckland partners, including Auckland Transport and the Ministry of Transport. Table 12 shows the selected scenarios.

All scenarios rely on a set of common rules for mode choice. Bike users keep using bike for trips shorter than 7 km and walkers keep walking for distances below 2 km. If walking and cycling trips are longer than their thresholds they become potential candidates to switch to shared mobility modes, although always with lower willingness to change than car and bus users (last set of users to adopt shared modes).

Conventional taxi mode is removed from the transport system, since its users shifted to the shared modes as well (mainly Shared Taxi). Taxi users are not allowed to travel alone in the simulation, being incorporated into the model as regular car drivers due to the small mode share (less than 1%). In a real context, it might be explored measuring the fare ride penalty to have a sole ride.

Rail and ferry modes are preserved with the current characteristics. Each ferry/rail user keeps using the same mode, if both origin and destination ferry/rail stations are within acceptable walking distance, and if, for rail, there are no transfers needed. Otherwise the user chooses shared mobility either for a trip direct or as a feeder service for ferry/rail.

Car users are shifted to the shared modes according to the degree of replacement set in each scenario; trips are sorted in a descending order by the probability of using shared mobility over the probability of riding car; so that the earlier adopters are chosen from the top of this sorted list. The rest of the list keeps using car.

Table 12. **Scenarios selected for tests**

Scenarios	Bus	Cars	Rail + Ferry + BRT
1	100% Replacement	100% of trips replaced	Keep
2	Keep	100% of trips replaced	Keep
3	100% Replacement	50% of trips replaced	Keep
4	100% Replacement	20% of trips replaced	Keep
5	Keep trips where bus with headway <5 min	100% of trips replaced	Keep
6	Keep trips where bus with headway <5 min	20% of trips replaced	Keep
7	100% Replacement	Large low emissions zone (LEZ) with all private car traffic constrained **during all day**	Keep
8	100% Replacement	Large LEZ with all private car traffic constrained **during peak hours**	Keep
9	100% Replacement	Small LEZ with all private car traffic constrained **during all day**	Keep
10	100% Replacement	Small LEZ with all private car traffic constrained **during peak hours**	Keep

If a person chooses a shared mode, the choice of Taxi-Bus or Shared Taxi is also defined depending on the estimated choice probabilities. If a person chooses Taxi-Bus but there are not enough people to share (not ensuring sufficient occupancy level in a Taxi-Bus vehicle), the service for this person is upgraded to Shared Taxi at the price of Taxi-Bus. The assumed minimum acceptable occupancy rate for a Taxi-Bus is four persons and a minimum occupancy level 0.5. If there is no Taxi-Bus stop in proximity a person will be automatically upgraded to Shared Taxi at the price of Taxi-Bus.

The choice between feeder and direct service with a shared mode is based on the computed choice probabilities and the rules for feeder services. Differential weights are assigned to walking (three times more) and the connecting Taxi-Bus time (1.5 times more) as compared with the time spent travelling in the rail-based public transport or ferry. The walking segment linking rail, ferry or BRT station with the trip end (origin or destination) point is less or equal to 10 minutes. The rail or ferry trip-leg must be with no transfers. The total distance in the feeding part of the trip (walking plus shared mobility) should always be shorter than the direct distance between trip origin and destination. This ensures that feeder services do not result in long detours from the most efficient path. For rail only feeder service on one end of the trip is allowed, while for ferry it is allowed on both ends.

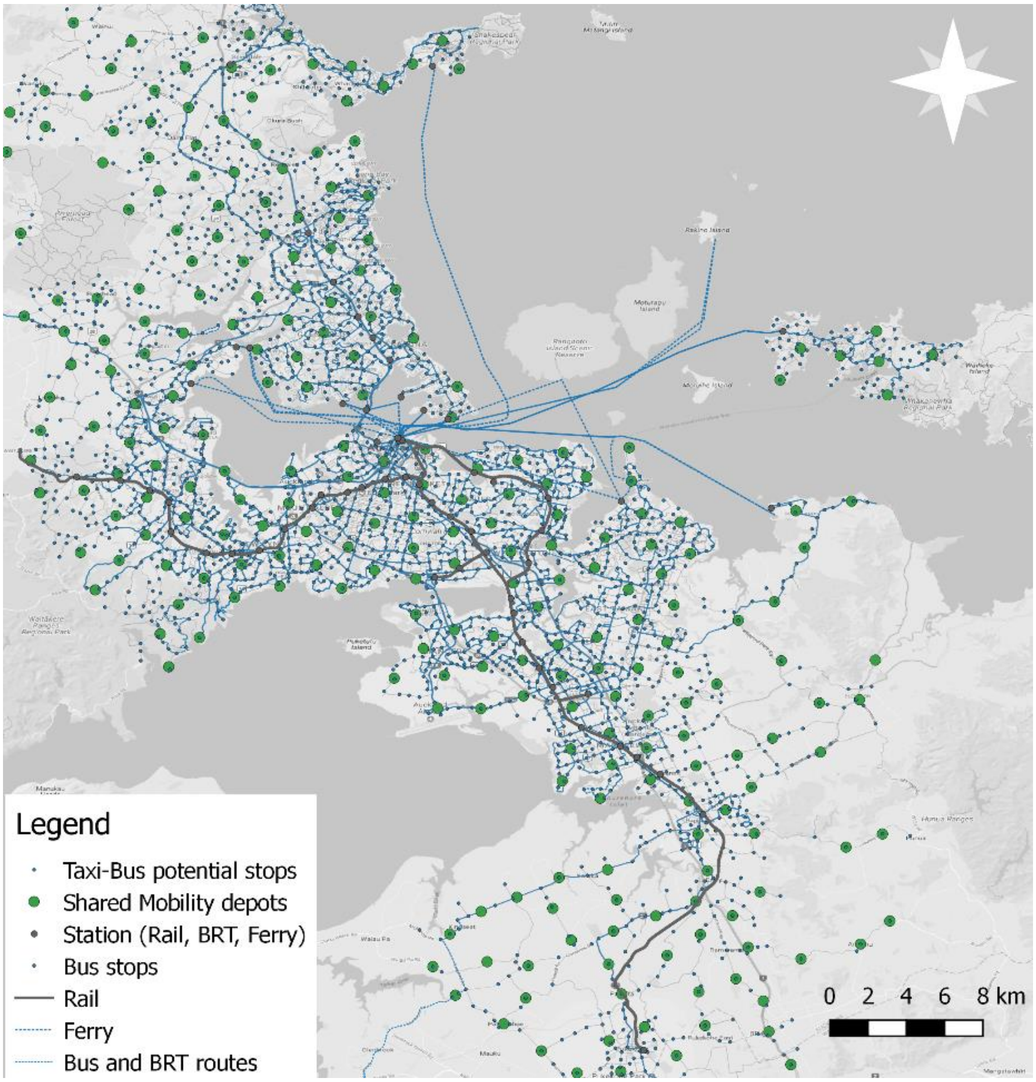
The choice probabilities are based on the utilities of the competing modes computed for each particular person and trip depending on his/her socio-demographic characteristics and mode-specific attributes for the trip. The probabilities are computed using the results of the stated preference online survey for Auckland (focus group participants and panel respondents), presented in the previous section.

For Shared Taxi, the fare is assumed to be equal to 75% of the current car full operating cost but never less than NZD 4, and for Taxi-Bus it is assumed to be 50% of the current car cost, but never less than NDZ 2. The car cost is calculated as: NZD 10 (daily value for the purchase price of the car + insurance, licensing, Warrant of Fitness + maintenance) divided by three trips per day, plus fuel cost per kilometre. The on-board travel time (which also includes the detour time) of Taxi-Bus never exceeds a time which is needed to travel along an Euclidian (linear) distance between the trip origin and destination at speed of 15 km/h.

Whenever a Shared Taxi vehicle is empty and not dispatched to a new trip, it relocates itself to the nearest station, called a depot, where idle vehicles are to be located. Figure 17 presents the location of the potential stops for Taxi-Bus and depots for the idle shared mobility vehicles adopted in all tested scenarios. The legend shows the total number of the stops and depots (in the square brackets).

All the shared mobility scenarios (see Table 12) can be conventionally split into three groups: the scenarios with pre-set different degrees of replacement of bus and car trips (Scenarios [Sc.] 1-4); the scenarios with keeping frequent bus trips and with varying degree of substitution of car trips (Sc. 5-6); the scenarios with different levels of adoption depending on the spatial location of the trips (low emission zones with restricted access for private cars) and time of day (Sc. 7-10). The scenarios' specific features for each group are presented below.

Figure 17. **Road, public transport and potential shared mobility networks (all scenarios)**



Source: ITF, Map tiles by QGIS.

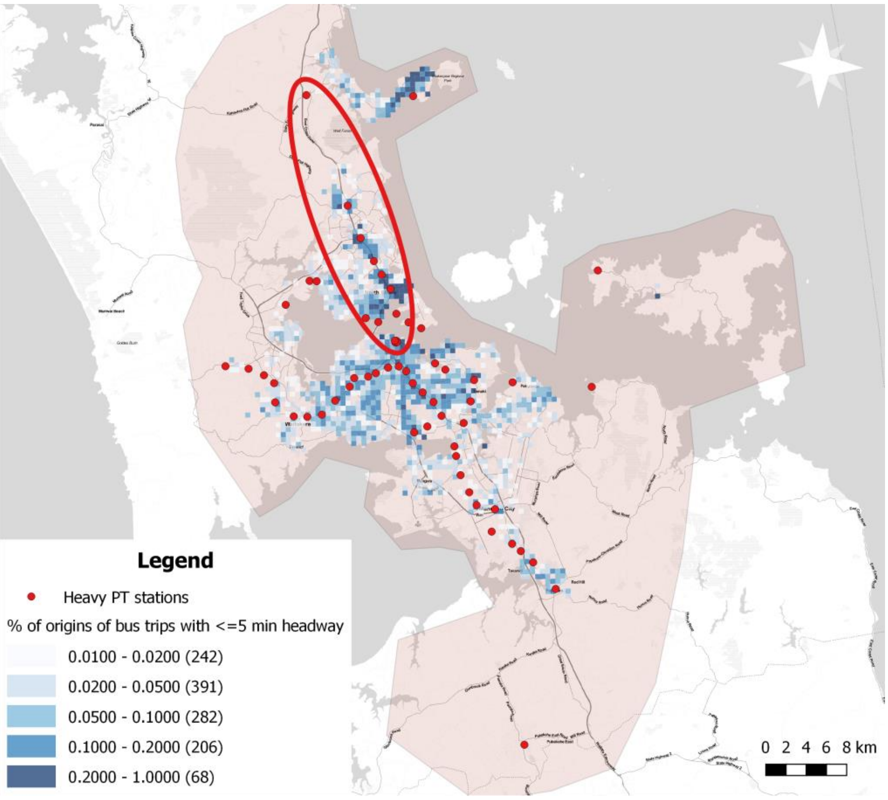
Scenarios with different degrees of replacement of bus and private car trips

In this group of scenarios bus trips are either all replaced by other modes (Sc. 1, 3, 4) or all kept. As the previous shared mobility study for the Lisbon Metropolitan Area (ITF, 2017) showed, replacing car trips at marginal rates does not have significant effect. Therefore, in the car replacement scenarios the replacement rates for car trips are 100% (Sc. 1-2), 50% (Sc. 3) or 20% (Sc. 4). Rail and ferry trips are kept if they are without transfers, otherwise they are substituted either by a direct trip by a shared mode or by a trip with a shared mode feeding the public transport station, based on the rules described in the previous section. The scenarios allow testing how different degrees of replacement of car, and keeping or removing the bus network, affect the performance indicators of the transport system.

Scenarios with keeping frequent bus trips

Scenarios 5 and 6 allow for analysing how keeping part of the buses would affect the transport system performance and efficiency. In both scenarios trips by bus with frequency above five minutes are replaced with trips by the shared modes while the rest are kept. Rail, BRT and ferry trips are kept if they are without transfers, otherwise they are substituted either by direct trip by a shared mode or by a trip with a shared mode feeding the public transport station, based on the rules described in the previous section. In scenario 5, 100% of trips currently made by private cars are replaced. In scenario 6, 20% of trips currently made by buses and private cars are replaced with Shared Taxi or Taxi-Bus. The choice of the trips to be replaced depends on the choice probabilities derived from the stated preference survey. Many of the bus trips kept are performed along the BRT Northway Corridor (Figure 18) and a few major routes.

Figure 18. **Origins of the kept bus trips and the BRT corridor**



Source: ITF, Map tiles by QGIS.

Scenario 5 allows analysing how keeping part of the buses would affect the system efficiency compared with scenarios 1 and 2. Scenario 6 allows analysing the system impact of a lower car replacement while keeping part of the bus service (compared with Scenario 5).

Low emission zone scenarios

Boundary design of low emission zones (LEZ) is based on the maximisation of the possibility of transfer of car drivers and passengers to public transport at park-and-ride stations near the boundaries.

The model was tested under two different geographical boundaries with constraints to private car circulation: a large LEZ and a small LEZ.

The small LEZ has a boundary that connects with the South and West rail lines, and the BRT Northway Corridor, trying to maximise public transfers after parking while minimising the shared mobility vehicles required for this operation. The small LEZ considers 13 stations, of which four coincide with a railway station and one with a BRT station, while the remaining eight serve the new shared mobility modes only. This boundary is sufficiently larger than the Auckland central B=business district bounded by highway connections and access points, but not by rail or BRT stations. This ensures that more people use the high-capacity PT modes and, therefore, reduces the movement of motorised vehicles inside the small LEZ (compared with the case if the restrictions were only within CBD).

The larger LEZ boundary follows the same logic for specification, trying to reduce as much as possible the motorised vehicles flows within the LEZ and promoting the transfer to high capacity public transport modes (rail, BRT and ferry). The large LEZ considers 13 stations, of which six coincide with a railway station, one with a BRT station and one ferry terminal, being the remaining five serve the new shared mobility modes only.

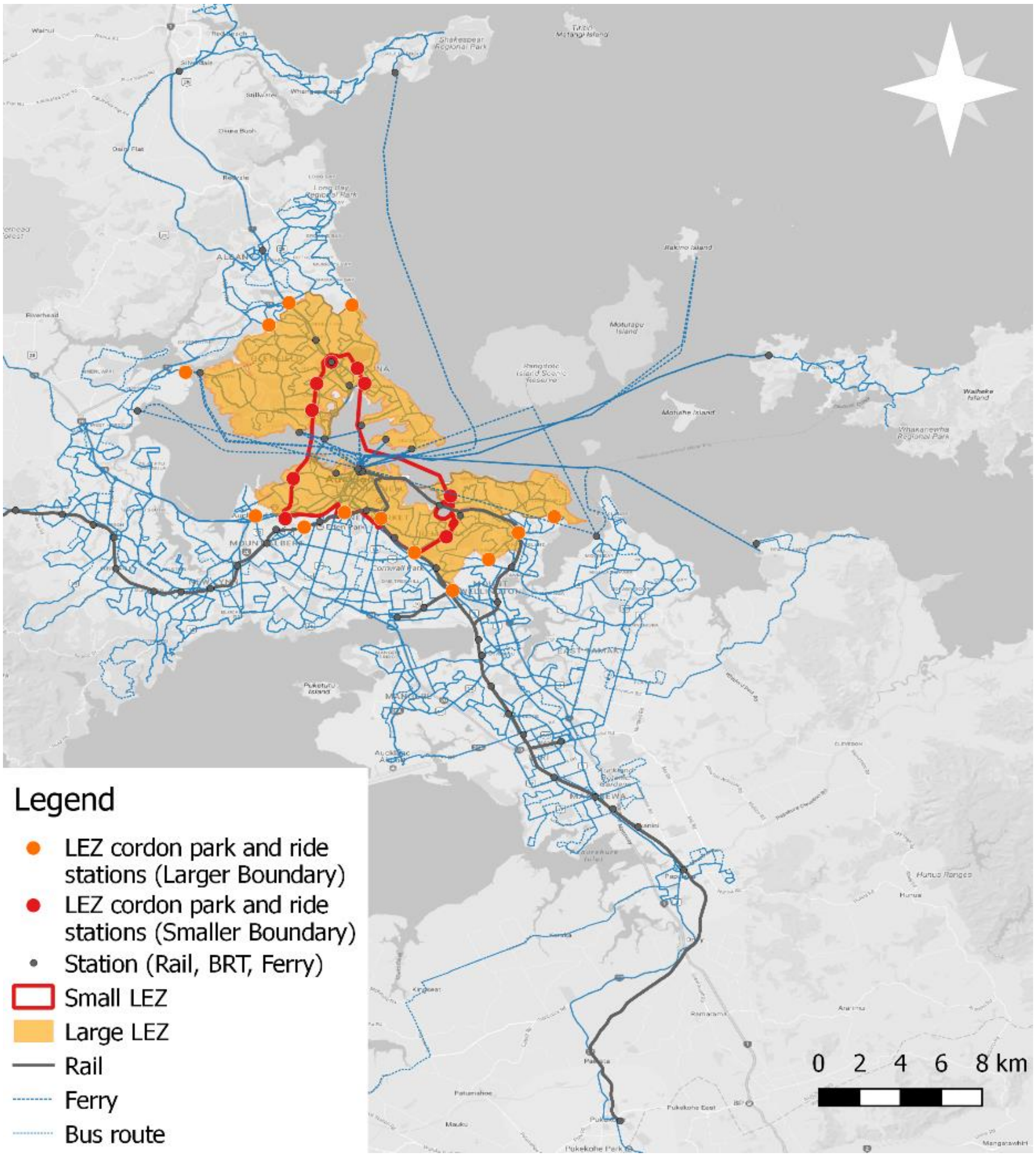
This group of scenarios (Sc. 7-10) shows the impact of restricting private cars within a LEZ during the entire day or peak hours. Travellers within the LEZ boundary, including residents, may use shared mobility solutions integrated with mass transit (rail, ferry and BRT) during the restriction periods, while external drivers may leave their car and the entry of the LEZ or use share mobility from their homes directly (20 %). Figure 19 shows the two kinds of LEZ with different sizes which are considered. 100% of trips made currently by buses and private cars are replaced. Rail and ferry trips are kept if they are without transfers, otherwise they are substituted either by direct trip by a shared mode or by a trip with a shared mode feeding the public transport station, based on the rules described in the previous section. The morning peak hours (Sc. 8, 10) are 6:00-9:00, and the evening peak hours are 15:00-18:00. The peak hours are assumed based on the current congestion, represented by volume to capacity ratios of the road network links.

For all the scenarios, general indicators and performance measures of the shared mobility services are calculated. The general indicators include traffic profiles at different sub-areas and road types, accessibility levels in the study area (access to jobs, compared with baseline), and average costs by mode and corridor. The performance measures contain waiting times distributions, times loss distributions, kilometres per day per vehicle, average occupation of vehicles along the day, percentage of upgraded passengers along the day, dynamics at shared mobility stations (depots), dynamics of boarding/alighting of shared vehicles at heavy public transport stations, and environmental performance (CO_2 emissions and local pollutants exhaustion).

Additionally, in-depth analysis for three selected scenarios was carried out. It includes tests for:

- Electric fleet: This implies optimisation of charging infrastructure considered in the simulation. The resulting charging infrastructure depends on the charging time specifications.
- Labour regulation of drivers: This component optimises the shift specification for each driver following the specific labour constraints in each country to obtain minimal labour costs and reduce the idle time of this resource. This includes a post-processing for each scenario to obtain an optimised working schedule for each driver and operating fleet dynamics. In case of self-driving fleet, the fleet dynamics is obtained directly from the model outputs.

Figure 19. **Definition of the large and small low emission zones**



Source: ITF, Map tiles by QGIS.

The performance measures include general mobility and accessibility indicators and some additional indicators specific to the shared modes performance. The former allow assessing the overall performance of the system while the latter provide insights on the costs and attributes of the shared modes, and resources needed to efficiently operate the system of shared vehicles, including required number of vehicles, drivers and depots, given the land-use configuration of the city and labour legislation.

The same scenarios were selected for in-depth analysis of the present situation and of the model for 2046. This consistency may allow for analysing more in detail the impact of the same policies in the two different contexts and the variation of performance for the same scenario in the future compared with the baseline year.

Impact of shared mobility

This section presents the results of the agent-based simulation model under the pre-set scenarios in terms of the overall performance of the transport system after the introduction of new shared mobility services. The results include aggregated indicators on passenger-kilometres (pkm), vehicle-kilometres (vkm), mode shares, emissions, accessibility and connectivity measures, and congestion levels for the scenarios, as well as changes in those indicators with respect to the baseline scenario. The chapter also presents operational performance indicators, such as average occupation and required fleet, of the shared modes.

Based on results from the original ten scenarios, three were selected for further, more in-depth, analysis. This section includes these results, with indicators disaggregated to the level of grid cells, road network links and time of day. The same three scenarios are analysed for the present case and the future case (year 2046).

Results for the present case

This section presents an analysis of the different tested scenarios in terms of the mobility, environmental performance, access and connectivity for the present case (base year 2013). The main users affected by each of the scenarios and the major differences are highlighted for further policy insight discussion. The section also contains a brief comparison of the main indicators with the ones obtained for the shared mobility study of Lisbon.

Major mobility outcomes

The vehicle-kilometres (vkm) and the levels of the CO_2 emission and congestion are the indicators which demonstrate the overall performance of the transport system in the study area and, compared with the baseline scenario, show if the scenario configuration brings significant benefits to the transport system. The congestion is calculated as the average of volume to capacity ratios for the actively used links. The CO_2 emissions are calculated as a sum of the emissions for each mode (Annex 4 contains the details) and represent only tank-to-wheel emissions, without taking into account the entire life cycle.

The resulting indicators suggest that targeting the car users is crucial for benefitting from shared mobility. Table 13 summarises changes in the three indicators compared with the baseline scenario. As it shows, the scenarios with 100% car replacement in the entire study area (Sc. 1, 2, 5) provide most of the reduction (around two times for each of the indicators). These scenarios are followed by scenario 3 with 50% of car replacement in the entire study area, bringing above 20% reduction in vkm and CO_2, and 17% reduction in congestion. Scenarios with 20% of car replacement (Sc. 4, 6) and scenarios with the large LEZ (Sc. 7, 8) reduce vkm and CO_2 emissions by more than 10% and the congestion by more than 6%. The two scenarios with the small LEZ (Sc. 9, 10) provide marginal reduction in vkm and CO_2 emissions and lead to even more congestion compared with the baseline scenario. The latter is due to the increased concentration of motorised vehicles in smaller streets around the LEZ border, as these streets are currently not designed for the purpose in terms of number of exits and entries to the parking facilities, intersections, etc. The additional congestion can be quite significant, especially when concentrated during the peak periods (Sc. 10) and could cause significant delays accessing the LEZ. For the scenarios with partial car replacement in the entire study area (Sc. 3, 4) the elasticity of the vkm reduction to the percentage of shift of the car users is smaller than 1.

Surprising results appear in the variations of the car and bus replacement rates, car restricted areas and time of day across the scenarios. Restriction on car use in the large LEZ during peak hours (Sc. 8) is even more beneficial according to the three indicators than restriction during the full day (Sc. 7). It can be explained by a more efficient use of shared modes during the peak hours when sufficient number of passengers is available compared with their average number across the day. For the small LEZ this does not hold: peak hour restriction (Sc. 10) brings even less benefits than the full day (Sc. 9). The very small difference between scenarios 1 and 2 (with bus replaced or kept) is due to the very low share of bus users in the study area. It should be noted that the presented congestion changes in all scenarios that have some degree of bus replacement do not include reduction of congestion due to decrease of bus vehicles, not measured at street level at the baseline scenario. However, this reduction is negligible since the bus share is small.

The assessment of the required motorised vehicle fleet is also pertinent. It was measured by taking a private car vehicle as the reference, with all other types of vehicles converted to a private vehicle equivalent, by applying a multiplying factor (see Table 13 note). In all tested scenarios the motorised fleets reduce when compared with the baseline scenario. LEZ scenarios, however, produce very small reductions, mainly just affecting private car use and not significantly affecting ownership, as private cars are still required to perform trips outside the LEZ. Normally the private car fleet reduction is significantly smaller than the reduction of private car trips, for example 31.7% fewer cars for a reduction of 50% of private car trips (scenario 3).

Table 13. **Changes in vehicle-kilometres, CO_2 emission and congestion compared with the baseline (%)**

Scenario	Vkm	CO_2	Congestion	Motorised vehicle fleet (equivalent private car vehicles)
1	-51.4	-54.4	-49.1	-92.8
2	-50.6	-53.3	-49.8	-92.9
3	-21.5	-22.7	-17.1	-31.7
4	-14.0	-14.6	-7.8	-11.1
5	-50.9	-53.9	-48.2	-92.9
6	-14.1	-14.7	-8.0	-11.3
7	-12.9	-13.3	-6.1	-3.4
8	-13.7	-14.1	-6.8	-1.4
9	-7.5	-7.9	11.6	-1.8
10	-2.8	-3.2	17.7	-0.2

Note: Parking requirements are measured in equivalent average private car vehicles, weighted by the following factors: private car: 1; conventional taxi: 1; Shared Taxi: 1.1; Taxi-Bus (8 seats): 1.3; Taxi-Bus (16 seats): 1.5; Bus and BRT: 3.

Changes in modal split and public transport ridership

All the scenarios result in pkm decrease for car and bus and increase for rail and ferry compared with the baseline scenario. Table 14 presents the pkm for each of the motorised modes while Table 15 presents the changes compared with the baseline scenario. For the scenarios with partial car replacement in the entire study area (Sc. 3, 4) the elasticity of the pkm reduction to the percentage of shift of the car users is smaller than 1 (similarly to the vkm). The impact of large LEZ on the car pkm with full car replacement is similar to the reduction achieved due to 20% of car trips replaced in the entire study area. The pkm by heavy modes increase dramatically compared with the current ones (the rail pkm double and the ferry pkm increase by more than 40%). The bus pkm reduce in most of the scenarios since the bus trips are substituted partly or completely by shared modes. Only in scenario 2, where all the current bus trips are kept, the bus pkm increase by 19%. This is due to the increase in BRT share driven by availability of shared modes to feed the BRT. However, the substantial increases of public transport pkm are applied to very small initial shares (around 1% for rail and ferry in total, and 3% for bus).

Table 14. **Passenger-kilometres (thousands)**

Scenario	Shared Taxi	Taxi-Bus	Car	Bus + BRT	Ferry	Rail
Baseline	-	-	43 391	974	28	148
1	28 517	35 722	-	236	102	1 492
2	28 493	33 707	-	1 168	100	1 473
3	8 391	15 570	26 742	86	42	515
4	3 204	6 258	34 412	57	41	361
5	28 395	34 721	-	369	93	1 469
6	3 195	5 928	34 371	186	40	335
7	1 785	5 310	35 915	68	41	452
8	2 269	5 956	35 250	77	42	424
9	2 522	5 514	37 860	85	45	602
10	1 661	3 657	40 702	69	43	454

Due to the detours of the shared vehicles the total pkm of the motorised modes - including car, bus and shared modes - are higher for the scenarios with larger car replacement rates, as could be expected. For the scenarios with 100% car replacement (Sc. 1, 2, 5) the sum of the pkm of the motorised modes is around 63-64 000, and for scenario with 50% car replacement (Sc. 3) it is almost 51 000. For most of the scenarios with the partial car replacement (Sc. 4, 6-10) the sum of the pkm by motorised modes is around the same value as in the baseline scenario, that is 43-46 000 pkm. Out of all the scenarios, only scenario 8 results in smaller pkm compared with the baseline, with a very small difference of around 300 pkm. However, as Table 13 shows, the scenarios with larger proportion of shared modes leads to more benefits for the city in terms of total vkm, CO_2 reduction and congestion, that is due to the higher occupancy of the vehicles in such scenarios.

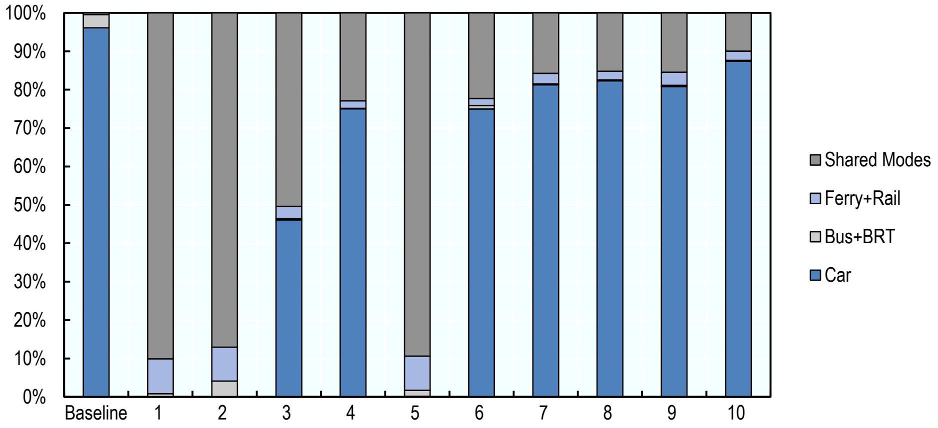
Table 15. **Change in passenger-kilometres compared with the baseline (%)**

Scenario	Car	Bus + BRT	Ferry	Rail
1	-100	-76	263	908
2	-100	20	255	895
3	-38	-91	48	248
4	-21	-94	45	144
5	-100	-62	230	892
6	-21	-81	42	126
7	-17	-93	45	205
8	-19	-92	49	186
9	-13	-91	60	307
10	-6	-93	53	207

The scenarios can be split into two major groups by the motorised mode shares based on the number of trips per mode: the scenarios with zero car share (imposed by the scenarios' rules) and the rest. In most of the scenarios of the second group, car is still a prevailing mode, with the exception of scenario 3. Figure 20 displays motorised mode shares based on the number of trips by each mode for each scenario, including the baseline. As Table 2 shows, the estimated mode share of private cars is 85.8%, when all modes are considered (walking and cycling). If only motorised modes are included, private car represents 97% of trips. All 100% car replacement scenarios (Sc. 1, 2, 5) lead to approximately the same share of rail and ferry passengers (almost 10%), while most of the trips are provided by the shared modes.

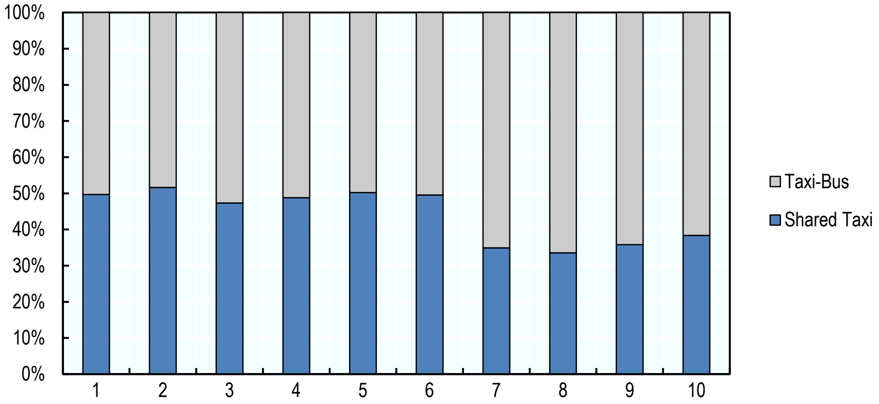
Scenarios with LEZ (Sc. 7-10) show very similar mode shares with slight variations. Scenario 9, with the small LEZ and cars restricted during the entire day, results in a smaller car share compared with the scenarios with the large LEZ (Sc. 7, 8). This is due to the fact that in the case of a smaller LEZ the number of travellers, who would be able to get to their destinations by rail with no transfers, increases. Therefore, more travellers shift to rail than in case of a larger LEZ. However, the actual number of trips by car for scenario 9 is slightly higher than for scenarios 7 and 8. And the small LEZ provides significantly fewer benefits in terms of changes in average pkm, vkm, CO_2 and congestion levels, as shown above.

Figure 20. **Motorised mode shares**



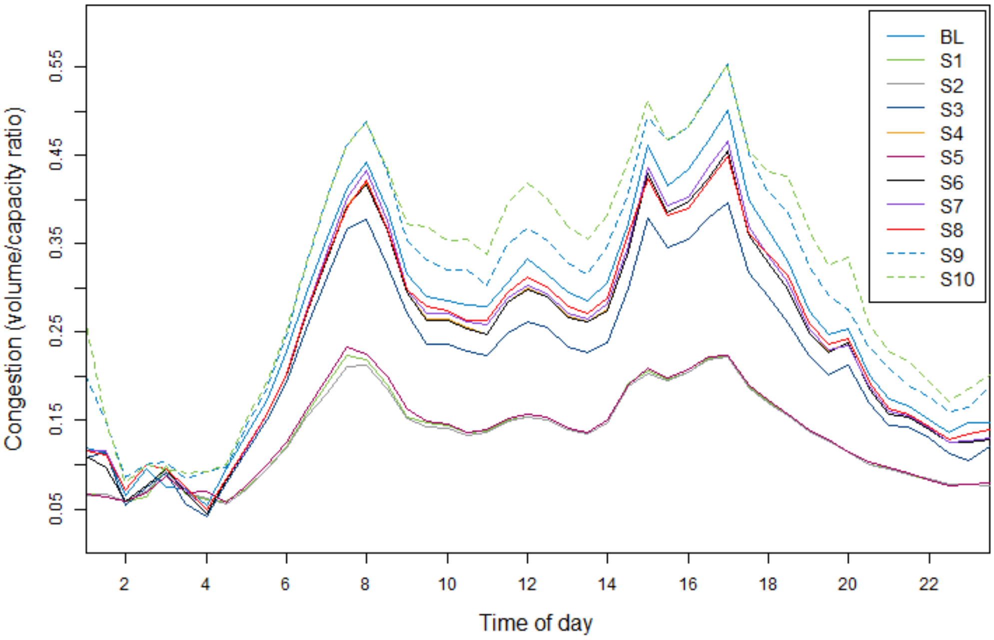
The percentage of trips performed by a certain shared mode shows how the transport system is efficient in terms of sharing (Figure 21). The larger share of Taxi-Buses means that there are more trips to share with more than four passengers. Most of the scenarios show nearly equal Shared Taxi and Taxi-Bus shares. Scenarios with LEZ (Sc. 7-10) show larger share of Taxi-Bus since the travellers are forced to park their cars at parking stations at the LEZ boundary and change to the shared modes or heavy public transport modes; this concentration of people at the boundary allow to match more people to go in Taxi-Buses in same directions. This might be seen as a measure of system efficiency, however, it should be coupled with the average occupancy rates. As Table 17 shows, in the case of scenarios 7-10 the Taxi-Bus occupancy rates are higher but the Shared Taxi occupancy rates drop (compared with all scenarios without LEZ), that is, the Shared Taxis become less efficient and make many trips carrying just one passenger.

Figure 21. **Mode share among shared modes**



The differences between the scenarios in congestion levels measured at different hours (Figure 22) are similar to the average ones presented in the previous sub-section. The congestion is calculated as an average volume to capacity ratio across all active links in the study area (more than 50 vehicle movements in one hour). In accordance with Table 13, the small LEZ scenarios (Sc. 9, 10) result in increased congestion compared with the current case, suggesting once again local congestion problems near the LEZ boundary but also significant cross traffic throughout the LEZ that has to be detoured; while scenarios with full car replacement (Sc. 1, 2, 5) provide the largest reduction. And, as could be expected, the difference is larger for the peak hours, especially in the evening, since during this time the congestion is the heaviest.

Figure 22. **Congestion per time of day**

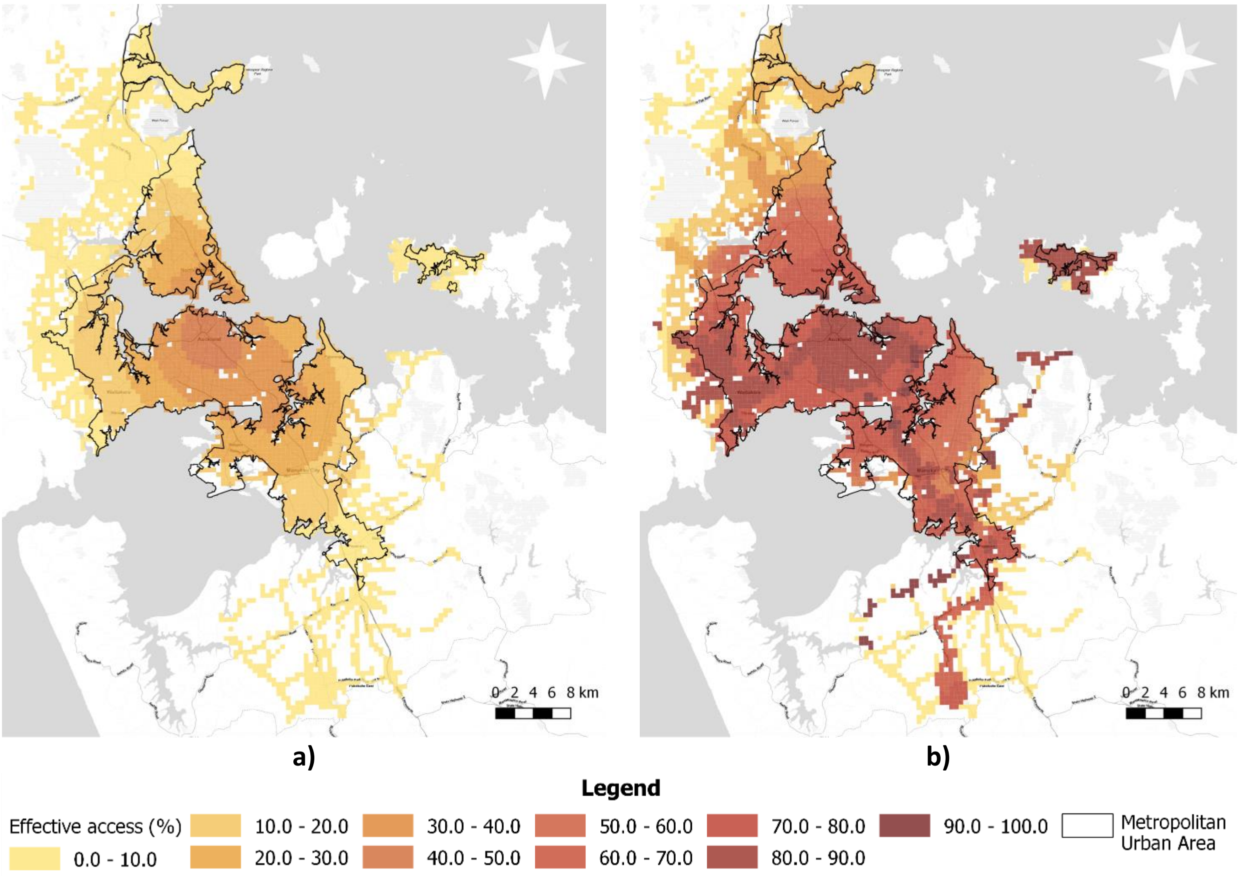


Changes in access and connectivity

Indications regarding levels of accessibility and connectivity are important measures as they show the potential of the transport system in linking people to activity opportunities (accessibility) and measure the performance for the actual trips (connectivity). More specifically, accessibility is defined as the ease of access to the amenities in the area in order to perform different kinds of activities, while connectivity is the performance of the transport system in terms of characteristics such as time, speed, number of transfers for a specific trip.

Shared mobility improves access significantly and provides more even distribution. Figure 23 shows the effective access for the PT system in case of baseline scenario and in case of full adoption (Sc. 1). The effective access represents the accessibility levels along a continuum of perception, taking into account the travel time related to a particular origin-destination pair by the attraction decay curve (see Annex 5). Currently (baseline scenario) the areas in the city centre and the one along the BRT line show better access. As the distance from the centre increases, the accessibility level drops with the lowest access for the part of the study area which is outside of the Metropolitan Urban Area (MUA). In case of full replacement the residents of the MUA are served very well; access also increased for other residents as compared with the baseline.

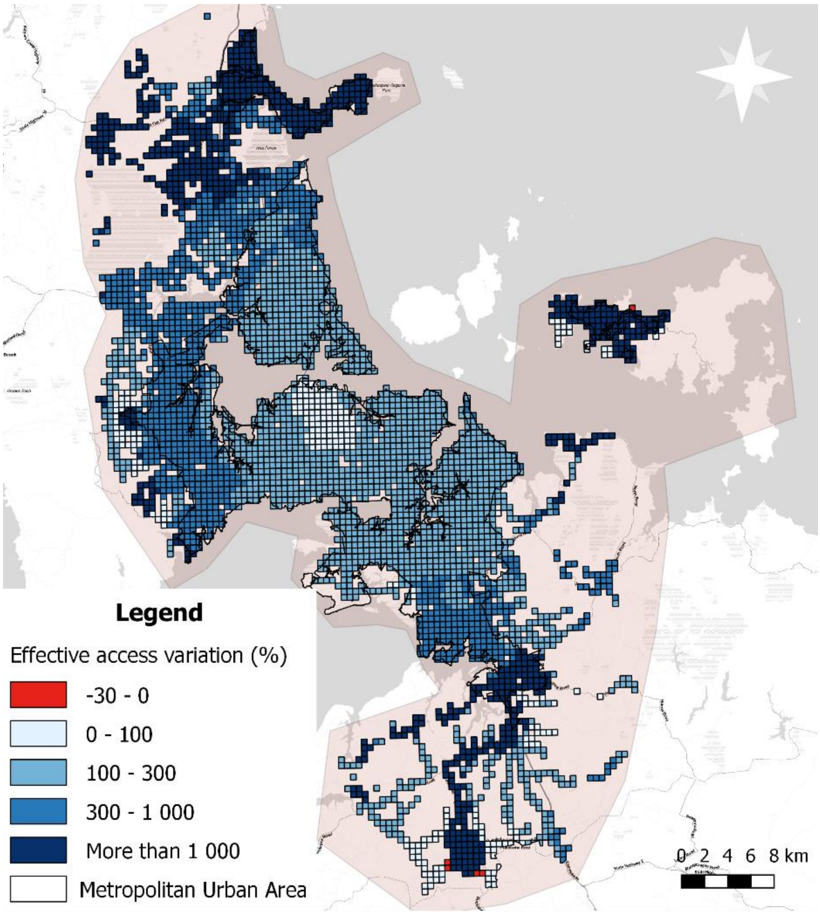
Figure 23. **Effective PT access to employment, (a) baseline and (b) potential of the full adoption scenario**



Source: ITF, Map tiles by QGIS.

Figure 24 shows the ratio of the effective access of the baseline scenario to the effective access of the full replacement (Sc. 1). The increase of the effective access of shared mobility is approximately proportional to the distance from the city centre. The average effective access for the baseline scenario across all grid cells is 23%, and for the full adoption it is 70%, which means that three times more people living in the study area will have good access to the jobs in the case of the full adoption scenario.

Figure 24. **Percent variation of effective public transport access to employment, as a ratio baseline and potential of the full adoption scenario**



Source: ITF, Map tiles by QGIS.

The graphical perception of the difference between the two configurations is strong enough to not need much further explanation, but it is worthwhile highlighting that in the current configuration the two lowest classes of accessibility dominate the landscape whereas in the simulated configuration the highest class is totally dominant, meaning that the majority of the grid cells have at least 50% of the reachable jobs in the city. Two quantitative indicators are given to express the scale of change on equity:

- The often-used ratio P90/P10 represents the quotient between the number of jobs accessible to the 10% best-served person and the number of jobs accessible to the 10% worst-served person. The value of this quotient goes down from a very inequitable 6.2 to a quite equitable 1.7.

- The Gini coefficient is the most-used indicator of inequality, often found in the distribution of income in societies. In the current configuration it takes the value of 0.13, a rather positive value in terms of equity, but in the simulated configuration it goes down to a very low 0.04.

All the scenarios with the shared modes lead to more even distribution of the quality of service across the residents of the study area. Table 16 shows the average trip attributes for the tested scenarios, differentiating their current mode choice (present car and PT users) and the resulting mode share under the scenario. The average trip attributes are connectivity indicators which serve as a proxy for the quality of service. In full replacement scenarios (Sc. 1, 2, 5) all the present car users had to shift to other modes so their average travel time increased to almost 30 minutes from 17.8 minutes (the baseline scenario). The travel time for all PT users decreased to around 30 minutes for all the scenarios except for scenario 2, where the current bus system was kept. This is due to the rules set in the simulation model where the bus users in scenario 2 would keep using the same mode and some rail and ferry users would shift to a combination of rail or ferry and a shared mode as a feeder. This would reduce the access time for these users, therefore affecting the average value. In addition, this would increase the number of transfers, the waiting time, and, as a result, the total travel time. Therefore scenario 2 results in a poorer performance both for car and PT users, that is to say, decreased connectivity for all. Scenarios with LEZ (Sc. 7-10) imply very small increase of average travel time for the current car users (around 1 minute) and significant improvements in connectivity for the PT users.

Table 16. **New mode shares (trips) and new average trip attributes for transport system users depending on the mode they use currently for the scenarios**

	Current car users	Current PT users					Car mode share (%)	PT and shared mobility mode share (%)
Scenario	**Travel time (min)**	**Total travel time (min)**	**Waiting time (min)**	**Access time (min)**	**On-board time (min)**	**Number of transfers**		
Baseline	17.77	44.42	18.02	11.97	0.86	0.86	82	4
1	29.00	31.29	9.07	8.05	0.37	0.37	-	86
2	28.93	48.91	18.24	11.79	0.97	0.97	-	86
3	24.33	28.60	8.16	8.63	0.36	0.36	49	38
4	20.18	27.87	7.58	9.01	0.36	0.36	68	18
5	28.92	29.98	8.68	8.98	0.46	0.46	-	86
6	20.20	29.11	7.72	9.60	0.46	0.46	68	18
7	19.09	28.32	6.87	9.40	0.35	0.35	77	14
8	19.24	28.21	6.83	9.44	0.35	0.35	78	14
9	18.92	28.25	6.81	9.43	0.35	0.35	79	14
10	18.56	28.13	6.69	9.52	0.35	0.35	81	9

Note: Car users that adopt shared mobility in each scenario result from the car mode share in the baseline minus the car share in each scenario. The mode shares do not add up 100% as the remaining not presented in the table refers to non-motorised travel (walking and cycling).

Operational performance

From the operators' perspective average occupancy of the new modes and the number of the required fleet are important indicators representing the efficiency of the system. Table 17 presents the corresponding values depending on the vehicle type. The vehicle types include the Shared Taxi and Taxi-Buses with 8 and 16 seats.

The average occupancy for each scenario is relatively good, enforced by the dispatchers' vehicle allocation algorithm design. Scenarios with full car replacement (Sc. 1, 2, 5) would require over 45 000 vehicles, scenario 3 with 50% of car trips replaced would require more than 22 000 vehicles, and the rest of the scenarios can be implemented with around 9-11 000 vehicles. This means that, given that in 2013 there were around 850 000 registered vehicles only in Auckland (estimated from the Household Travel survey), Shared Mobility could replace all car travel in the study area with around 5% of the existing number of private cars (7% of equivalent private car vehicles as discussed in Table 13).

New shared services in the Auckland study area could be covered with only few vehicle types (i.e. only with Shared Taxis), just differentiating the service by required access to a stop, the need of pre-booking, and more flexible detour and waiting times for customers. This possibility is based on the observation that the required number of Taxi-Buses with 8 seats is much lower compared with the other vehicles, especially for the scenarios with higher car replacement rates. This could lead to a more optimal allocation of vehicles.

Table 17. **Estimates for number of vehicles and occupancy**

	Average occupancy (pax)			Number of vehicles		
Scenarios	**Shared Taxi**	**Taxi-Bus 8**	**Taxi-Bus 16**	**Shared Taxi**	**Taxi-Bus (8 seats)**	**Taxi-Bus (16 seats)**
1	2.35	3.92	10.48	21 944	3 519	21 850
2	2.34	3.88	10.37	21 891	3 045	19 617
3	2.32	3.77	10.25	7 023	2 113	13 171
4	2.09	3.80	10.08	3 432	1 368	6 291
5	2.34	3.90	10.45	21 966	3 367	20 698
6	2.09	3.82	10.07	3 343	1 357	5 628
7	2.02	4.03	10.50	2 973	1 037	4 967
8	2.05	4.23	10.72	4 017	1 219	6 678
9	1.98	4.22	10.75	3 462	929	4 412
10	1.88	4.09	10.59	3 434	927	4 407

Comparison with Lisbon study

A brief comparison with the previous case study in the Lisbon Metropolitan Area (LMA) is presented in Table 18 for the full replacement scenario. The results suggest similar positive outcomes as in the original study.

Table 18. **Comparison of results with the Lisbon Metropolitan Area study**

	% Reduction to baseline	
Case studies, full replacement	**Vkm (weighted)**	**CO_2 emissions**
Auckland study area	51	54
Lisbon Metropolitan Area	48	62

Although the results are similar, they are driven by different factors and departing points of private car mode share. Similar land-use structure could lead to a greater vkm and CO_2 reductions in Auckland, as the private car mode share of Lisbon is approximately 50% lower than in Auckland. Nevertheless, the lower population density in the Auckland study area (maintaining the same standards of service quality) lead to lower vehicle occupancy levels of Shared Taxis and percentage of population served by Taxi-Bus services. This fact leads to a smaller elasticity of percentage of vkm saving per percentage of private car mode share reduction (1.09 in Lisbon and 0.62 in Auckland in the present). Spatial configuration, user preferences, transport infrastructure and land-use layout lead the observed elasticity drop of 42%.

This result is reflected in the mode share variations in both cities (Table 19). While in Lisbon, Taxi-Buses remain with a significantly higher mode share than Shared Taxi, in the case of Helsinki they become approximately the same. Furthermore, the mode share of heavy public transport in Lisbon in the "full replacement" scenario is significantly higher. In the case of CO_2 emissions, as the car fleet in Lisbon is older, the CO_2 reduction is greater than in Auckland despite a smaller reduction in vkm.

Table 19. **Mode shares of daily weekday trips (by number of trips) in Lisbon Metropolitan Area (2011) and Auckland study area, 2013 (%)**

Baseline	Heavy capacity	Bus	Car	Walk + Cycling
Auckland study area	below 1	3	82	14
Lisbon metropolitan area	12	20	50	19
Full replacement	Shared Taxi	Taxi-Bus	Heavy capacity	Walk + Cycling
Auckland study area	39	40	8	13
Lisbon metropolitan area	28	38	17	16

Note: Heavy capacity in Lisbon encompasses rail, ferry and metro, in Auckland it includes rail, ferry and BRT.

Detailed analysis of selected scenarios

A more in depth analysis was undertaken for some scenarios that were considered to provide greater insights regarding the shared mobility detailed performance, costs and test alternative vehicle engine specification. The additional indicators focus mainly on the system performance, both from a supply and user perspective. Three scenarios were selected for further analysis: Scenario 1 (full replacement), scenario 6 (20% replacement of private cars) and scenario 10 (the small LEZ).

As discussed in the beginning of the previous chapter, scenario 1 (full replacement of all road motorised trips and bus trips) provides a benchmark of comparison to other case studies. It also provides indicators for the city impacts and system performance when shared mobility is deployed at its fullest.

Scenario 6 represents a more realistic scenario where a portion of private car users are attracted to the new shared mobility services. In this scenario, keeping the high performance bus services, mainly represented by the BRT Northway Corridor, and replacing 20% of private car uses already leads to significant vkm and CO_2 savings. The stated preference survey suggests that a reduction of 20% of private car users is a plausible scenario, provided that the system is able to provide the level of quality stated in the survey.

The scenario with LEZ provides insights to the needs for additional infrastructure for the creation of park and ride stations. While the vkm and CO_2 reductions are not as significant as in other scenarios, it is also important to understand the underlying reasons for these results.

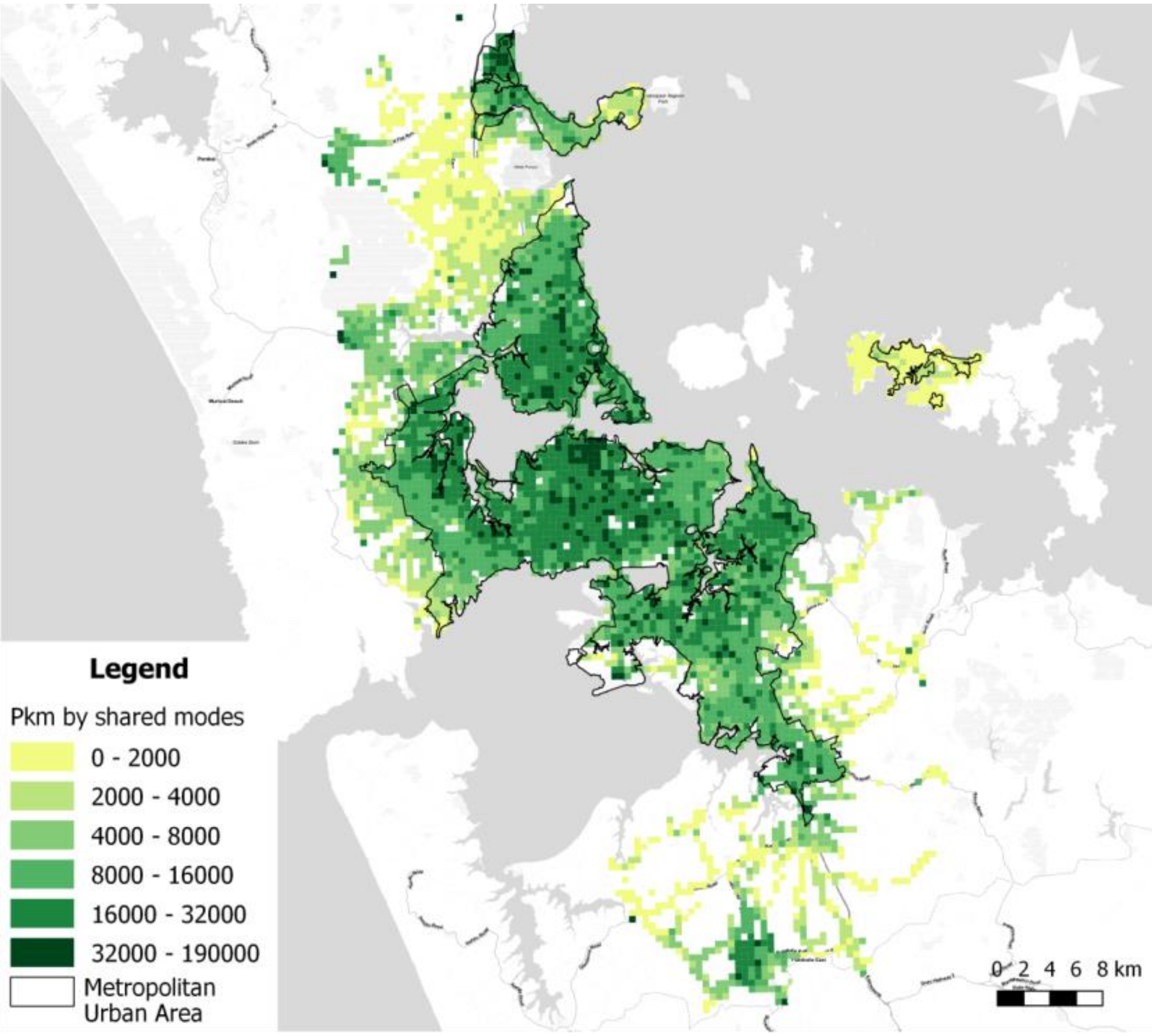
Additional analysis is presented below on congestion, parking and other space requirements, operational performance, costs and quality of services for the selected three scenarios.

Detailed mode share and public transport ridership assessment

The analysis of the spatial distribution of the trip departure location of pkm produced in the study area (Figure 25 to Figure 27) shows that the pkm by car and the shared modes are generated mostly within the boundaries of the MUA, with shared modes more employed in the south in scenario 6 and in the CBD in scenario 10. The same scale range is used for depicting the pkm in the current case (Figure 9) and of the scenarios.

In the full replacement scenario (Sc. 1) only shared mobility services are available with no private car or bus operation in place. Most of the passenger-kilometres depart from the city centre or from remote suburban areas connected by the highway system to the city centre. The spatial distribution of the pkm by shared mobility is very similar to the spatial distribution of the pkm by car in the baseline scenario (Figure 9).

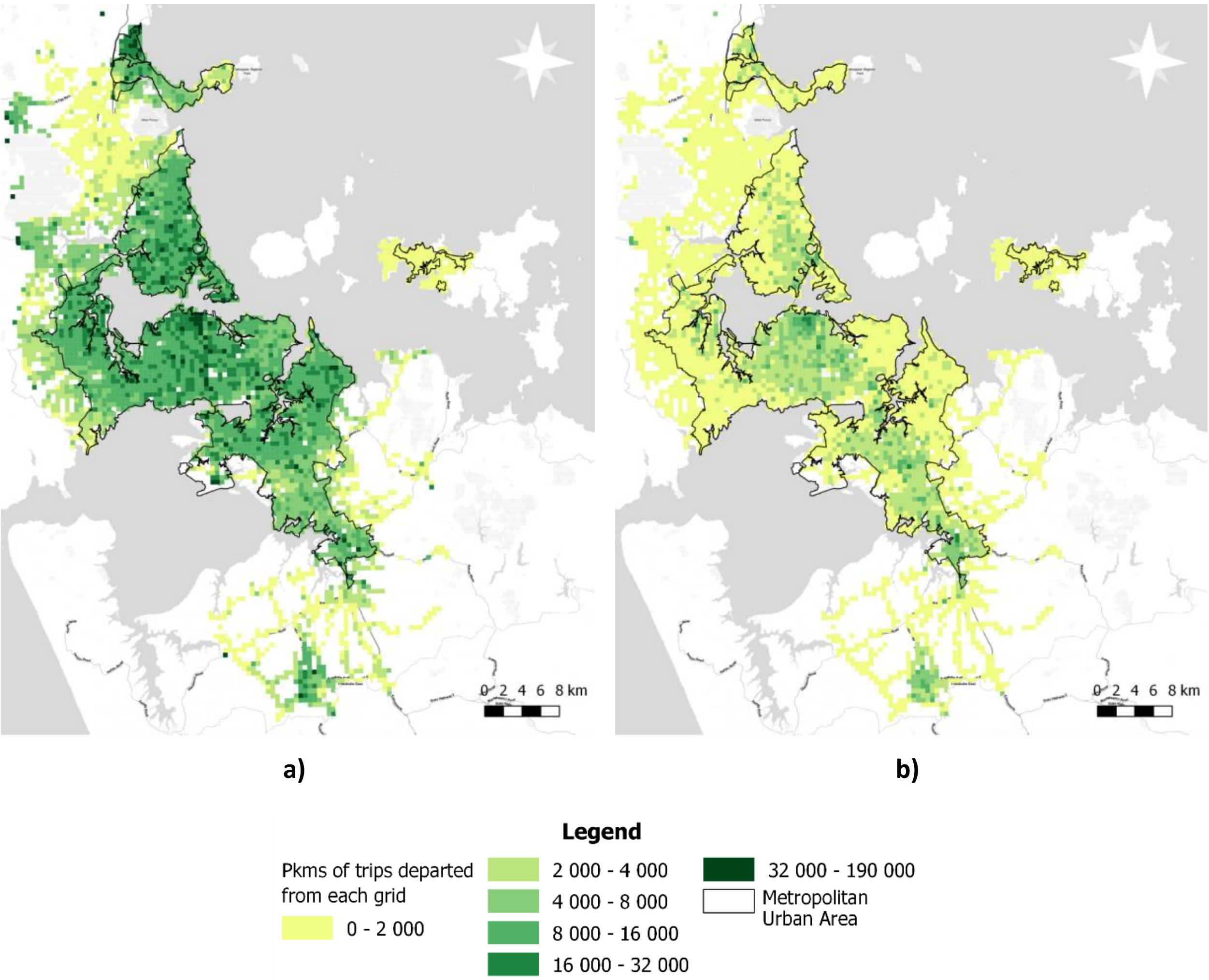
Figure 25. **Passenger-kilometres by shared modes by grid (scenario 1)**



Source: ITF, Map tiles by QGIS.

Scenario 6, which replaces 20% of private car trips by new shared mobility services, results in a different mode share by detailed area. While private car users remain concentrated in the same areas as in scenario 1, shared mobility users concentrate mainly in the southern part of the study area.

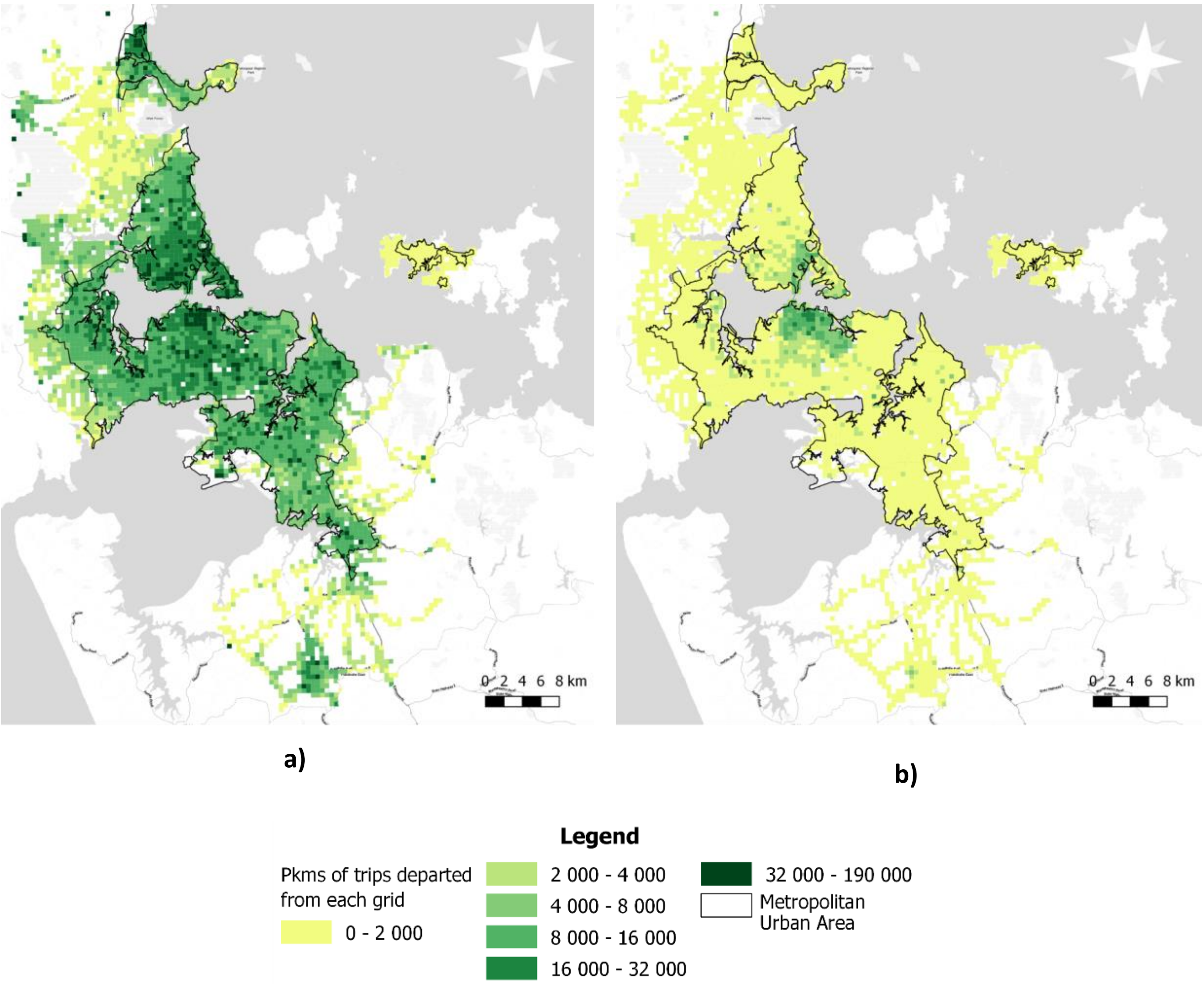
Figure 26. **Passenger-kilometres by car (a) and shared modes (b) by grid (scenario 6)**



Source: ITF, Map tiles by QGIS.

The small low emission zone scenario focusing in the peak periods (scenario 10) produces a concentration of shared services within the LEZ and the neighbouring areas. Private car pkm profiles remain similar to the other scenarios although restriction of their operation during the peak periods inside the LEZ diminishes the difference in pkm generated in the centre and other areas.

Figure 27. **Passenger-kilometres by car (a) and shared modes (b) by grid (scenario 10)**

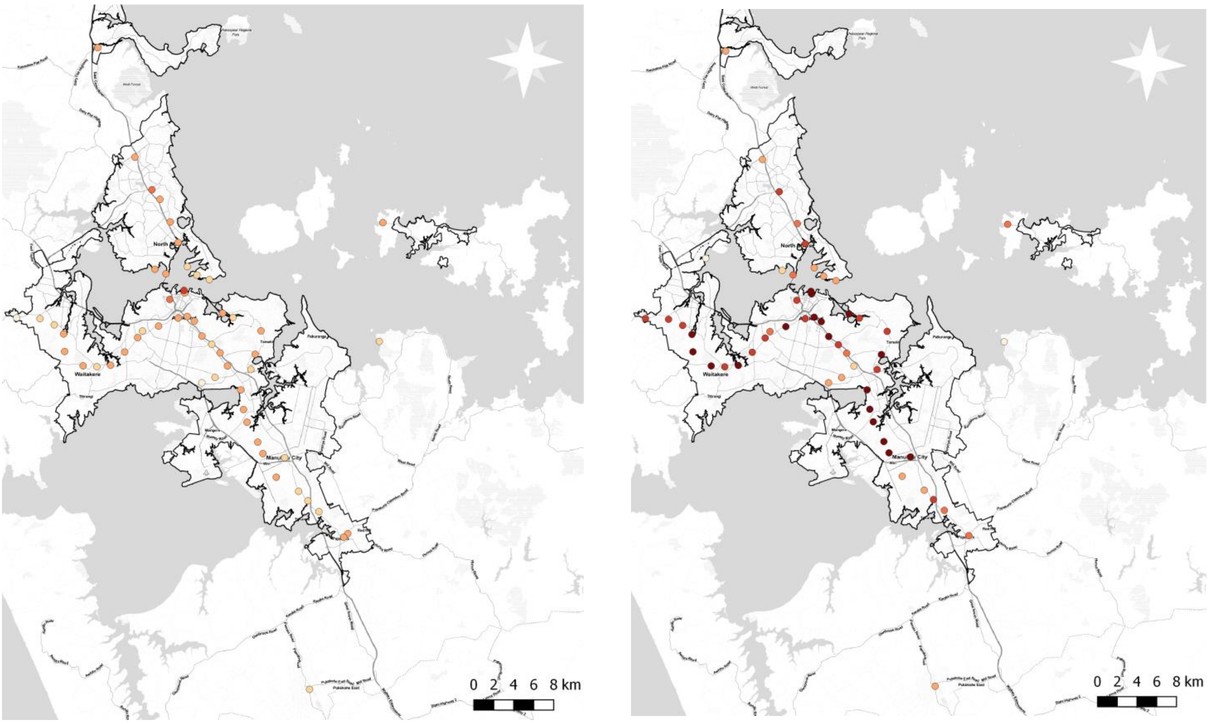


Source: ITF, Map tiles by QGIS.

In all scenarios, even with small car replacement shares, the public transport ridership potentiated by the presence of shared mobility services is very large.

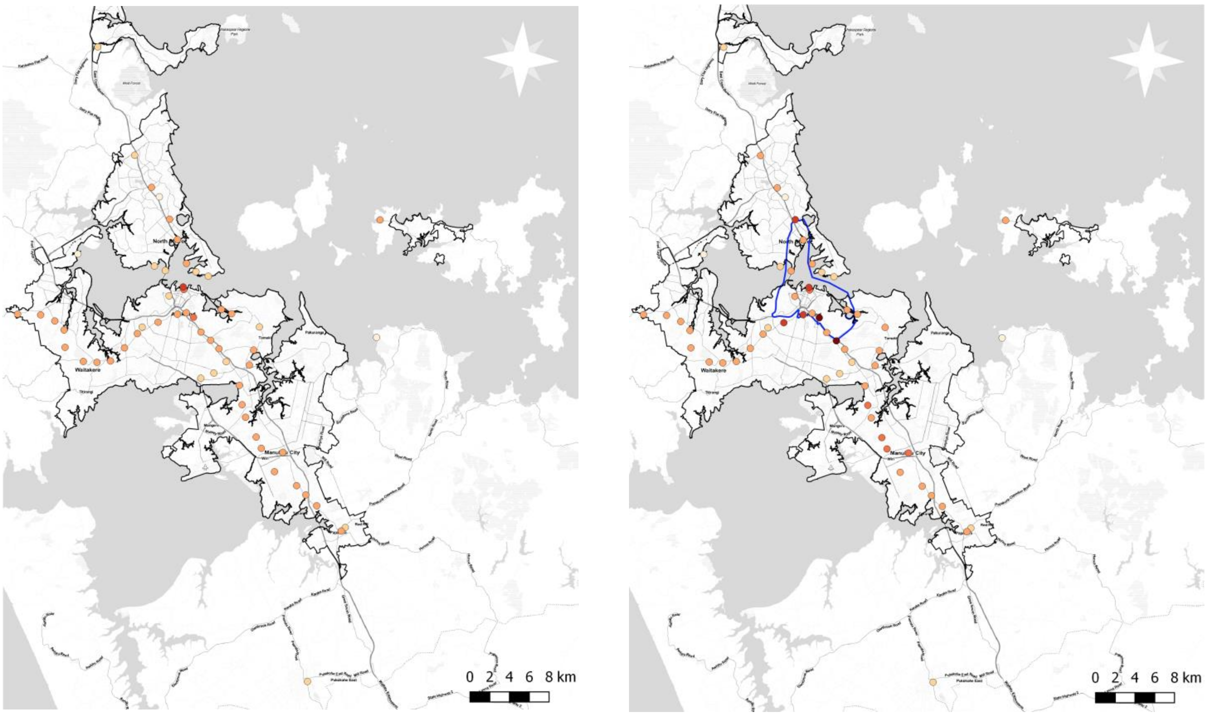
Figure 28 presents the number of boardings observed at rail, ferry and BRT stations. While in scenario 1 the growth is strong everywhere, especially in the Southern and Western rail line stations, scenario 6 and 10 show the largest increases near the city centre.

Figure 28. **Ridership by number of boardings at each station for the baseline and selected scenarios**



Baseline

Scenario 1



Scenario 6

Scenario 10

Legend Boardings at stops

○ 1-200 ● 200-1 000 ● 1 000-5 000 ● 5 000-10 000 ● 10 000 - 20 000 ● 20 000+

▭ Metropolitan Urban Area

▭ small LEZ

Source: ITF, Map tiles by QGIS.

Disaggregation by mode and by sub-area shows substantial boardings' increase at rail and ferry stations in the sub-areas where this kind of stations exists. Table 20 displays detailed spatial distribution of boardings in the sub-areas introduced in Figure 28 for the different scenarios aggregated by mode of transport. In the full replacement scenario (scenario 1) rail boardings increase very strongly. Ferry boardings are also expected to grow in the services connecting to the Harbour Ferry Station. The bus services are just preserved under BRT, mainly in the northern area and its connections to the city centre. The other scenarios lead to less strong increases, especially in scenario 6.

Table 20. **Ridership by number of boardings on rail, ferry and BRT by area – comparison of baseline and selected scenarios**

Area	Baseline (pax, thousands)			Scenario 1 (%)			Scenario 6 (%)			Scenario 10 (%)		
	Rail	Bus	Ferry	Rail	Bus	Ferry	Rail	Bus	Ferry	Rail	Bus	Ferry
North Centre	0.0	78.4	2.2	0	-49	234	0	-89	-57	0	-75	-17
North Far	0.0	10.7	0.0	0	-82	0	0	-85	0	0	-83	0
South Centre	35.2	142.6	10.7	1 229	-86	153	60	-88	19	265	-88	22
West	7.0	29.4	0.0	1 736	-100	0	106	-85	0	99	-85	0
South	10.9	50.1	0.0	1 199	-100	0	71	-91	0	189	-91	0
Waiheke	0.0	0.9	3.6	0	-100	104	0	-100	4	0	-100	8
Total/average	53.1	312.1	16.5	1290	-80	155	69	-89	7	228	-85	15

The increase in parking and ridership might lead to a lack of the existing parking lots around the train stations and insufficient train services capacity. The estimated values evidence the need to verify capacity availability at the four rail suburban lines operating in the study area. Some of the lines present already a double track configuration and are electrified. Yet there are still some segments near the city centre that are still single lines, significantly limiting the capacity and frequency of the services. Both stations and trains have to be adapted to this new potential reality where the ridership could increase more than tenfold. Moreover, the access to the stations will be performed mainly by Taxi-Buses and Shared Taxis which might require an adaptation of the stations to have space to pick up and drop off passengers. As Table 20 shows, the need for parking lots at stations grows on average 12 times (up to 18 times for some stations in scenario 1).

Quality of service

The detailed analysis of the scenarios shows that shared mobility can provide quite a high quality of service to the clients, leading to low waiting time and detour time apart from removing transfers and ensuring a seated place for passengers. Table 21 presents the statistical distribution of waiting time by travel distance range for each tested scenario. All the scenarios for the Shared Taxi present very good performance for all distance ranges; less than 25%of the customers wait more than three minutes. The stability of performance in this indicator is due to the design of the model, and more specifically, the optimisation constraints. The Taxi-Bus presents inferior performance indicators. Yet, the indicator for Taxi-Bus does not represent a waiting time at the stop, but rather a time deviation from the reported intended boarding time. Even if the boarding time is delayed 10 minutes the user is notified and can also delay the access to the Taxi-Bus stop.

Table 21. **Statistical distribution of waiting time (min) by travel distance class and scenario**

Mode		Scenario 1			Scenario 6			Scenario 10		
	Travel distance (km)	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.
Shared Taxi	< 2 km	1	1	2	1	1	2	1	1	2
	[2, 5] km	1	1	2	1	1	2	1	1	2
	[5, 10] km	1	2	3	1	1	2	1	2	2
	>10 km	1	2	3	1	2	3	1	2	3
	Average	1	2	2	1	1	2	1	1	2
Taxi-Bus	< 2 km	2	4	9	0	1	5	0	2	7
	[2, 5] km	5	10	15	5	10	15	6	11	16
	[5, 10] km	8	13	16	8	13	16	9	13	17
	>10 km	8	13	17	8	13	16	9	13	17
	Average	6	11	16	4	9	14	5	11	15

Table 22 presents another key indicator of the shared mobility performance: the total detour time. This indicator is the sum of waiting time and the additional time spent on board by a client compared with the private car travel. This indicator is set as a constraint of the dispatch algorithm of the Shared Taxi service, being a function of the travel distance. The results show that only for trips longer than 10 kilometres would the deviation from the private car on-board time would be greater than 10 minutes. The results for different scenarios show that there is some increase of large detour times for smaller shared mobility mode shares due to the reduction of probability of ride-matching.

Taxi-Bus services present significantly higher detour times that comply with a commercial speed of 15 km/h. In 25% of long trips, the delays can last more than 40 minutes in direct travel by private car. The average value for the 75th percentile for scenario 1 is 16 minutes, indicating than in 25% of the cases a client might be delayed more than 16 minutes compared with the travel by private car. This value grows significantly for the other tested scenarios with a smaller shared mobility share. This factor shows the importance of the market scale to ensure good quality of service at affordable prices.

Table 22. **Statistical distribution of detour time (min) by travel distance class and scenario**

Mode		Scenario 1			Scenario 6			Scenario 10		
	Travel distance (km)	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.
Shared Taxi	< 2 km	2	2	3	2	2	3	1	2	3
	[2, 5] km	3	4	5	3	4	5	3	4	5
	[5, 10] km	6	8	10	6	7	9	6	7	9
	>10 km	13	17	24	10	13	17	13	17	23
	Average	6	10	17	3	5	8	3	6	14
Taxi-Bus	< 2 km	5	8	12	6	10	17	6	11	18
	[2, 5] km	10	16	22	10	16	21	11	17	22
	[5, 10] km	19	24	30	19	24	30	19	25	31
	>10 km	25	33	43	27	34	42	27	34	43
	Average	14	21	29	11	17	25	12	20	28

Table 23 analyses the spatial detour of shared mobility services under different scenarios. The spatial detour is the ratio of the in-vehicle travel distance by a shared mode to the in-vehicle distance for the same trip if it was performed by private car, along the shortest path. In-vehicle distance by a shared mode can be shortened compared with the corresponding in-vehicle distance by car by a walking distance to and from the stops, but can be longer due to the detour. If these two differences are approximately equal, they cancel each other out and the result detour ratio is equal to 1. In the case of Shared Taxi it can also be 1 when the two paths travelled in-vehicle are identical.

Shared Taxis services evidence very low spatial detour ratios in all scenarios. These results are a consequence of the service design requirements and the high standards set. The obtained values for different travel distance ranges show that the larger detour ratios happen for distances between 2 and 5 km. This results in longer trips reaching the maximum detour time allowed by model constraints to ensure the desired quality of service.

The Taxi-Bus services also present a good spatial performance, which is stable throughout the scenarios. The obtained values can produce a 50% increase of the travel distance when compared with the direct and shortest path. A good performance in this indicator is important for clients and operators as it provides a high quality service at an affordable price.

Table 23. **Statistical distribution of spatial detour ratio by travel distance class and scenario**

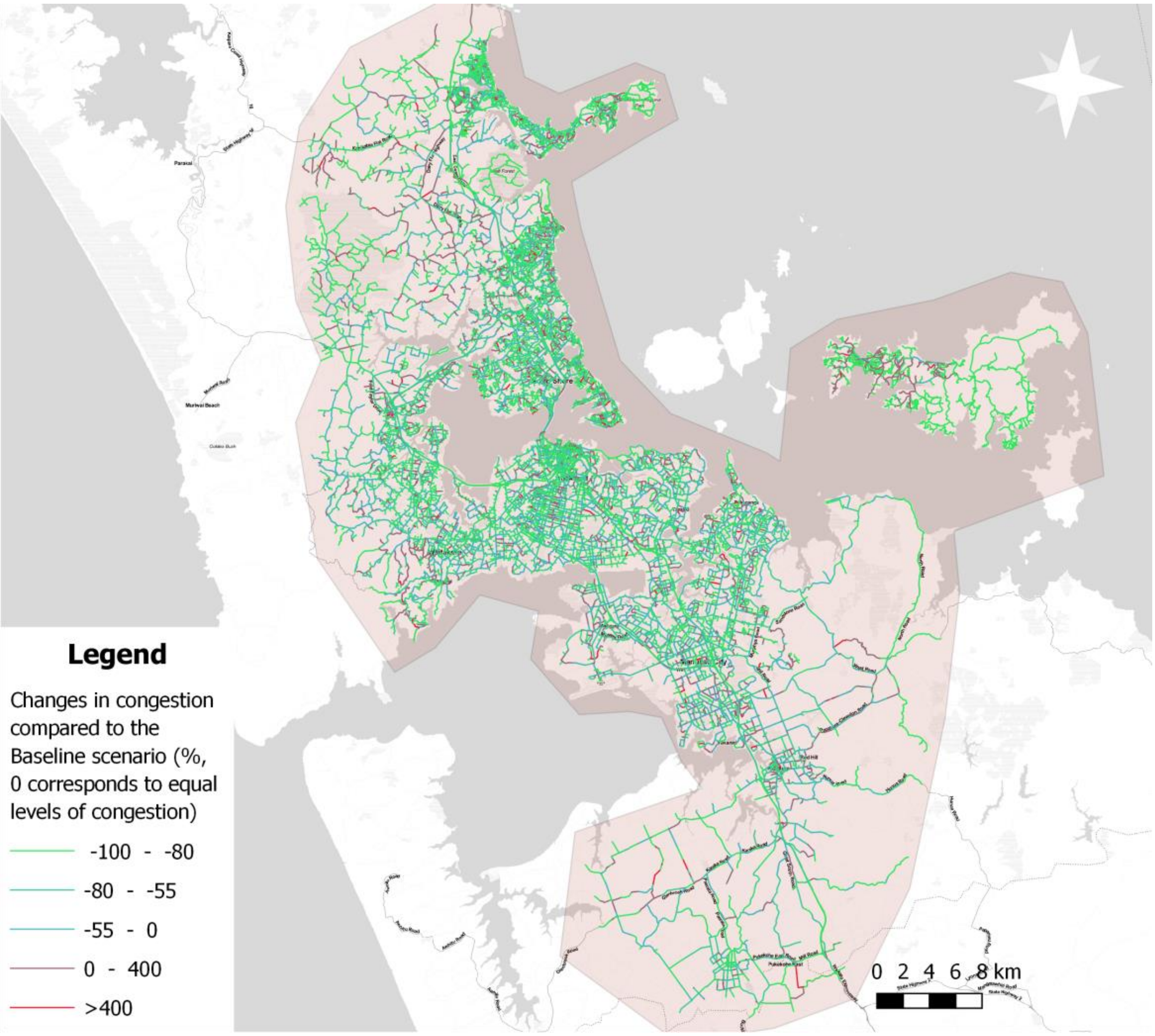
Mode		**Scenario 1**			**Scenario 6**			**Scenario 10**		
	Travel distance (km)	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.
Shared Taxi	< 2 km	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0
	[2, 5] km	1.0	1.3	1.7	1.0	1.0	1.3	1.0	1.0	1.1
	[5, 10] km	1.0	1.1	1.3	1.0	1.0	1.2	1.0	1.0	1.1
	>10 km	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0
	Average	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.0
Taxi-Bus	< 2 km	1.0	1.0	1.3	1.0	1.3	1.7	1.1	1.3	1.7
	[2, 5] km	1.0	1.2	1.5	1.0	1.2	1.6	1.0	1.1	1.5
	[5, 10] km	1.0	1.2	1.6	1.0	1.1	1.5	1.0	1.2	1.5
	>10 km	1.0	1.0	1.3	1.0	1.1	1.3	1.0	1.1	1.3
	Average	1.0	1.2	1.5	1.0	1.2	1.5	1.0	1.2	1.5

Congestion

The congestion levels per each road network link are reduced for most of the links in the three scenarios (Sc. 1, 6, 10) if compared with the baseline scenario. This assessment was performed as a perceptual variation of hourly motorised traffic during the evening peak in each road link. The travel savings observed in each link will depend on the volume-capacity ratio observed already in the baseline. For road links currently congested (over 75% volume-capacity ratio) a reduction of 50% in congestion would result in 40% less travel time than in baseline scenario, while for a low congested road (less than 25% volume-capacity ratio) a reduction of 50% in congestion would only result in 3% less travel time than in baseline scenario.

Figure 29 resents the current congestion levels during evening peak hours. This baseline level is compared with scenario 1 in Figure 29. There is a sharp decrease in congestion in the regional highway network and in the main roads in the Auckland city centre. Additionally, some sections of the main arteries that access the city centre are also relieved from congestion. Only a few sections see congestion increase, mainly because they are used to access shared mobility depot stations or heavy public transport stops. These capacity constraints should be mitigated with a proper local circulation plan near the depots ensuring a smooth movement of vehicles in the nearby area and providing several access points from the depot to the road network to distribute traffic.

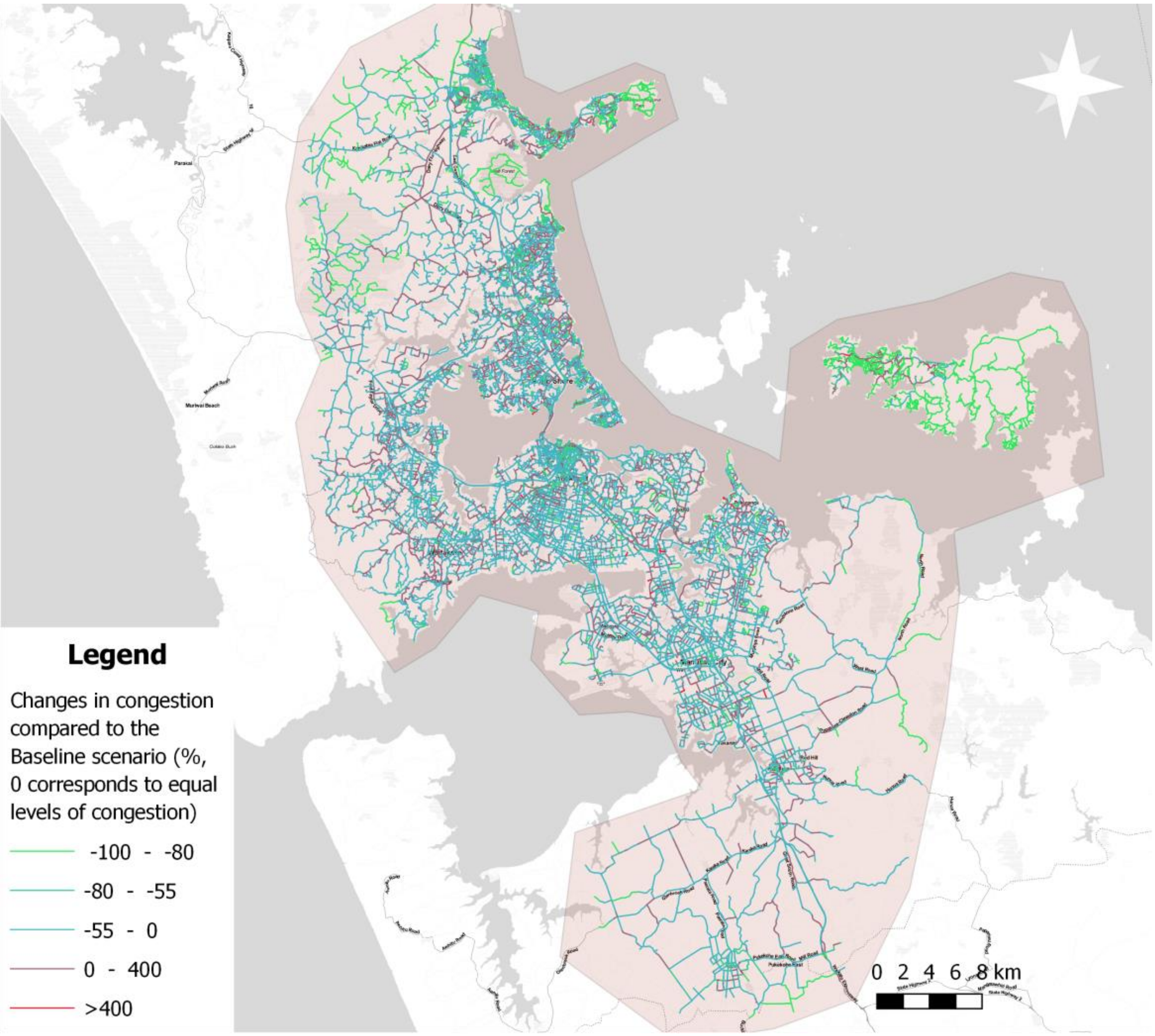
Figure 29. **Changes in congestion compared with the baseline (evening peak) (scenario 1)**



Source: ITF, Map tiles by QGIS.

In scenario 6, where the efficient bus services were kept and 20% of car users were diverted to shared mobility solutions, congestion results are also quite positive (Figure 30). Congestion is reduced up to 60% in most of the network links compared with the baseline scenario. Nonetheless, as in scenario 1, additional traffic is observed near shared mobility depots and heavy public transport stops.

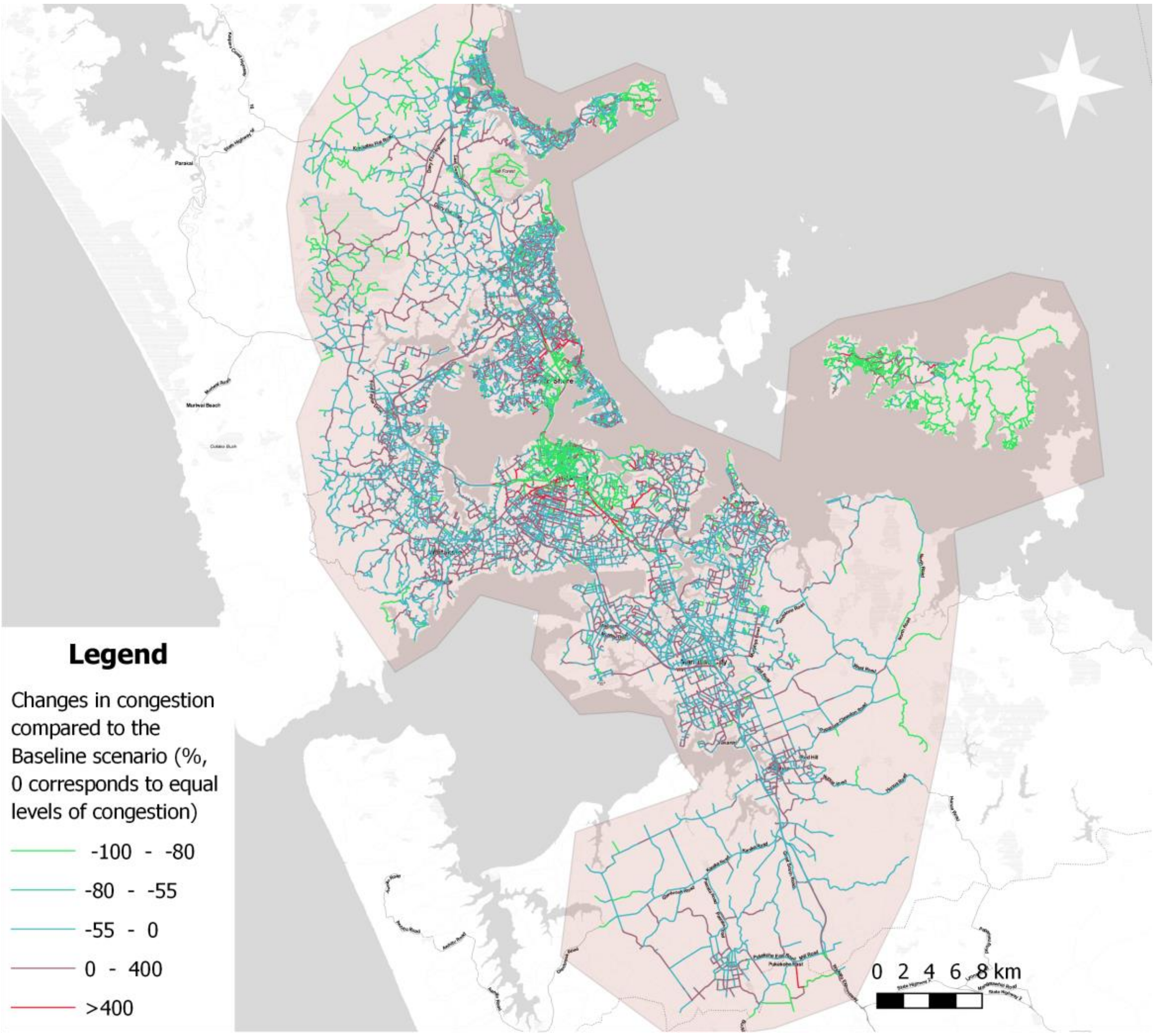
Figure 30. **Changes in congestion compared with the baseline (evening peak) (scenario 6)**



Source: ITF, Map tiles by QGIS.

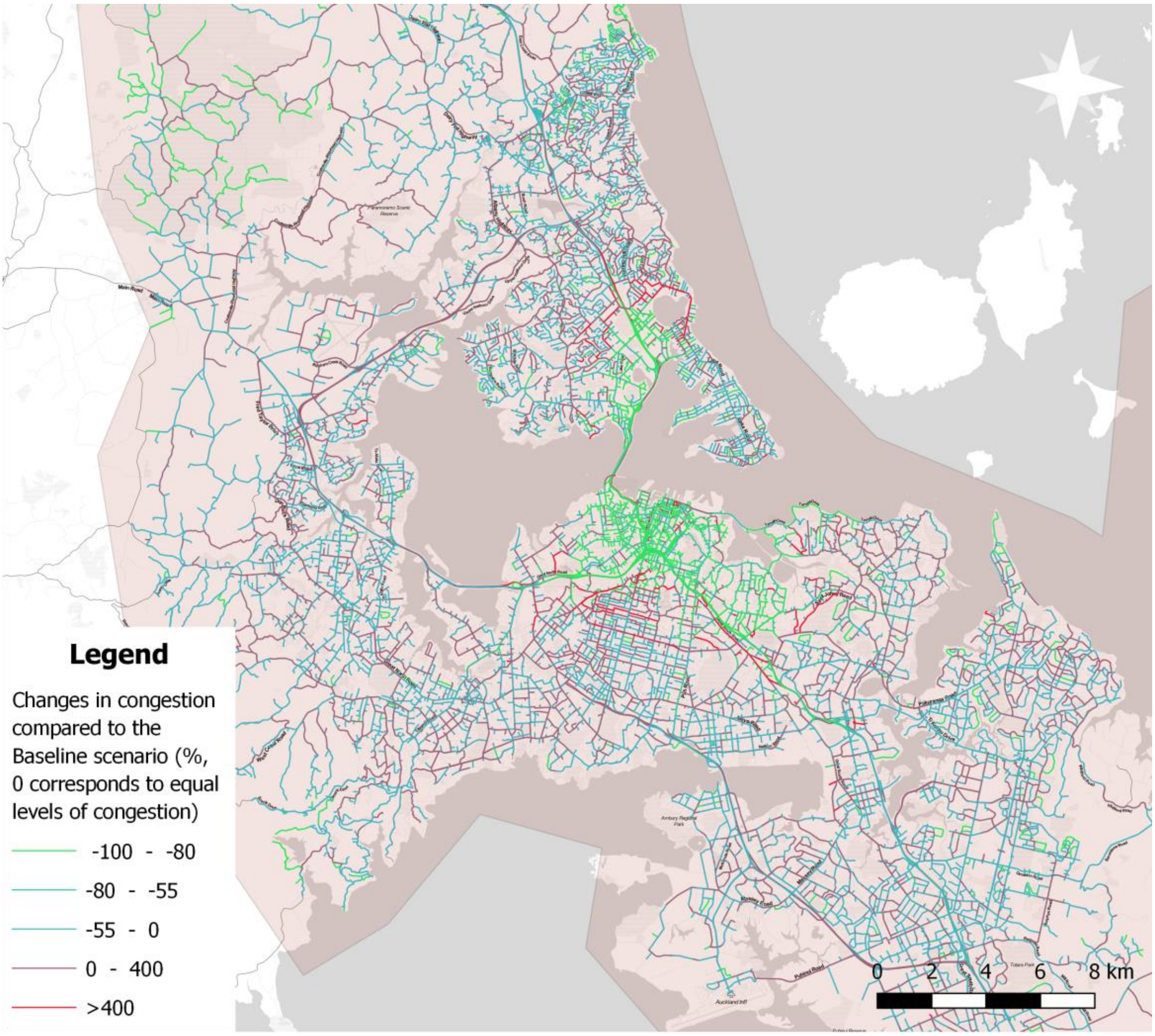
In scenario 10, where a small low emission zone boundary is set, results are positive inside the area while there are major problems around the LEZ boundary. The streets within the LEZ see drastic decrease in congestion (Figure 31 and 32). Yet, this reduction leads to concentrated congestion near the park-and-ride stations where drivers have to park their car when accessing the LEZ. There is some congestion reduction in the rest of the network, as some car users will shift to public transport. However, significant local congestion occurs close to Shared Taxi depots which would need to be addressed if this type of service was introduced.

Figure 31. **Changes in congestion compared with the Baseline (evening peak) (scenario 10), whole study area**



Source: ITF, Map tiles by QGIS.

Figure 32. **Changes in congestion compared with the Baseline (evening peak) (scenario 10), small LEZ focus**



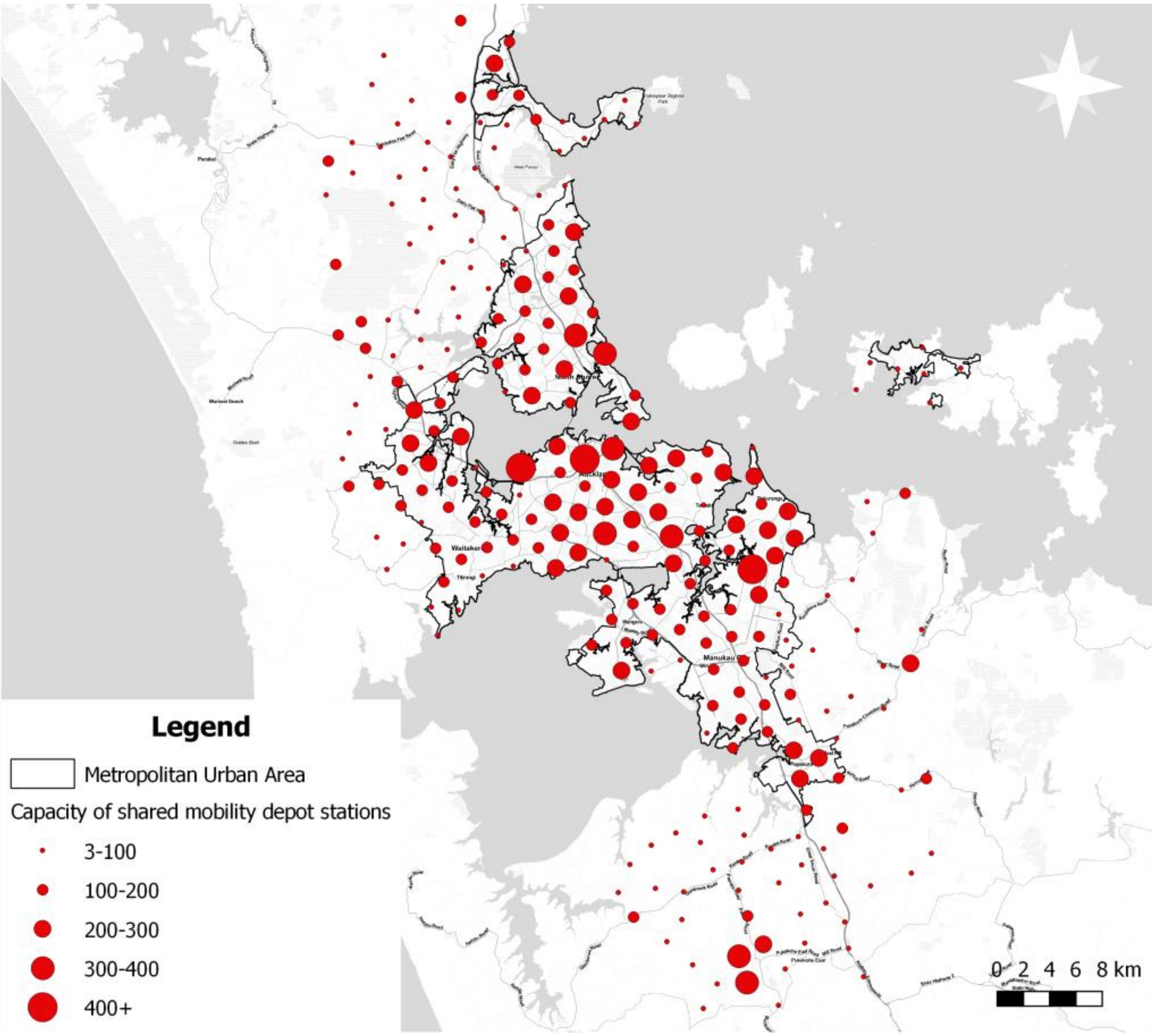
Source: ITF, Map tiles by QGIS.

Parking requirements

In Auckland most of the parking at residential locations takes place within private property, hence limiting the reduction of parking requirements only to private cars parked at streets close to home. This reduces the overall impact of shared mobility services on parking reduction in public streets, although in the centre, where most of the people work, reductions are more significant. This is different from the findings in the case of Lisbon, where reduced parking requirements and increased public space were among the main benefits of shared mobility.

Still, scenario 1 (full replacement scenario) estimates parking requirements of approximately 62 000 parking spaces for the whole study. This translates to 92% reduction of parking requirements. The needed parking facilities are mainly concentrated in depot stations for the shared mobility services, designed as off-street parking stations in the model. Figure 33 presents the spatial distribution of depot parking spaces. However, some of the large depots are located near the main activity areas for storing the vehicles, especially during the night. This may create additional space requirements in the CBD.

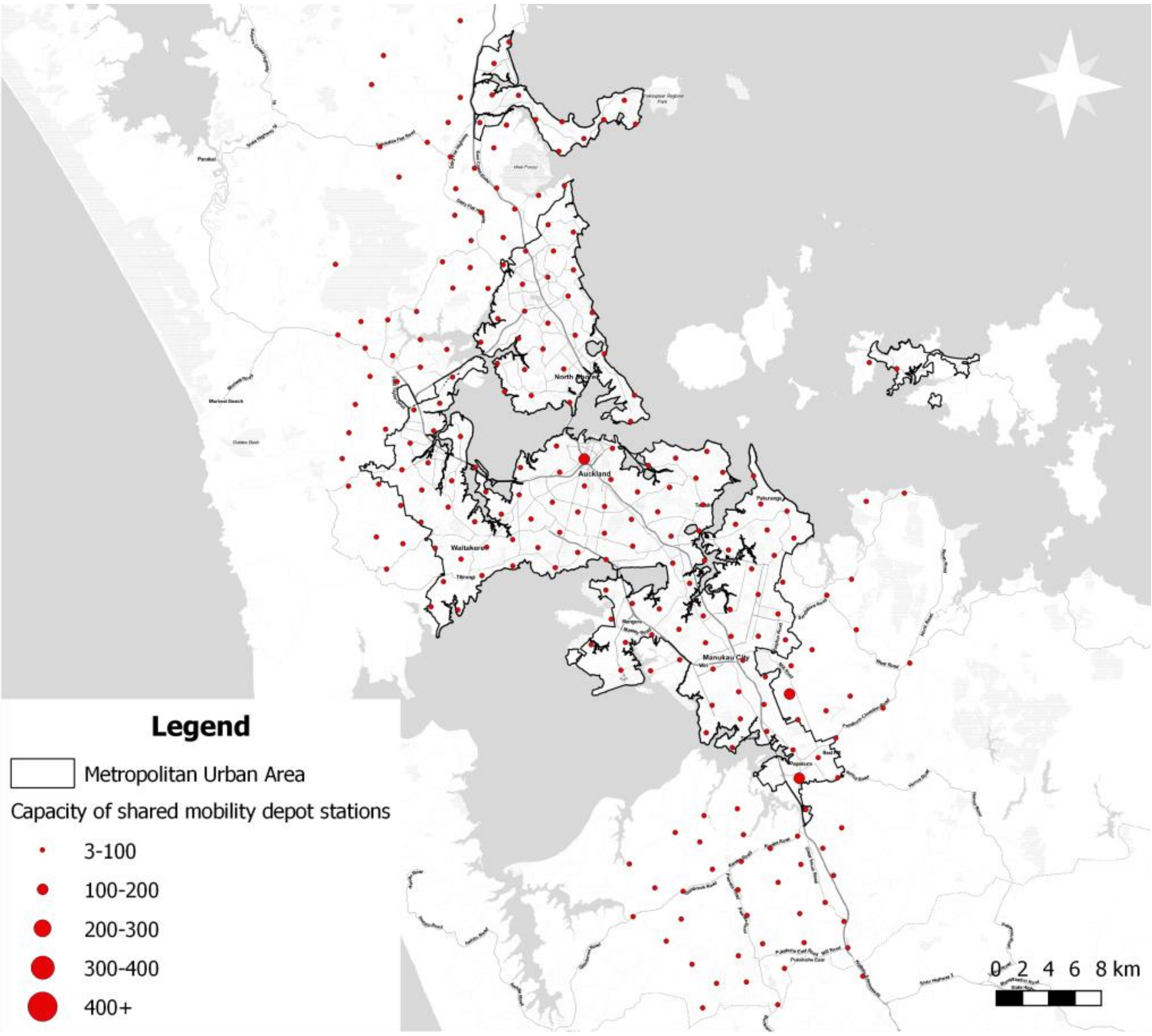
Figure 33. **Distribution of depot stations in the Auckland study area (scenario 1)**



Source: ITF, Map tiles by QGIS.

In scenario 6, parking requirements are not as significantly reduced. Since 20% of private car users are using shared mobility services, the remaining private cars still require traditional parking space. The shared mobility depots require around 6 000 parking places and the overall reduction in parking space is estimated at 11%. Figure 34 shows the spatial distribution of the three largest depot stations near the largest activity centres (i.e. CBD).

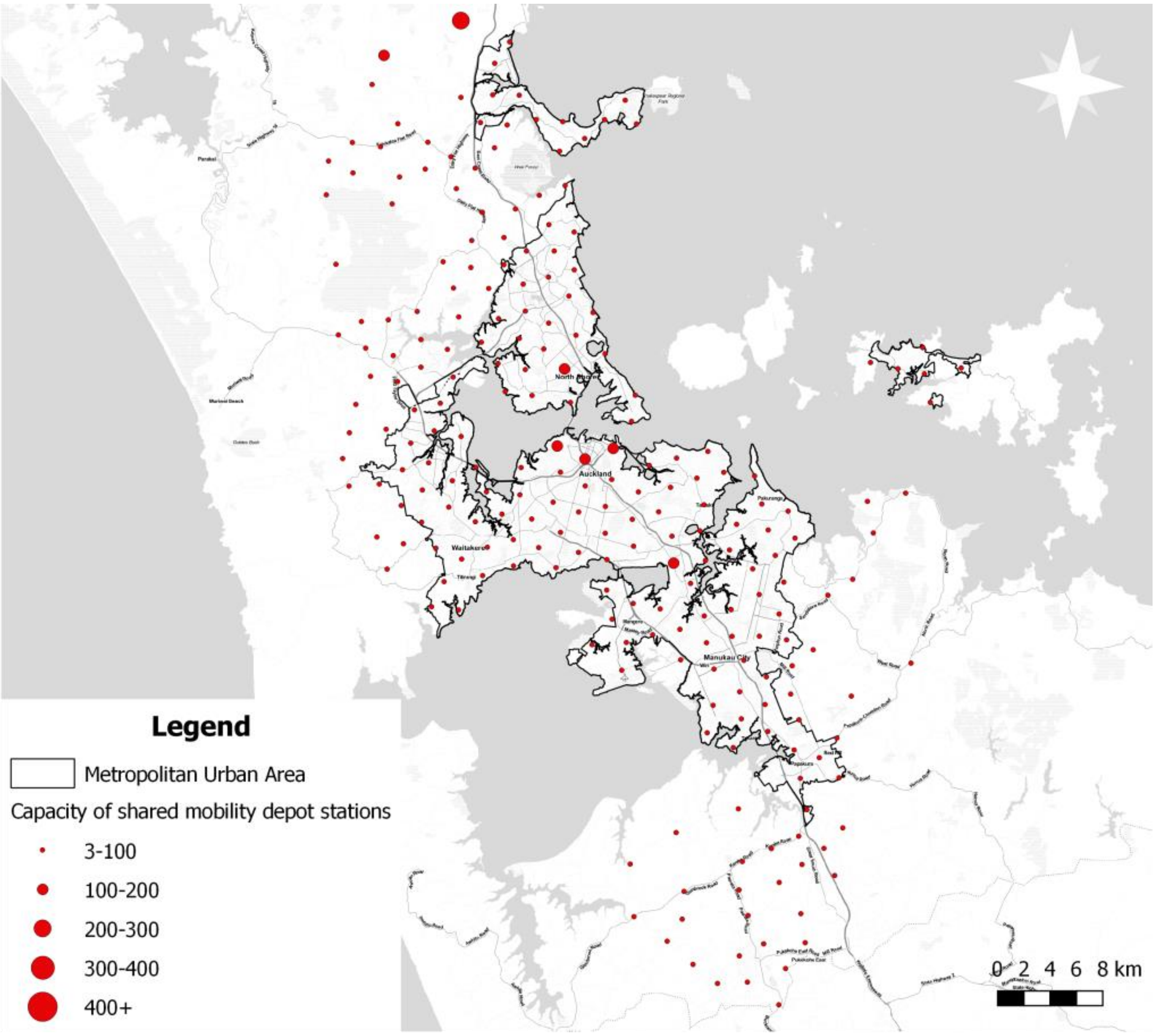
Figure 34. **Distribution of depot stations in the Auckland study area (scenario 6)**



Source: ITF, Map tiles by QGIS.

In scenario 10, parking requirements are at the same level as today. This is due to the fact that most of the private vehicles keep travelling throughout the day. The main depots for the shared mobility services are located near the LEZ boundary or in some suburban areas with large number of commuters to the city centre (see Figure 35).

Figure 35. **Distribution of depot stations in the Auckland study area (scenario 10)**



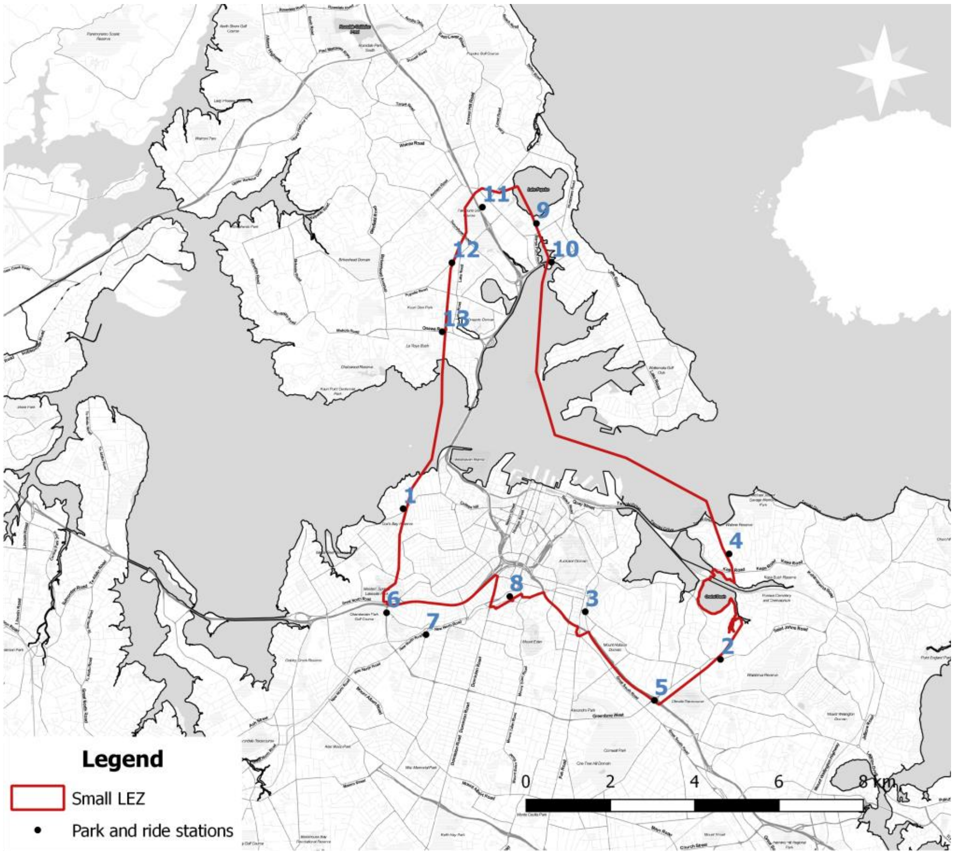
Source: ITF, Map tiles by QGIS.

The required park-and-ride capacity is also relatively significant in the scenario 10. The model considers 13 stations, of which four coincide with a railway station, one with a BRT station while the remaining ones serve the new shared mobility modes. The South stations (3, 5, 7 and 8) present the largest flows along with the Auckland Harbour Bridge station (see Table 24 and Figure 36). These park–and-ride stations require more than 1 000 parking lots to accommodate morning and afternoon peak demand. The space required for Shared Taxis drop-off/pick-up areas is reduced just reaching a value greater than 10 at the Smales Farm BRT station (park-and-ride station number 11). The estimated requirements of drop-off/pick-up areas of Taxi-Buses for 8 to 16 passenger vehicles tend to vary between five and 15 lots. This value seems to be not high and spatially feasible in most of the locations that could be devoted to park-and-ride stations.

Table 24. **Park and ride stations, flow and capacity (scenario 10)**

Park and ride stations	Arrivals			Departures			Required parking capacity		
	Car	Taxi-Bus	Shared Taxi	Car	Taxi-Bus	Shared Taxi	Cars	Taxi-Buses	Shared Taxis
1	8 058	5 581	0	6 618	6 429	0	610	12	0
2	10 641	6 964	0	9 474	8 396	0	1 353	9	0
3	13 852	8 266	107	14 956	6 923	2 127	1 091	15	1
4	4 512	3 694	602	4 610	3 697	473	794	10	1
5	13 162	5 207	124	12 982	5 056	516	823	9	1
6	6 373	4 846	0	5 589	5 675	0	503	7	0
7	11 674	6 967	3	11 939	8 591	450	1 013	14	1
8	13 985	8 419	74	15 560	8 843	1 093	1 503	11	1
9	1 921	1 132	0	1 949	1 404	0	240	2	0
10	4 798	3 814	0	4 240	4 393	0	411	9	0
11	7 660	5 017	4 433	8 664	4 820	3 962	730	19	14
12	7 078	4 586	0	6 805	5 312	0	807	8	0
13	10 393	8 653	0	11 117	7 890	0	875	11	0

Figure 36. **Park and ride stations (scenario 10)**



Source: ITF, Map tiles by QGIS.

Operational performance throughout the day

As discussed above, the reduction in the number of vehicles required to deliver the same mobility as today with the new shared modes is significant for the whole study area. Yet, from the operator's perspective mobilising the fleets for the stronger shared mobility implementation scenarios may be difficult. To shed light upon these issues analysis of the fleet requirement, dynamics and efficiency was undertaken for the three in-depth scenarios.

The full replacement (Sc. 1) produces a stable vehicle use rate, driven by the service design (Figure 37). The occupancy level of Taxi-Buses remains high throughout the day. Its drop at night is caused by clients that are promoted to Shared Taxi services since at that time the Taxi-Bus is not efficient.

Figure 37. **Average occupancy (a) and number of vehicles (b) (scenario 1)**

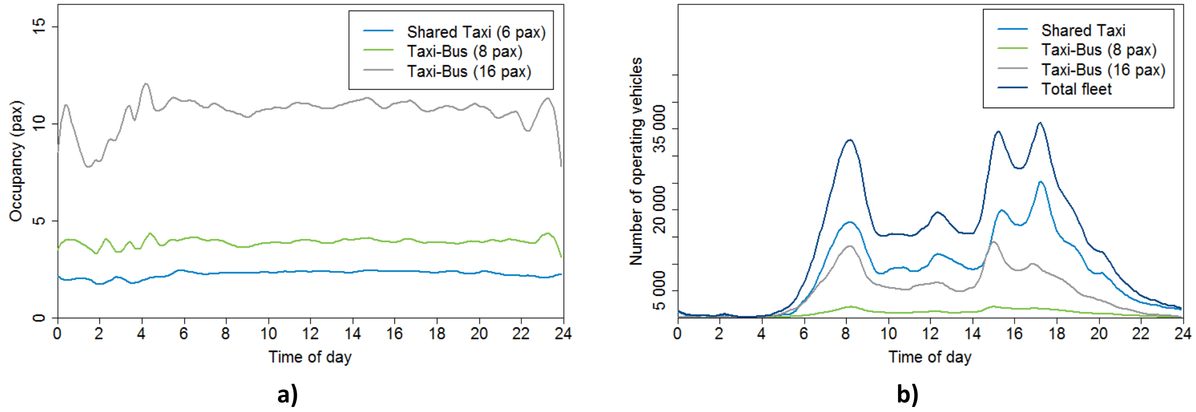
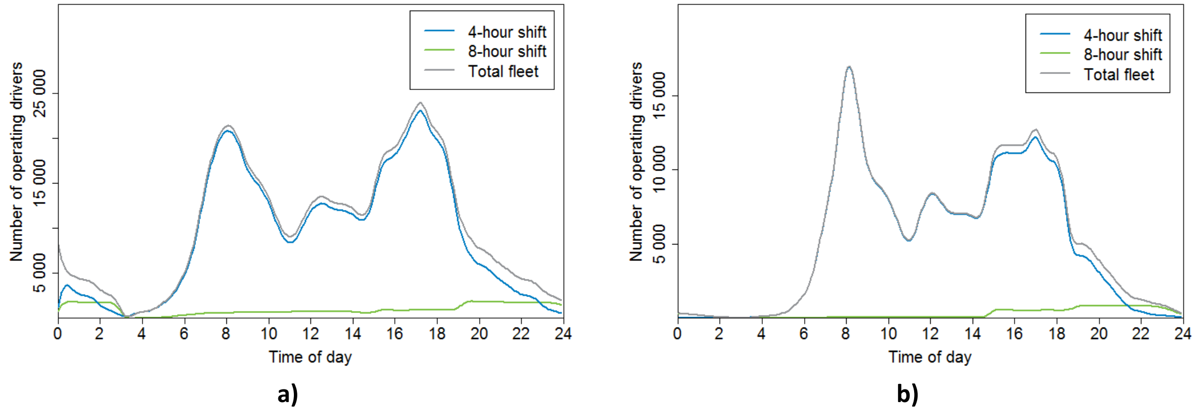


Figure 38. **Operation shifts of Shared-Taxis (a) and Taxi-Buses (b) (scenario 1)**

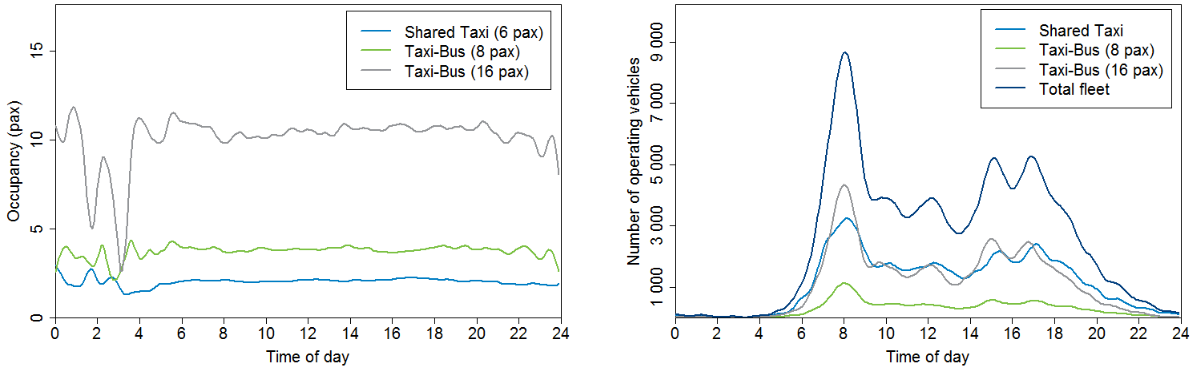


In terms of optimising the labour requirements, for both Shared Taxis and Taxi-Buses, a four-hour working shift results in a better outcome than other shifts as working periods are separated into more than two periods (Figure 38). During the morning peak a greater concentration of demand requires a larger number of Taxi-Buses drivers than in the afternoon peak, although the total demand along the whole period is smaller. During the afternoon peak more demand is served by Shared Taxi services than

Taxi-Buses, changing the fleet requirements during the day. From the operator's perspective, a more affordable operation could be achieved if some form of demand management was in place to reduce peak demand (and related fleet requirements). Additionally, vehicles that are idle during off-peak periods could be used for other purposes requiring large vehicle fleets, for example for urban logistics and deliveries.

Scenario 6 results in significantly more unstable occupancy levels for the different services throughout the day, especially during the low demand periods (Figure 39). This fact reduces the system efficiency significantly although in overall it is not significantly impacted as the demand during these periods is quite low. Vehicle fleet dynamics are quite similar to Scenario 1, although the dominance of Shared Taxis during the afternoon peak is not so visible.

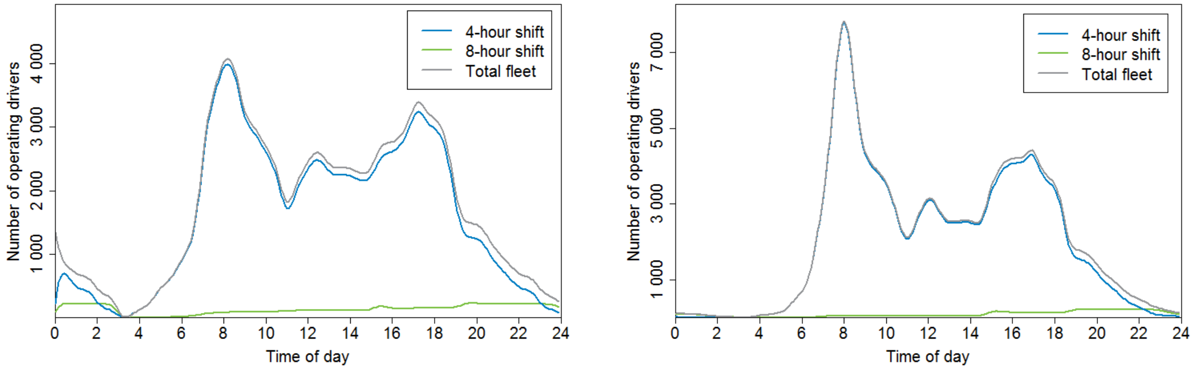
Figure 39. **Average occupancy (a) and number of vehicles (b) - Scenario 6**



a) **b)**

From the labour perspective, four-hour shifts would seem to be more efficient for both shared services, as Figure 40 shows. However, in this case some vehicles might not be at the right depot during the day, resulting in higher fleet requirement than necessary. This would obviously reduce the efficiency of the shared mobility vehicles overall.

Figure 40. **Operation shifts of a) Shared-Taxis and b) Taxi-Buses (scenario 6)**



a) **b)**

The small LEZ scenario with constraints during the peak periods (scenario 10) results in highly unstable operational indicators, as Figure 41 and 40 display. As the fleets are mainly used during peak periods the vehicles become idle during the day and efficiency of the fleet use falls significantly. There are also consequences in terms of labour as drivers might only operate during the peak periods. As a result, the overall efficiency declines while planning and managing operations become more complicated, and this affects the system affordability. The matching probability drops largely in a very narrow spatial area as it becomes difficult to ensure the service specification constraints without single-occupancy client rides. This fact almost converts the planned Shared Taxi service into a conventional taxi or transportation network companies (TNC) (i.e. Uber, Lyft) service.

Figure 41. **Average occupancy (a) and number of vehicles (b) (scenario 10)**

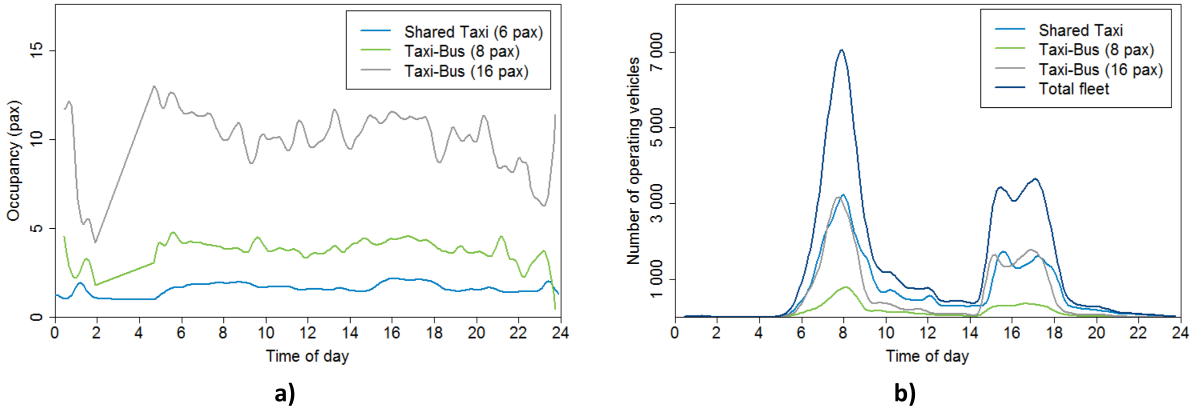
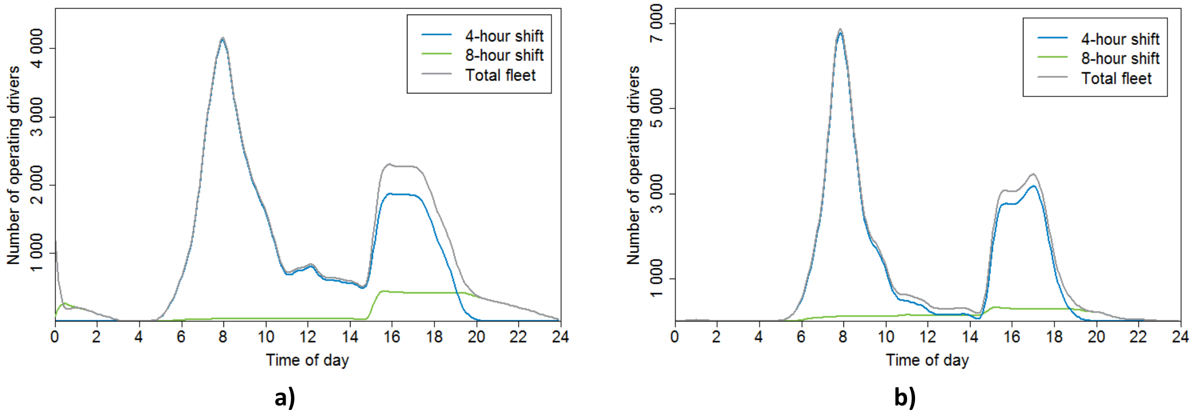
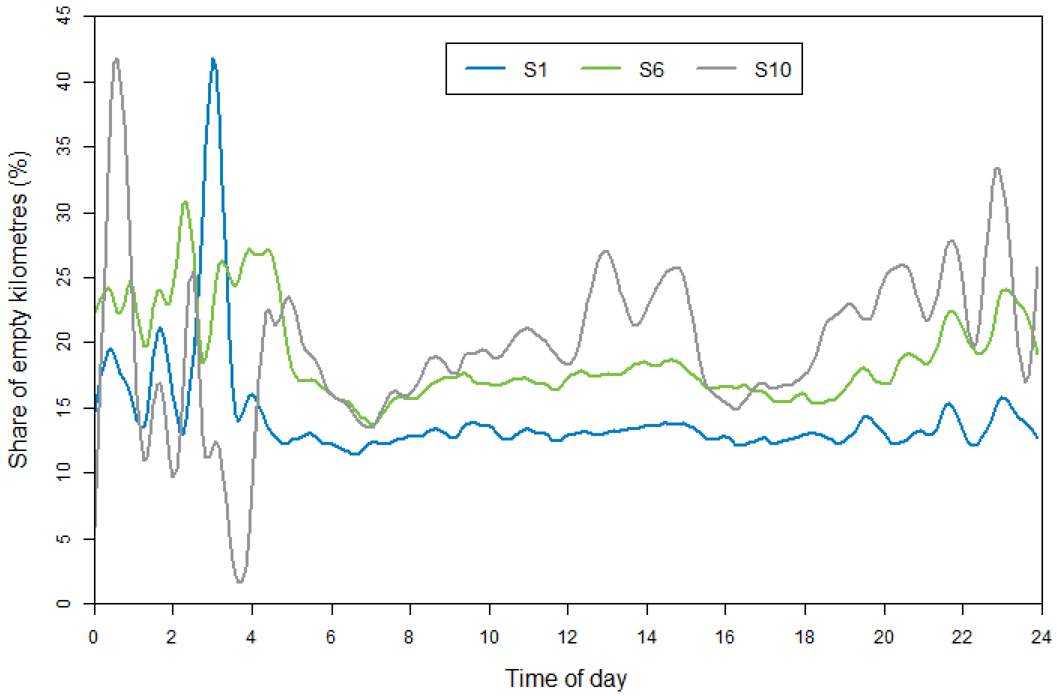


Figure 42. **Operation shifts of a) Shared-Taxis and b) Taxi-Buses (scenario 10)**



Finally, the model allows for estimating how many vehicles are idle at any moment of the day. Generally, increase of vehicle-kilometres of TNC and taxis services is reported in some contexts (Rayle et al., 2016) due to the large idle distances driven by vehicle to search for new clients, reducing the benefits for the overall mobility system in terms of CO_2 emissions and congestion. The ITF model by design does not allow this behaviour and vehicles are always diverted into a depot when idle, minimising idle vehicle-kilometres and minimising the need for the road and parking capacity. Figure 43 shows that even in the scenario 6 with lower demand for shared mobility services, the idle kilometres performed by drivers are not significantly increasing.

Figure 43. **Share of empty kilometres for shared mobility services in three scenarios**



Costs

All costs analysis presented in this section were performed considering regular vehicles with drivers and constrained to the working shifts regulation. Under this assumption, the price per kilometre for the Shared Taxi users is lower than the one of the current taxi and for the Taxi-Bus users the price is cheaper than in the case of PT (Table 25). The price of the shared modes is the break-even calculated to cover all costs associated with the vehicles (acquisition/capital, maintenance and operation) and drivers (salary and social charges), plus management costs and margin for profit (a 20% margin of labour and vehicles costs). Annex 6 shows the values and sources employed in these calculations. As the table shows, the price of the Shared Taxi is within 20-28% of the conventional taxi price and is around 1.7-2.4 times higher than the current PT fare. The Taxi-Bus ticket price is within 6-7% of the cost of a conventional taxi and is around two times lower than the current PT fare.

The model estimates for self-driving operation result in reductions of approximately 50% on the prices for Shared Taxi and Taxi-Buses per kilometre for scenario 1. This reduction would lead to Shared Taxis being cheaper than current public transport in Auckland. The estimated values are aligned with recent studies that assessed the cost of shared self-driving vehicles (Stephens et al., 2016).

Table 25. **Prices of Shared Taxi and Taxi-Bus services as percentage of current taxi and public transport fares (with driver operation)**

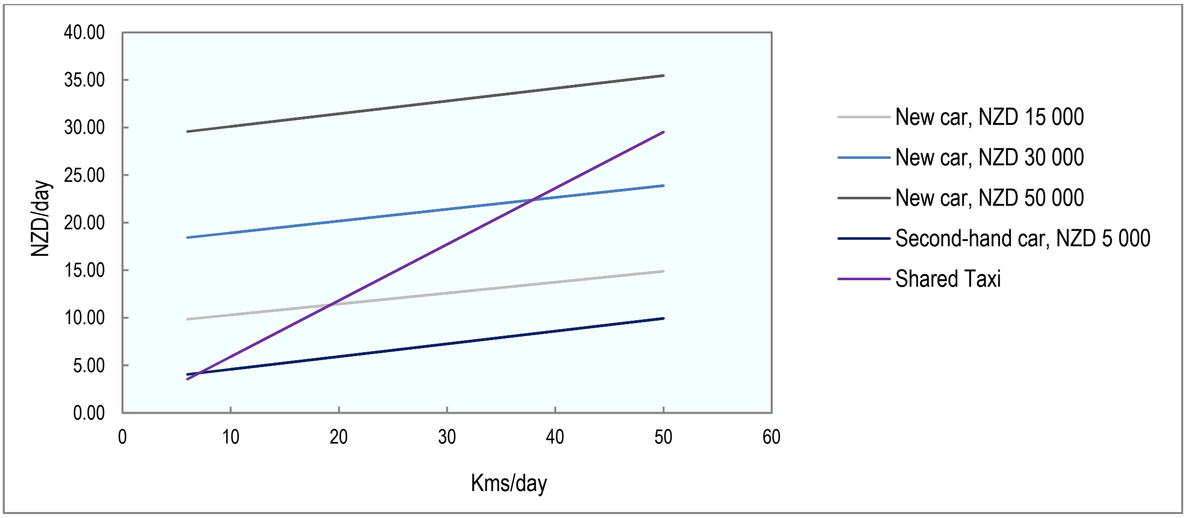
Scenarios	Shared Taxi (NZD/km)		Taxi-Bus (NZD/km)	
	Average taxi trip	PT cost for user	Average taxi trip	PT cost for user
1	20	169	7	57
6	22	186	6	54
10	28	240	6	49

Therefore, Taxi-Bus services can be offered to potential users at the prices significantly below PT. This is a remarkable result taking into account that in the focus group and stated preferences survey PT users showed some willingness to pay for these new services values higher than for PT and the cost was pointed out as one of the most relevant elements for shared mobility adoption. This indicates that a segment of these users might even be attracted to the Shared Taxis, although its costs are between three and five times higher.

Shared Taxis cost more than PT for the users, but they can be offered at a third or less of the cost of the conventional taxi services. It should be noted that the shared mobility prices were calculated based on the current study area driver's costs. Forms of procurement whereby Auckland Transport is not the direct supplier of these services will have different cost structures and be subjected to a different regulatory framework. This can potentially be used to leverage more competitive prices for the end user. The calculations were performed not considering any public service compensation to public transport operators that worldwide vary between 20 and 60%of the public transport operator's revenues in urban areas (Roth and Kåberger, 2002; Tscharaktschiew and Hirte, 2012).

There are economies of scale in the offer of these services. It is important to acknowledge that scenario 1, where all car drivers and bus clients switch to shared mobility, is not the scenario that leads to the most affordable Taxi-Bus services. Universal coverage of the shared mobility services may lead to an increase in unit cost but warrants a good spatial equity within the study area. Regarding Shared Taxis the size of the market for lower ridership levels may normally be positively impacted by the scale.

Figure 44. **Total commuting cost per day and km of car ownership vs Shared Taxi (scenario 1)**



In Figure 44 and Table 26 the price of Shared Taxis is compared with the costs of owning a car (excluding parking costs). This comparison is made per km of use per day. Different car types are included in the comparison, from an inexpensive second-hand car that costs NZD 5 000 to the most expensive segment that costs NZD 50 000.

Compared with a new car from the highest segment Shared Taxi has a lower cost unless the daily commute by car surpasses 40 km in scenario 10, 49 km in scenario 6, and 63 km in scenario 1. In contrast, a second-hand car has a lower cost unless it is used less than around 5 km per day. Driving an economic new car (NZD 15 000) is more onerous than riding in a Shared Taxi if it is used less than 12 to 19 km per day depending on the scenario.

Table 26. **Break even for commuting distances (km) required for car to be less expensive than Shared Taxis**

Scenarios	Second-hand car, NZD 5 000	New car, NZD 15 000	New car, NZD 30 000	New car, NZD 50 000
1	7	19	37	63
6	5	14	29	49
10	4	12	24	40

Electric vehicles fleet

The simulation also tested the adoption of an electric vehicles fleet. We assumed an electric fleet with autonomy of 150 kilometres, four hours fast charging to 100%, two hours fast charging to 75% and that no vehicle starts operation with less than 75% charging level. The three tested scenarios showed that the required fleet would need to be increased between 2.3% and 10.3% to ensure short- and long-term charging operations. The requirements are lower for the scenarios with higher car replacement shares (Table 27). The electric vehicles autonomy, required charging times and charging stations where all taken into account.

Table 27. **Number of additional electric vehicles required compared with combustion engine vehicles (%)**

Scenarios	Shared Taxis	Taxi-Bus	Total
1	2.31	1.10	1.66
6	7.35	2.38	3.99
10	10.29	0.32	4.22

Large fleets in scenario 1, especially in the Taxi-Buses that present less distance travelled per vehicle, require a very small fleet increase. The other scenarios with smaller fleets lead to significantly larger fleet requirements, especially for Shared Taxis. The result is mainly driven by the probability of proximity of a vehicle with sufficient charge to provide the service. In scenario 10, where the locations of Taxi-Bus requests are very concentrated near the park and share stations, the additional fleet requirements are almost none. By the contrary, in scenario 10 Shared Taxis require a significant fleet increase as they operate mainly in LEZ but can also be requested from a suburban area to access to LEZ, which increases the complexity of the efficient fleet allocation in the modelled area.

Integration of the charging outlets and the parking depots requires changes in the existing infrastructure. Table 28 and Figure 45 characterise the charging and parking requirements for scenario 1. The values show that less than one-third of the parking spaces needs to have charging infrastructure. Additional employees are required at depot stations to move vehicles from charging locations to simple parking while vehicles are waiting to be picked up by a driver or waiting to be charged.

Table 28. **Characterisation of charging and parking requirements with electric vehicles (scenario 1)**

Variable	Value
Maximum station charging outlets capacity	74
Minimum station charging outlets capacity	3
Average station charging outlets capacity	12.35
Total charging capacity	3 322
Charging operations	26 974
Charging time (hours)	13 487
Maximum charging outlets use rate (%)	72.40
Average charging outlets use rate (%)	20.80
Parking capacity total	11 362
Minimum parking capacity per station	5
Maximum parking capacity per station	337
Average parking capacity per station	79.50

The spatial distribution of the parking capacity is similar to the distribution of the parking stations for the scenarios presented earlier in this section (Figure 33). Nonetheless, the percentage of parking spaces with electric charging outlet follows a different spatial layout. The depots located in suburban residential areas present a higher share of parking spaces with electric charging outlets that are used during the night to be fully charged in the morning for commuting trips (Figure 45). The depots within and closer to the CBD also present charging outlets, but normally as the cars are more dynamic in these locations, vehicles do not have to stay charging for long to recover 75% of the charging capacity.

The adoption of electric fleets for the operation of Shared Taxis and Taxis-Buses varied in terms of full operational costs for each tested scenario (see Table 29). The cost variation results from the additional vehicle acquisition costs (vehicles cost assumed NZD 15 000 more expensive for either Shared Taxi or Taxi-Bus) and derived insurance and maintenance costs, the additional fleet requirements and the new cost of energy costs, estimated per vkm as 26% of the current diesel costs. In Shared Taxis, electric fleets lead to a cost reduction in all tested scenarios; the driven kilometres (vkm) was the most relevant cost component and compensated for additional fleet costs. In Taxi-Buses, the additional fixed cost component (additional fleet and fleet costs) only compensates in scenarios where the fleet is intensively used, with an average vkm/vehicle value greater than 80 km/vehicle, which was not achieved in scenario 10. This threshold is achieved very easily for Shared Taxis and but not so easily in small range or adaption level for Taxi-Buses.

Figure 45. **Share of charging outlets at the parking spaces (scenario 1)**

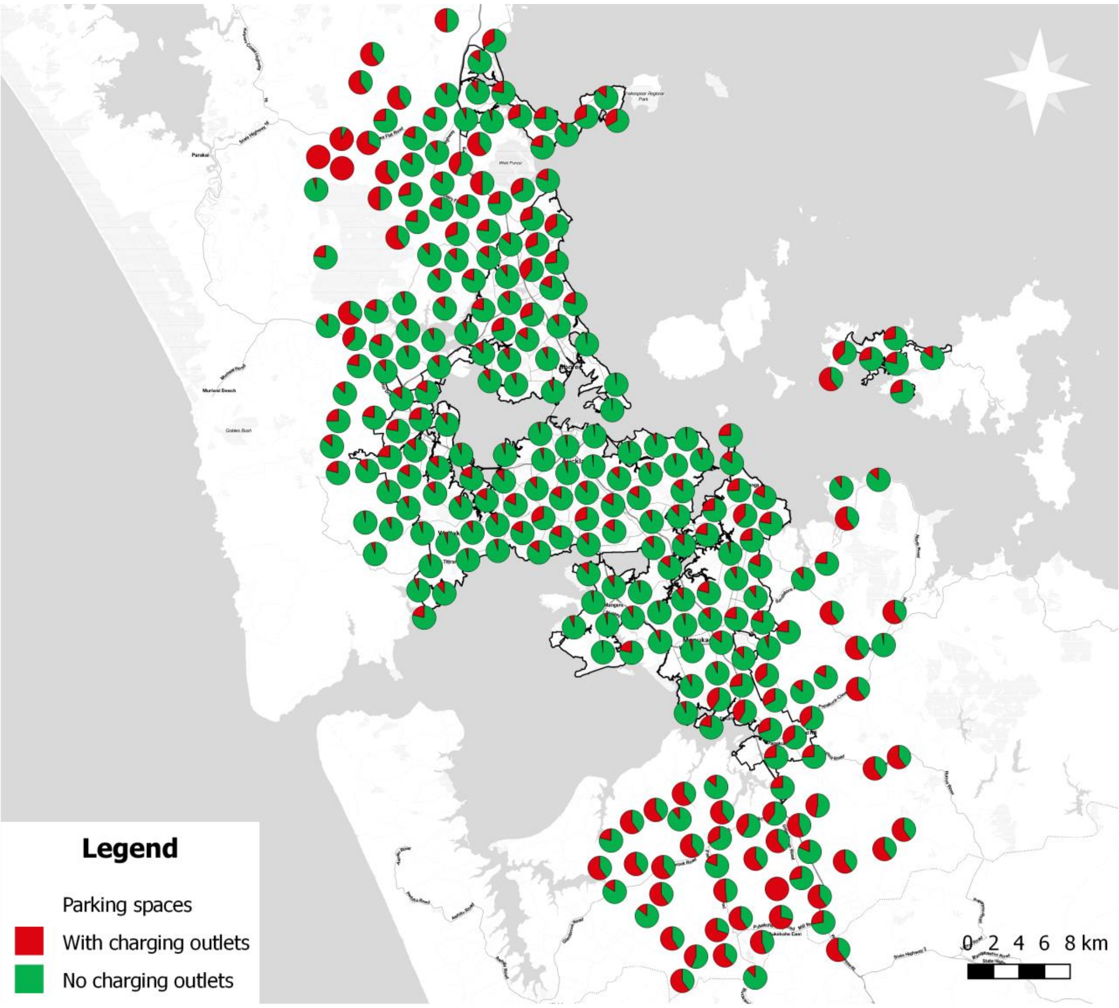


Table 29. **Variation of full operational costs compared with combustion engine vehicles (%)**

Scenarios	Shared Taxis	Taxi-Bus
1	-8.84	-5.97
6	-5.52	-0.45
10	-1.33	3.28

Electric fleets can also further reduce CO_2 emissions. The reduction in CO_2 tank/plug-to-wheel emissions would be 99% in scenario 1, 22% in scenario 6 and 7% in scenario 10. These are all sizable reductions; even for scenario 6, which seems more achievable. The introduction of shared mobility services provided by electric vehicles would lead to a very ambitious CO_2 reduction.

Impacts on present mobility key findings

As a summary, the key findings regarding the shared mobility impacts on the Auckland study area obtained from the simulation results are:

- Shared mobility can bring substantial improvements to the city and its transport system in terms of reduction of congestion and CO_2 emissions. The positive gains are strongly coupled with the share of car users shifted to the shared and PT modes.

- Shared mobility leads to a large increase of access in non-private modes and promotes evenly distributed accessibility amongst the area's residents (spatial and social equity). The introduction of the shared modes and their combination with the existing heavy PT modes substantially increases connectivity by PT, especially for those residents who currently have relatively poor service. At the same time the PT system and the shared modes are able to serve the former car users providing an increase in flexibility (i.e. freeing users from needing to drive and maintaining vehicles during their daily travels) at the price of a small penalisation of waiting and detour time.

- Shared mobility has the potential to considerably increase rail, ferry and BRT ridership. This fact might require revisiting the capacity of the current rail system and stations. Furthermore, the stations layout might need adaption by providing easier access and ensuring locations for vehicles to park, in addition to drop-off/pick-up areas.

- Introduction of a too narrow operation area for shared mobility solutions can compromise the benefits of sharing. The probability of matching for short trips and for a small number of users may be minor, reducing the efficiency of the proposed solutions as observed in the small LEZ scenarios. Furthermore, the tested small LEZ led to local heavy congestion effects around the park and ride stations. The obtained results did still bring some marginal benefits in terms of vkm and CO_2 emission reduction, but by forcing more people (compared with the large LEZ) to change their mobility patterns.

- The affordability of shared mobility services is affected by the scale of adoption. Small adoption rates and time focused implementations (e.g. peak periods), as tested in scenario 10, may decrease the vehicle usage efficiency strongly. The results show that market shares close to 20% produce some gains already and lead to efficient solutions. Moreover, the focus group discussion envisages a potential willingness of adoption of more than 20% of users to the proposed shared mobility solutions.

In the next section we analyse the same detailed scenarios selected in the current mobility analysis under future conditions.

Results for the year 2046

This section presents an analysis of the three scenarios (scenario 1, 6 and 10) for the future projections (year 2046). The results include mobility, environmental performance, operational, and access and connectivity indicators. Differences with the current case (baseline scenario of the present) and the three corresponding scenarios of the present are highlighted.

Major mobility outcomes

Similarly to the present case we start by analysing the vkm and the levels of the CO_2 emission and congestion, which are the indicators showing the overall performance of the transport system in the Auckland study area and the improvements compared with the baseline scenario. The comparison here and throughout this section is performed with the baseline scenario for year 2046, unless stated differently. The congestion levels and the CO_2 emissions are calculated similarly to the present.

Table 30 summarises changes in the three indicators compared with the baseline scenario. As expected, scenario 1 with 100% car replacement in the entire study area provides most of the reduction (above 60% for each of the indicators). Scenario 6 provides moderate improvements while scenario 10 provides only marginal improvements in vkm and CO_2 but leads to more congestion, similarly to the corresponding scenarios of the present case. The reductions of all the future scenarios are greater than the corresponding reductions of the present scenarios. This is because the larger population density projected in the study area will lead to a more efficient operation of shared mobility services.

Table 30. **Changes in vehicle-kilometres, CO_2 emission and congestion compared with the baseline (2046) scenario (%)**

Scenario	Vkm	CO_2	Congestion
1	-62.5	-65.1	-60.8
6	-15.1	-16.0	-9.1
10	-4.9	-6.0	12.2

Changes in modal split and public transport ridership

Table 31 presents the absolute values for passenger-kilometres of the motorised modes while Table 32 presents the changes in pkm compared with the baseline scenario. The increase in the ferry share is very large (from a very small original share) while the increase in the rail share is smaller than in the present scenarios. These differences in percentages are due to the smaller initial projected ferry pkm (five times smaller than in the present) and larger rail pkm (four times larger than in the present). All the scenarios provide some decrease in private car passenger-kilometres.

Table 31. **Passenger-kilometres (thousands)**

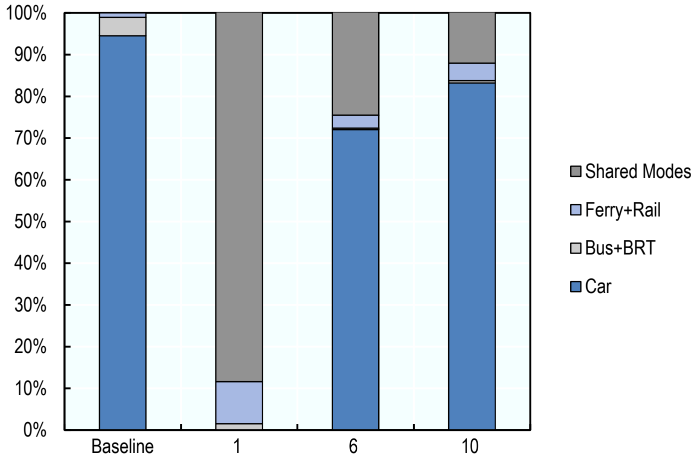
Scenario	Shared Taxi	Taxi-Bus	Car	Bus + BRT	Ferry	Rail
Baseline	-	-	53 622	3 759	5	688
1	37 640	28 130	-	79	196	1 895
6	3 131	11 211	43 143	68	136	1 002
10	2 752	9 548	48 619	34	147	1 222

Table 32. **Passenger-kilometres compared with the Baseline (2046) scenario (%)**

Scenario	Car	Bus + BRT	Ferry	Rail
1	-100	-98	4 127	176
2	-20	-98	2 820	46
3	-9	-99	3 058	78

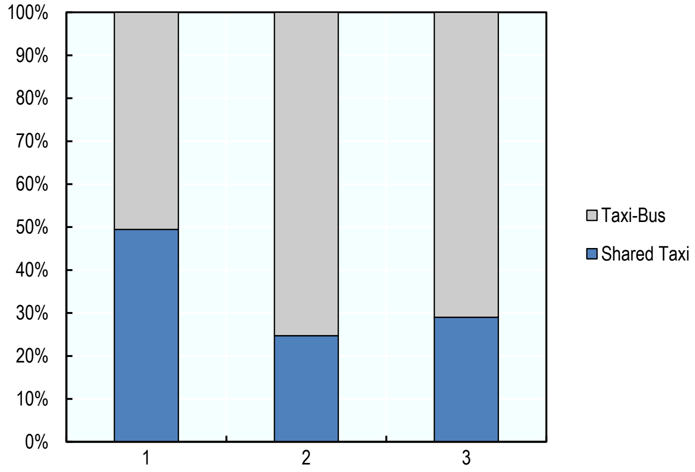
Figure 46 displays motorised mode shares based on the number of trips by each motorised mode in the baseline for the year 2046. Similarly to the present, 97% of the passenger-kilometres are made by private car. Overall, the future mode shares are similar to present mode shares of the corresponding scenarios.

Figure 46. **Motorised mode share in scenarios**



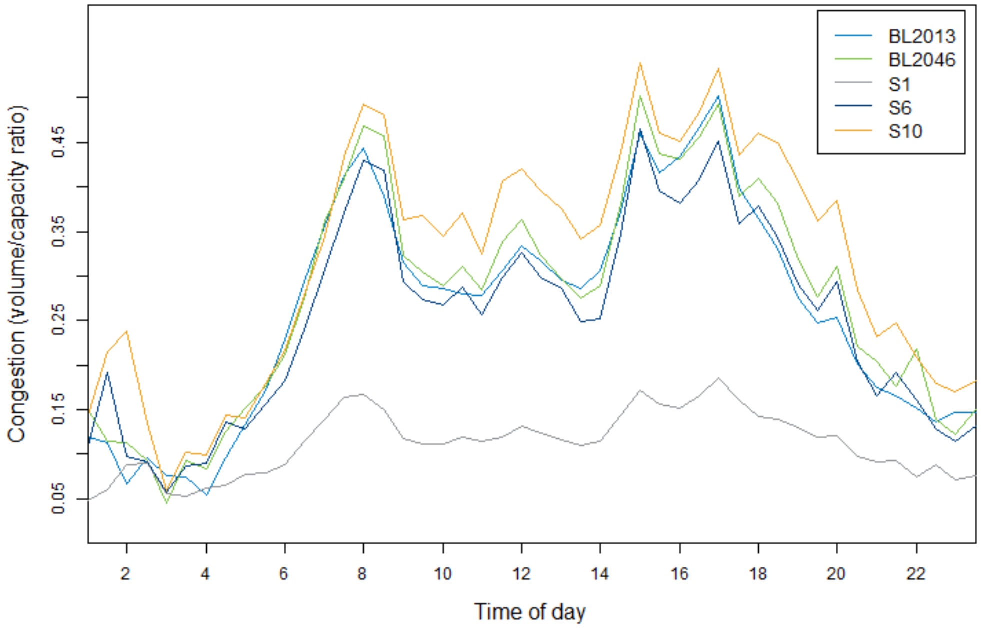
Mode shares between Taxi-Bus and Shared Taxi are less even than in the scenarios modelling the present (Figure 47). The scenario with 20% car replacement (Sc. 6) leads to a larger share of Taxi-Bus trips but with a smaller average occupancy rate for Shared Taxis. This means that many of those trips previously performed by private car can be efficiently combined into Taxi-Bus rides, while the small portion of these trips is scattered and needs Shared Taxis with less occupancy. The scenario with small LEZ (Sc. 10) shows a larger share of Taxi-Bus since the travellers are forced to park their cars at parking stations at the LEZ boundary and change to the shared modes or heavy public transport modes, similarly to the results of the present case LEZ scenarios. As Table 33 shows, the Shared Taxi occupancy rates drop in scenario 10, that is, the Shared Taxis become less efficient and performs many trips with just one passenger.

Figure 47. **Mode share among shared modes**



The future congestion levels for most time periods of the day will be higher. Figure 48 presents congestion for different hours of the day and includes the four scenarios for the future (Sc. 1, 6, 10 and the baseline) and the baseline scenario from the present. Similarly to the observations of the study of the present case, the small LEZ scenario (Sc. 10) results in increased congestion compared with the baseline while the scenario with full car replacement (Sc. 1) leads to the lowest congestion.

Figure 48. **Congestion by the time of day**



Operational performance

Higher and denser mobility demand in the future produces greater operational efficiency for shared mobility services. For the implementation of the full replacement scenario (Sc. 1) in the future, more vehicles are needed than in the present (51 000 vs. 45 000), that is, less vehicles per trip. Similarly, more Shared Taxis are needed but their occupancy also increases (Table 33). The other two scenarios imply the above-mentioned opportunities and the problems for the corresponding scenarios of the present. Scenario 6 with less demand leads to less-efficient sharing solutions than the full replacement scenario; yet it is significantly more efficient than in the present due to the new scale and space distribution of demand. Scenario 10 leads once again to very low efficiency of Shared Taxis operating in the LEZ or providing some services directly from the suburbs to the centre and to high efficiency of Taxi-Buses mainly boarded and alighted at park and ride stations at the LEZ boundary.

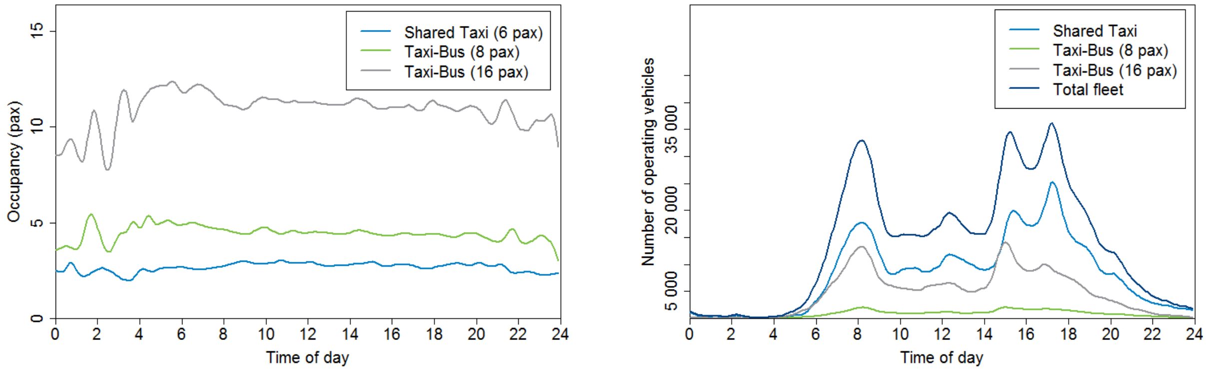
Table 33. **Estimates for number of vehicles and occupancy**

	Average occupancy (pax)			Number of vehicles		
Scenarios	Shared Taxi	Taxi-Bus 8	Taxi-Bus 16	Shared Taxi	Taxi-Bus 8	Taxi-Bus 16
1	2.78	4.52	11.07	29 675	2 642	18 589
6	2.21	4.51	11.03	3 838	1 367	7 611
10	1.83	4.68	11.70	5 587	1 143	6 199

The operational performance throughout the day is quite stable, with strong fleet requirements during the peak periods. Figure 49 shows the average occupancy and number of vehicles required for scenario 1. The results reveal a significant improvement when compared with the present due to the larger demand but also the spatial concentration of demand under a denser urban configuration. During peak periods, Shared Taxis vehicles reach a maximum of approximately 30 000 vehicles in operation, while in the present they are approximately 22 000. This means a 36% increase in vehicles, but with a 53% increase in mobility.

Future technologies with self-driving and large scale introduction of electric vehicles might lead to significant improvement of operational performance and reduction of costs. This is due to the stability throughout the day of the average occupancy, which is especially compatible with self-driving technologies.

Figure 49. **Average occupancy (a) and number of vehicles (b) - Scenario 1**



a) **b)**

Impacts on future mobility key findings

Similarly to the present scenarios, shared mobility can bring substantial improvements to the city and its transport system in terms of reduction of congestion and CO_2 emissions, and the benefits depend strongly on the share of car users shifted to the shared and PT modes. The reductions in all the future scenarios are greater than the corresponding reductions in the present scenarios. This is because the larger population density projected in the study area will lead to a more efficient operation of shared mobility services. The elasticity of vkm to car ridership reduction increases from 0.62 to 0.77 (that is an increase by 24% of the vkm reduction efficiency). This is paramount for setting targets for CO_2 reduction.

The congestion levels will increase in 2046, especially for the peak hours, if the current PT modes are kept and no shared modes are introduced - even if rail supply increases. Introduction of shared mobility can largely increase rail, ferry and BRT ridership, which might imply rethinking the future network and stations layout to incorporate the new paradigm of shared mobility integration in public transport services. Rail stations need to have good access for the users of non-motorised modes, and also drop-off/pick-up areas for travellers to board/alight shared vehicles efficiently and safely.

Higher and denser mobility demand in the future produces greater operational efficiency for shared mobility services. The operational performance along the day is quite stable and implies strong fleet requirements during the peak periods. Even without self-driving vehicles it is possible to provide affordable services, with good working conditions and stability for the drivers.

Key findings and further research

Our results suggest that shared mobility services can deliver significant positive impacts to the Auckland region. Nonetheless, the tested scenarios do not intend to provide an optimal configuration or suggest a pathway to implementation. These scenarios aim to assess the range of outcomes that can be achieved when such a system is implemented.

All scenarios tested, even the small low emission zone scenario (Sc. 10) with car constrained only during the morning and afternoon peak periods, lead to reductions in CO_2 emissions. These gains become more significant when implemented in the whole study area even at a lower car replacement rate (e.g. scenarios 4 and 6). Under these targeted policy scenarios the model showed increases in accessibility and quality of service, decreases in congestion, and the release of public space occupied by private parking.

Spatial characteristics of the regions should be kept in mind when implementing the new shared services. The different calculated scenarios show that either the low-demand density of the region leads to a large share of clients either choosing Shared Taxi services, or clients need to be promoted to Shared Taxi services due to the lack of sufficient demand for larger Taxi-Buses. This result suggests that for the Auckland region an efficient shared mobility service could be delivered by using a single type of vehicle instead of different sizes. The quality of service could be still differentiated in terms of the distance required to walk to/from bus stops.

Previous studies and the results of the small low emission zone scenario show that low uptakes or focused spatial implementations lead to no significant impacts on the city and instead might even increase congestion. For the three in-depth scenarios tested, the price at which the new services can be offered is competitive for their respective segments. But under the condition that there is a significant adoption of shared mobility, e.g. 20% of car trips shift to the new modes. This scale of operations also opens opportunities to engage in partnerships with third parties for procurement, maintenance and operations management which can potentially be used to leverage more competitive prices for the end user. These partnerships might include new mobility service providers, vehicle manufacturers or even other public transport operators. In addition, fleets of this dimension provide economies of scale that might be used as entry points for emerging technologies such as electric powered vehicles or driverless cars.

The heavy public transport networks (rail, ferry and BRT) benefit strongly from the new shared mobility services. Shared mobility can, beyond complementing the existing PT services, offer a better service level, especially for less frequent and low occupancy public transport services. This has a great potential to increase the mode share of rail and ferry while contributing to reducing congestion and emissions. However, additional system capacity may be required for rail, BRT and ferry to accommodate the increased ridership without compromising the current ridership quality by increasing the frequency of services. It may become necessary to adapt station designs to accommodate for the increased demand. Furthermore, station layouts may need to be rethought for the future to incorporate the new paradigm of shared mobility integration in public transport services. Rail stations need to have good access for users of non-motorised modes, and also dedicated areas for shared vehicles to efficiently and safely pick up and drop off travellers.

Auckland has a strong private car culture. However, our results from the focus group survey suggest there is interest in testing shared mobility services as long as good quality of service is being offered. Still, many users would need, at least in the beginning, to have their private car still available. The positive sentiment and the generalised familiarity with digital technologies suggest app based system would not constitute barriers to the implementation of shared mobility services.

The possibility to reach positive impacts in the region depends on the ability of attracting car users to the new types of transport solutions. Policy measures, incentives, new services and information campaigns should be targeted to ensure that potential early adopters and those with long current trips are attracted to these services. The price of such services can be attractive if designed correctly. Our results also suggest that the price of using a Shared Taxi would be lower than operating and owning a private vehicle for travel of less than 25 kilometres per day.

All tested scenarios show a huge potential of shared-mobility services for reducing parking requirements, especially on-street parking. This new paradigm may also change how the access to the kerb is perceived, evolving from a parking location to a pick-up drop-off zone. This will be especially important near public transport interfaces.

The integration of shared mobility services with electric vehicles is compatible with its operation requirements; it would bring minimal increases of fleet size and a major decrease in CO_2 emissions.

The introduction of shared mobility at the scale studied in this report implies changes to travel behaviour and the overall transportation system that are hard to grasp by any single model or study. In addition, there are impacts to other areas beyond transportation. For instance, the modelling framework assumes static demand patterns. The simulation employed provides a very detailed analysis of several scenarios, but it does not take into account changes induced to travel behaviour by a wide adoption of these services. Beyond transportation this can affect land use and value. The increases in accessibility for currently more remote areas can increase their commercial attractiveness and even foster a degree of urban sprawling. Future scenarios tested envisage a more efficient land use layout that reduces the mobility requirements per inhabitant. Creating policies that ensure this estimated sprawl reduction may be preserved for the future.

While the share of non-motorised modes in Auckland is not very high, an increase of density and space freed by the release of on-street parking and decreased congestion could potentially lead to a significant improvement in the city’s liveability.

Finally there is a host of issues related to who and how these services will be provided. The required level of funding and unprecedented scale of deployment of these services points to a collaborative effort that can involve other public transport operators, ride services and taxis, vehicle manufactures, and other institutions.

References

Al-Olayan, S. (2017), "Renault Espace 2017", Flickr, http://preview.tinyurl.com/ycn9zgej (accessed July 1, 2017).

Auckland Council (2014), *Role of Cycling in Auckland, Report to the Infrastructure Committee*, Auckland, New Zealand.

Auckland Transport (2017a), "Transport plans & strategies", Auckland Transport, https://at.govt.nz/about-us/transport-plans-strategies/ (accessed November 1, 2017).

Auckland Transport (2017b), "An extra million on the trains in just three months", Auckland Transport, https://at.govt.nz/about-us/news-events/an-extra-million-on-the-trains-in-just-three-months/ (accessed April 6, 2017).

Austroads (2016), *Congestion and Reliability Review: Full Report*, *AP-R534-16*, Sydney.

Balcombe, R. (2004), *The demand for public transport: a practical guide*, TRL Limited.

Chorus, C. G., E. J. E. Molin and B. Van Wee (2006), "Use and effects of Advanced Traveller Information Services (ATIS): a review of the literature", *Transport Reviews*, Vol. 26/2, pp. 127–149.

Chowdhury, S. and S. B. Costello (2016), "An examination of cyclists' and non-cyclists' mode choice under a new cycle network", *Road & Transport Research: A Journal of Australian and New Zealand Research and Practice*, Vol. 25/4, pp. 50.

Douglas, N. (2016), "Pricing strategies for public transport", *NZ Transport Agency Research Report*, N^{o} 565.

Guest, G., E. Namey, J. Taylor, N. Eley and K. McKenna (2017), "Comparing focus groups and individual interviews: findings from a randomized study", *International Journal of Social Research Methodology*, pp. 1–16.

Imran, M. (2014), *Auckland Experience of the Bus Rapid Transit (BRT)*, Massey University, New Zealand.

ITF (2017), "Transition to Shared Mobility: How large cities can deliver inclusive transport services", *International Transport Forum Policy Papers*, N^{o} 33, https://doi.org/10.1787/b1d47e43-en.

ITF (2016), "Shared mobility: innovation for liveable cities", *International Transport Forum Policy Papers*, N^{o} 21, https://doi.org/10.1787/24108871.

Leung, C., K. Destremau, D. Pambudi and M. Bealing (2017), *Benefits from Auckland road decongestion*, *NZIER*, Wellington, New Zealand.

Litman, T. (2008), "Developing Indicators for Comprehensive and Sustainable Transport Planning", *Transportation Research Record*, Vol. 2017/1, pp. 10–15, https://doi.org/10.3141/2017-02.

Martinez, L. M. and J. M. Viegas (2017), "Assessing the impacts of deploying a shared self-driving urban mobility system: An agent-based model applied to the city of Lisbon, Portugal", *International Journal of Transportation Science and Technology*, June, pp. 1–15, https://doi.org/10.1016/j.ijtst.2017.05.005.

Martínez, L. M. and J. M. Viegas (2013), "A new approach to modelling distance-decay functions for accessibility assessment in transport studies", *Journal of Transport Geography*, Vol. 26/0, pp. 87–96, https://doi.org/http://dx.doi.org/10.1016/j.jtrangeo.2012.08.018.

Morikawa, T., M. Ben-Akiva and K. Yamada (1991), "Forecasting intercity rail ridership using revealed preference and stated preference data", *Transportation Research Record*, Vol. 1328, pp. 30–35.

Papaioannou, D. (2017), *Assessing the relation between mode choice, user satisfaction, and quality for public transport systems*, University of Lisbon.

Rayle, L., D. Dai, N. Chan, R. Cervero and S. Shaheen (2016), "Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco", *Transport Policy*, Vol. 45, pp. 168–178, https://doi.org/10.1016/j.tranpol.2015.10.004.

Roth, A. and T. Kåberger (2002), "Making transport systems sustainable", *Journal of Cleaner Production*, Vol. 10/4, pp. 361–371, https://doi.org/10.1016/s0959-6526(01)00052-x.

Steg, L., C. Vlek and T. Rooijers (1995), "Private car mobility. Problem awareness, willingness to change, and policy evaluation: A national interview study among Dutch car users", *Studies in Environmental Science*, Vol. 65, pp. 1173–1176.

Stephens, T. S., J. Gonder, Y. Chen, Z. Lin, C. Liu and D. Gohlke (2016), *Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles*, National Renewable Energy Laboratory, NREL/TP-5400-67216.

Sullivan, C. and C. O'Fallon (2003), "Vehicle occupancy in New Zealand's three largest urban areas", in *26th Australasian Transport Research Forum*, Wellington, New Zealand.

Tertoolen, G., D. Van Kreveld and B. Verstraten (1998), "Psychological resistance against attempts to reduce private car use", *Transportation Research Part a-Policy and Practice,* Vol. 32/3, pp. 171–181.

Thøgersen, J. (2006), "Understanding repetitive travel mode choices in a stable context: A panel study approach", *Transportation Research Part A: Policy and Practice*, Vol. 40/8, pp. 621–638.

Transport for London (2014), "Travel in London", *Report 7*, pp. 1–236.

Tscharaktschiew, S. and G. Hirte (2012), "Should subsidies to urban passenger transport be increased? A spatial CGE analysis for a German metropolitan area", *Transportation Research Part A: Policy and Practice*, Vol. 46/2, pp. 285–309, https://doi.org/10.1016/j.tra.2011.09.006.

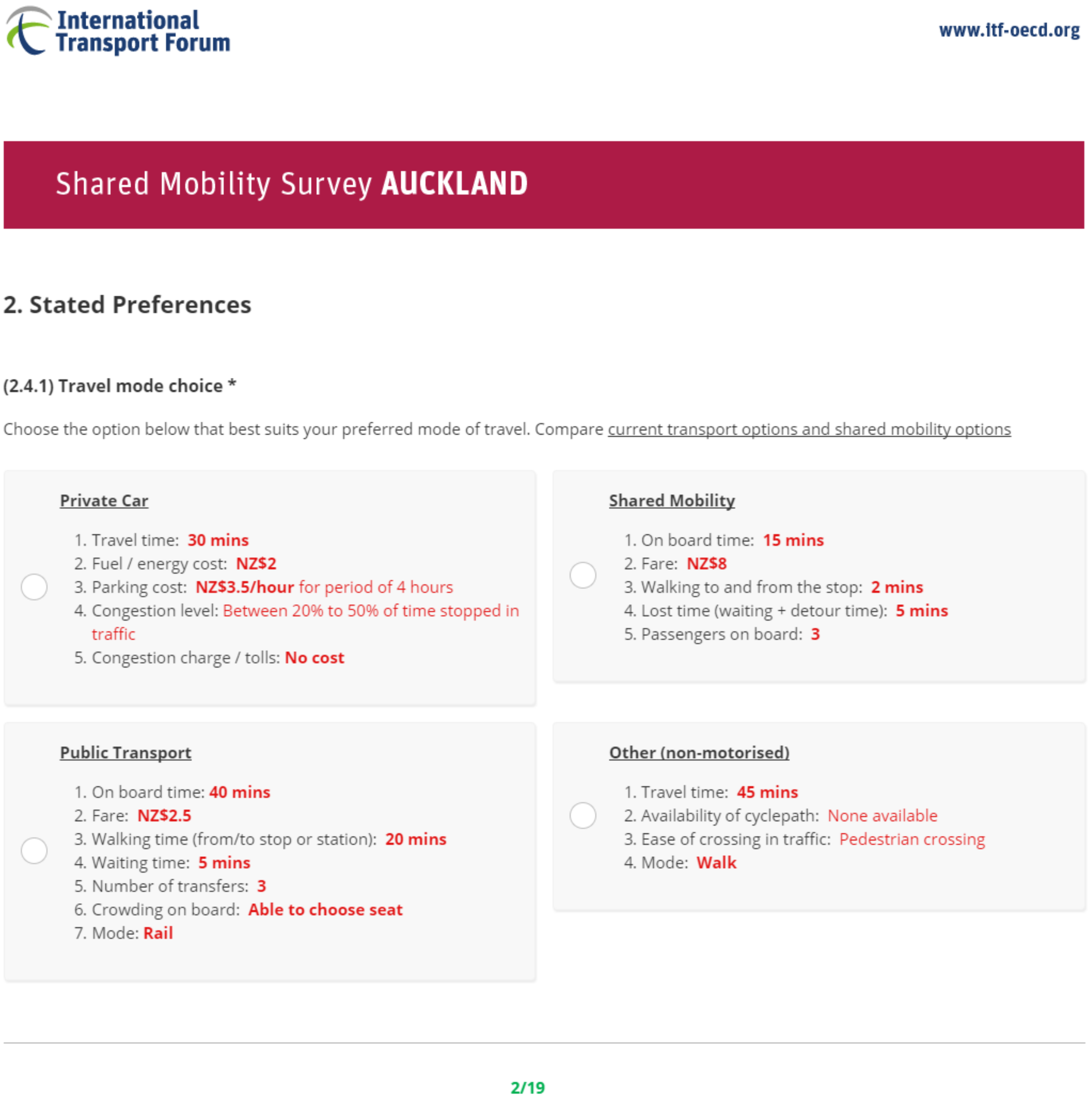
TTC 9701 (2015), "Karsan Demo", Flickr, http://preview.tinyurl.com/ybuhvqdf (accessed October 1, 2017).

UITP (2015), *Mobility in cities database*, Union Internationale des Transporteurs Publics.

Wallis, I., K. Rupp and R. Alban (2015), "Travel time saving assessment", *NZ Transport Agency Research Report*, N^o 570.

Zegras, P. and R. Gakenheimer (2006), "Driving Forces in Developing Cities' Transportation Systems: Insights from Selected Cases", *Developing Country Urban Transport Cases*, December.

Annex 1. Example of a stated preference survey question



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Shared Mobility Survey **AUCKLAND**

2. Stated Preferences

(2.4.1) Travel mode choice *

Choose the option below that best suits your preferred mode of travel. Compare current transport options and shared mobility options

○ **Private Car**

1. Travel time: **30 mins**
2. Fuel / energy cost: **NZ$2**
3. Parking cost: **NZ$3.5/hour** for period of 4 hours
4. Congestion level: Between 20% to 50% of time stopped in traffic
5. Congestion charge / tolls: **No cost**

○ **Shared Mobility**

1. On board time: **15 mins**
2. Fare: **NZ$8**
3. Walking to and from the stop: **2 mins**
4. Lost time (waiting + detour time): **5 mins**
5. Passengers on board: **3**

○ **Public Transport**

1. On board time: **40 mins**
2. Fare: **NZ$2.5**
3. Walking time (from/to stop or station): **20 mins**
4. Waiting time: **5 mins**
5. Number of transfers: **3**
6. Crowding on board: **Able to choose seat**
7. Mode: **Rail**

○ **Other (non-motorised)**

1. Travel time: **45 mins**
2. Availability of cyclepath: None available
3. Ease of crossing in traffic: Pedestrian crossing
4. Mode: **Walk**

2/19

Annex 2. Characteristics of the two respondents groups

Table A1. **Respondents' distribution by age and residential location (%)**

Residential location	**Age cohort**					
	<=25	**26 - 35**	**36 - 45**	**46 - 55**	**56 - 65**	**>65**
Focus group						
Close to the centre	5	0	0	0	0	0
Far from the centre (>10 km)	16	16	11	5	5	5
In the city centre	16	0	5	5	11	0
Panel respondents						
Close to the centre	2	13	16	8	9	4
Far from the centre (>10 km)	2	6	6	10	10	9
In the city centre	0	2	1	1	0	1

Figure A1. **Respondents' occupation**

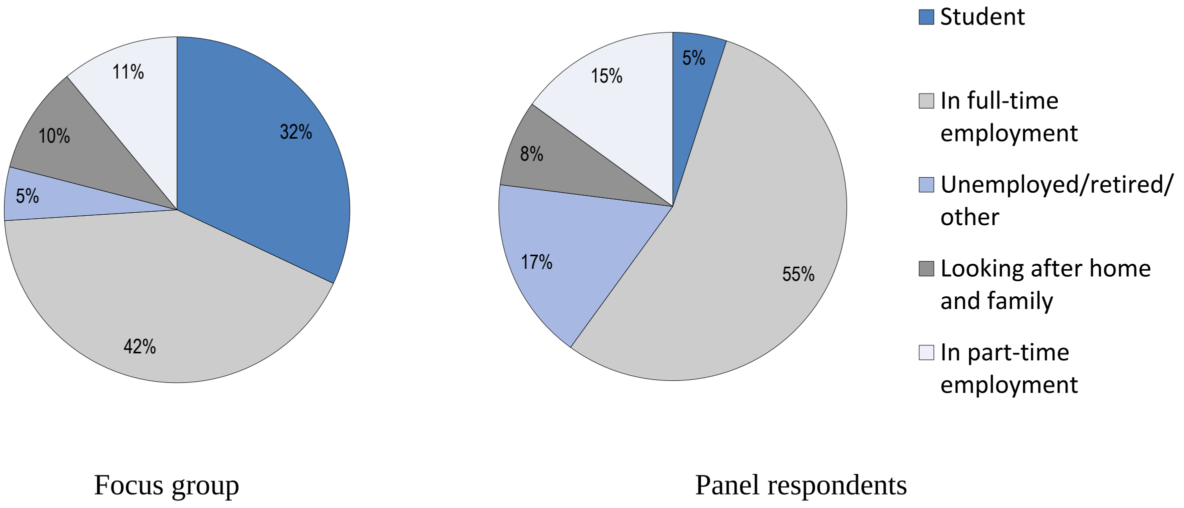


Figure A2. **Number of respondents using smartphones and tablets**

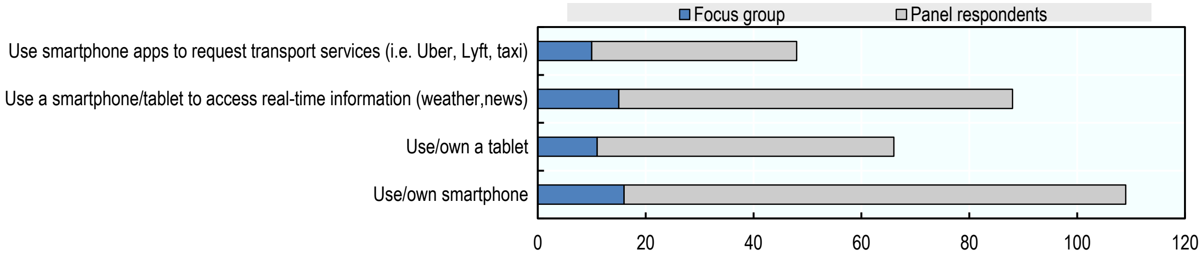


Table A2. **Current mobility patterns of the survey respondents**

Activity	Focus group			Panel respondents		
	Average number of weekly trips	Average trip duration (min)	Most commonly used modes	Average number of weekly trips	Average trip duration (min)	Most commonly used modes
Travel to/from work or place of study	8.6	41.73	Private car - driver (61%), Bus (15%)	6.29	28.42	Private car - driver (64%), Bus (12%)
Travel to drop off/pick up children at school or childcare, if trip does not include a place of work or study	2.2	5.56	Private car (100%)	2.52	7.97	Private car (89%), walking (11%)
Daily shopping (e.g. supermarket)	1.93	14.94	Private car – driver (75%), Walk (17%)	2.25	11.73	Private car (95%)
Social activity (e.g. visiting friends or family)	2.73	34.29	Private car – driver (58%), Private car – passenger (17%), Walk (17%)	2.43	30.71	Private car (93%)
Leisure activities (e.g. sport)	1.86	30	Private car – driver (50%), Walk (40%)	2	18.35	Private car – driver (73%), Walk (14%)
Personal matters (e.g. doctor's appointment)	1.07	23.08	Private car – driver (72%)	1	15.73	Private car – driver (87%)
Other	1.33	22.86	Private car – driver (50%)	1.56	19.39	Private car – driver (71%)

Table A3. **Respondents' profiles depending on the transport modes they use most (%)**

User profile	Age cohort					
	<=25	**26 - 35**	**36 - 45**	**46 - 55**	**56 - 65**	**>65**
Focus group						
Regular car user	21	11	11	11	11	5
Regular bus user	0	0	5	0	5	0
Regular user of rail or/and ferry	11	5	0	0	0	0
Other (e.g. walking, cycling)	5	0	0	0	0	0
Panel respondents						
Regular car user	1	16	17	19	18	12
Regular bus user	2	3	4	0	0	0
Regular user of rail or/and ferry	0	1	0	0	1	0
Other (e.g. walking, cycling)	1	1	2	0	0	2

Annex 3. Attitudes towards the shared modes and their attributes of the two respondents groups

Figure A3. **Attitudes of car users towards fares of shared mobility modes**

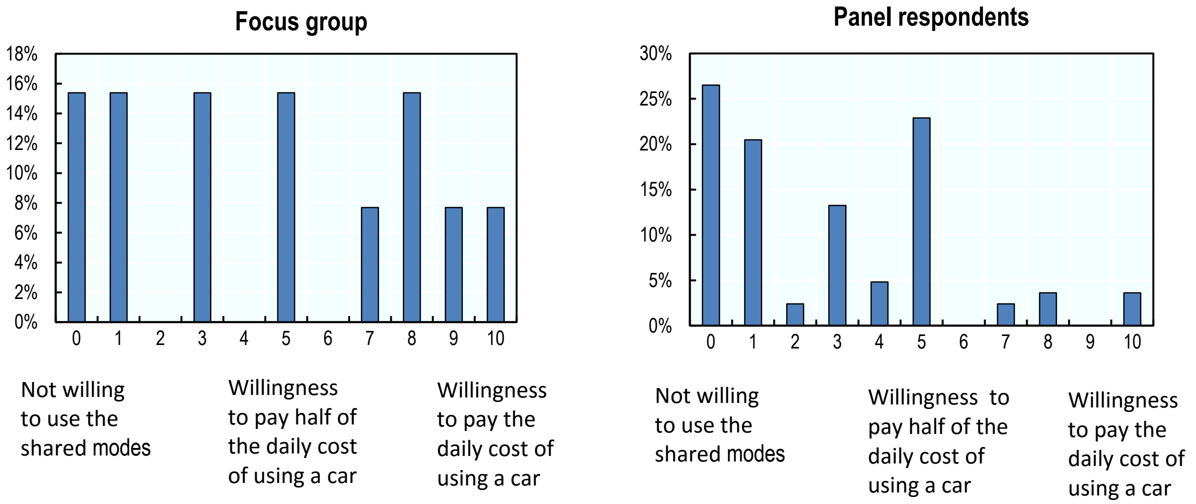


Figure A4. **Attitudes of bus and rail users towards fares of shared mobility modes**

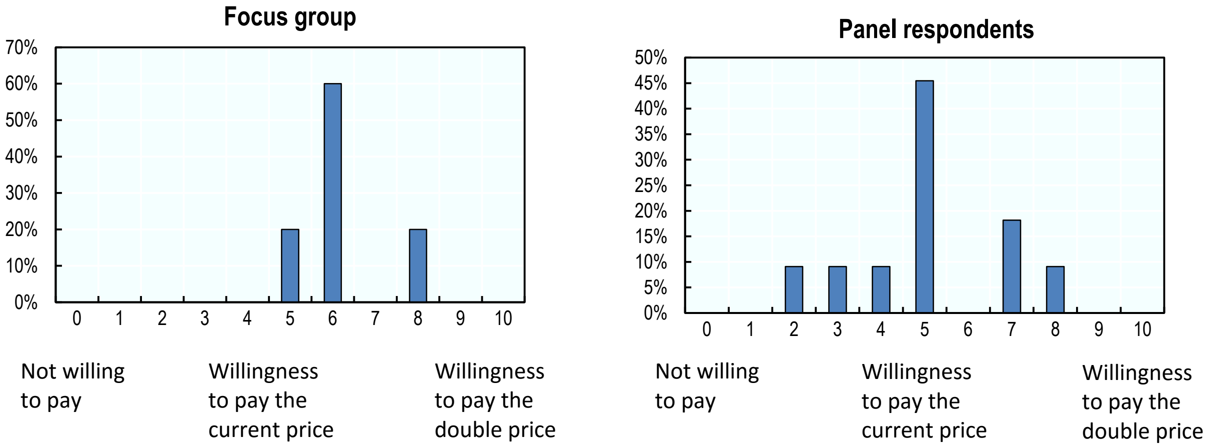


Figure A5. **Attitudes of car users towards accessibility/walking time to stop**

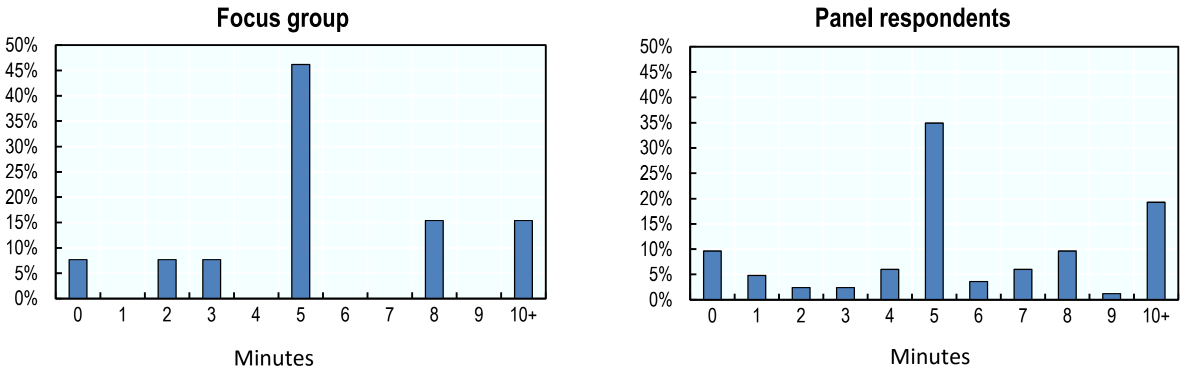


Figure A6. **Attitudes of bus and rail users towards accessibility / walking time to stop**

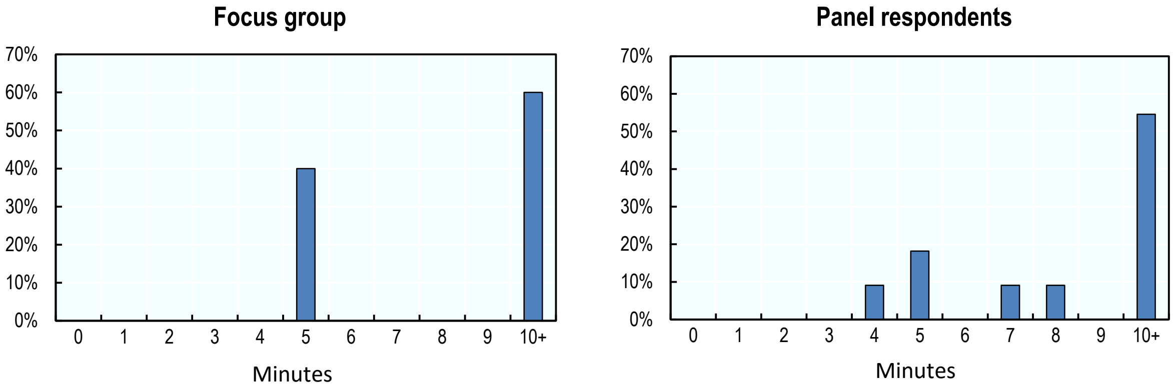


Figure A7. **Attitudes of car users towards lost time with shared mobility modes**

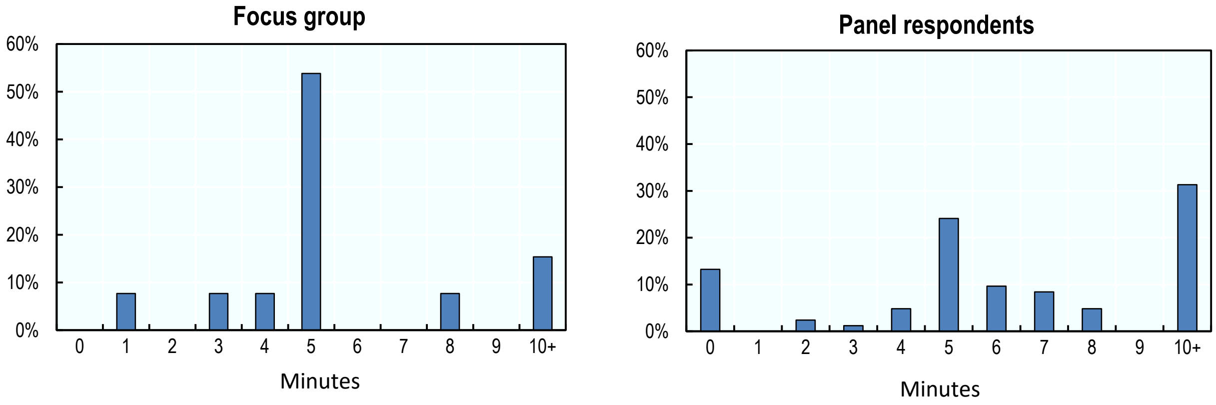


Figure A8. **Attitudes of bus and rail users towards lost time with shared mobility modes**

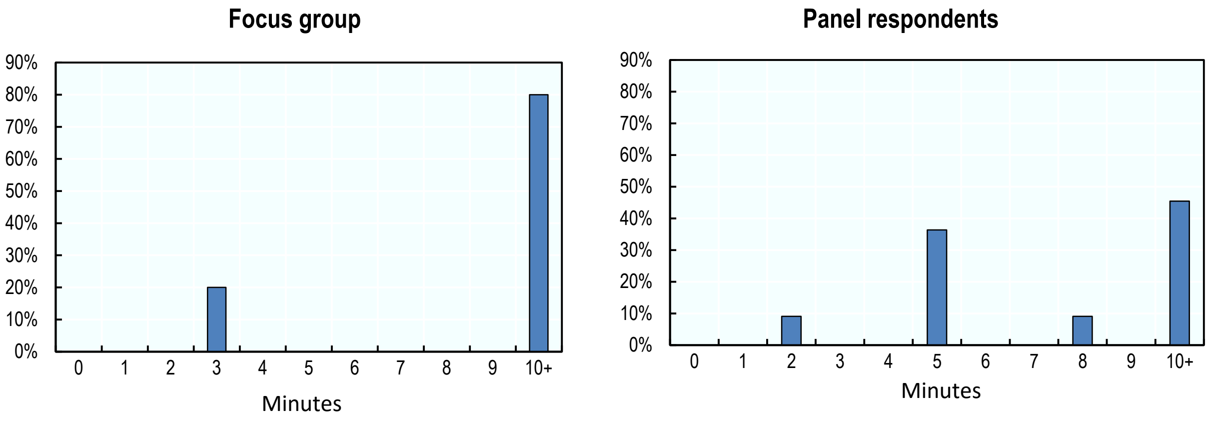


Figure A9. **Attitudes of car users towards shared mobility modes used as feeder service**

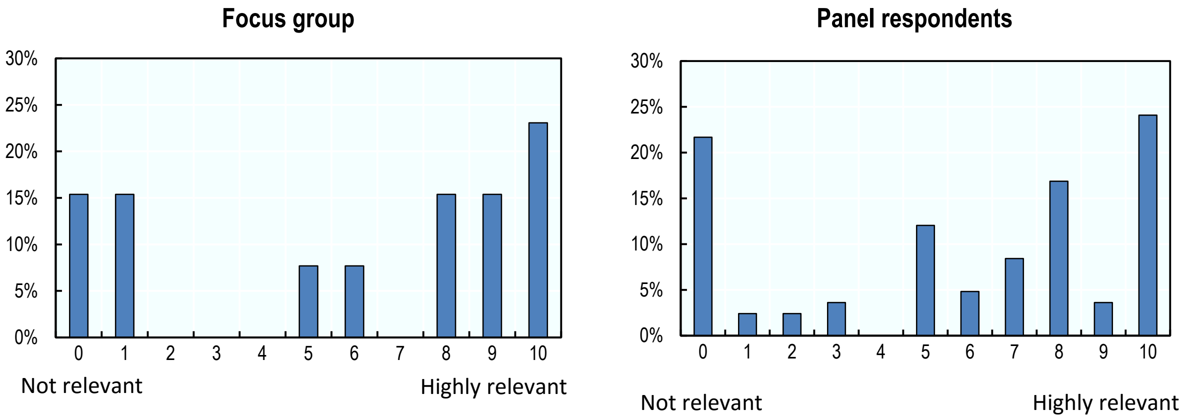


Figure A10. **Attitudes of bus and rail users towards shared mobility modes used as feeder service**

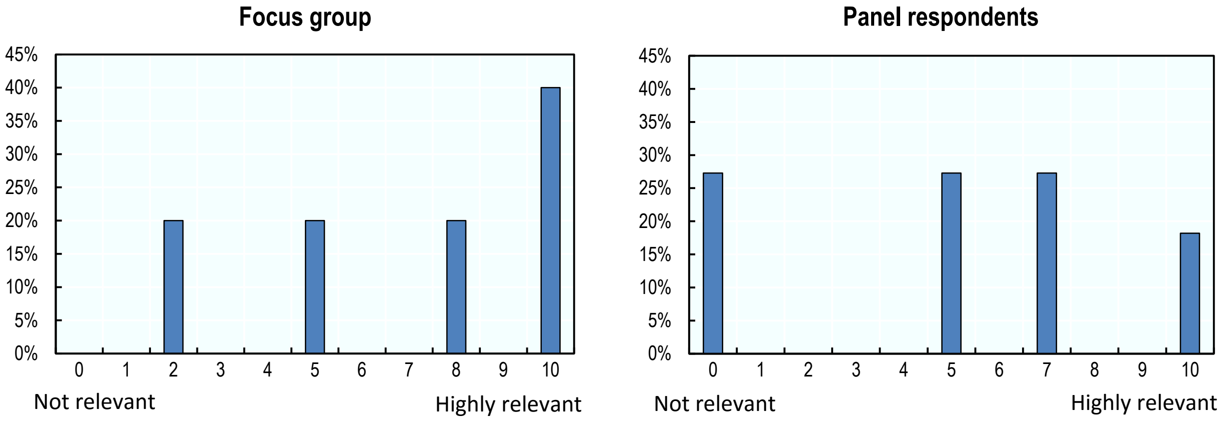


Figure A11. **Attitudes of car users towards number of passengers on board shared mobility modes**

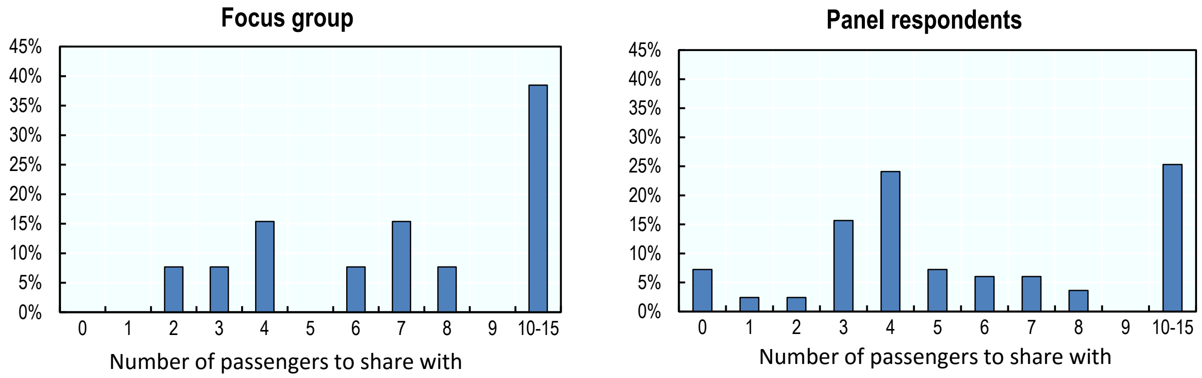
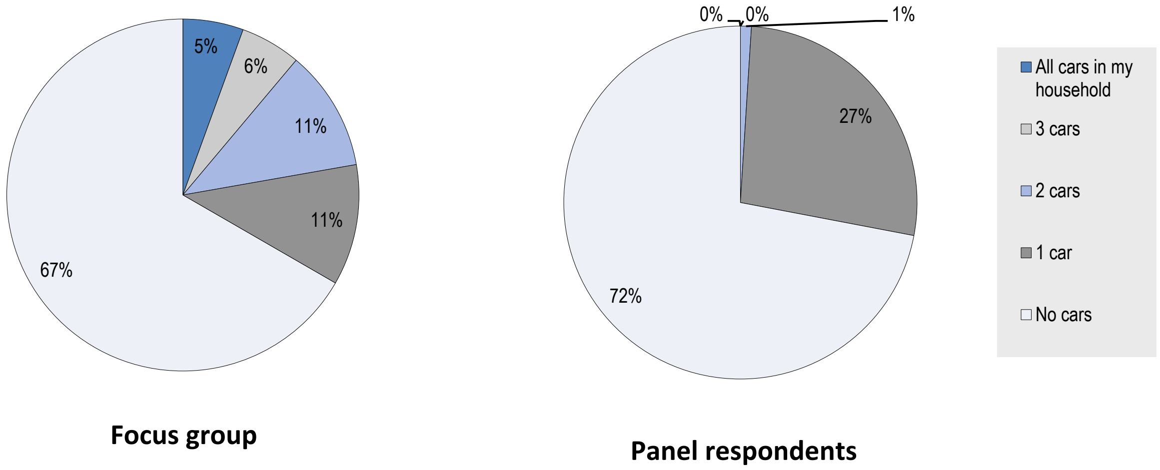


Figure A12. **Number of cars a respondent would sell if shared mobility modes were available**



Annex 4. Calculation of the CO_2 emissions

This annex presents the assumptions behind the CO_2 emissions calculations for this report. The emissions for the PT modes are estimated based on the CO_2 grams per vehicle-kilometre (g/vkm) data for different modes, provided by the local project partners. Emissions for the new shared modes are taken from the Lisbon study (ITF, 2016). CO_2 emissions for private cars are calculated using data on CO_2 emissions depending on speed. The average speed was calculated as a ratio between the average distance for trips (around 11 km) and the average travel time by car (17.8 min). Table A4 summarises the emissions per vkm used in the calculations.

Table A4. **CO_2 emissions of different modes**

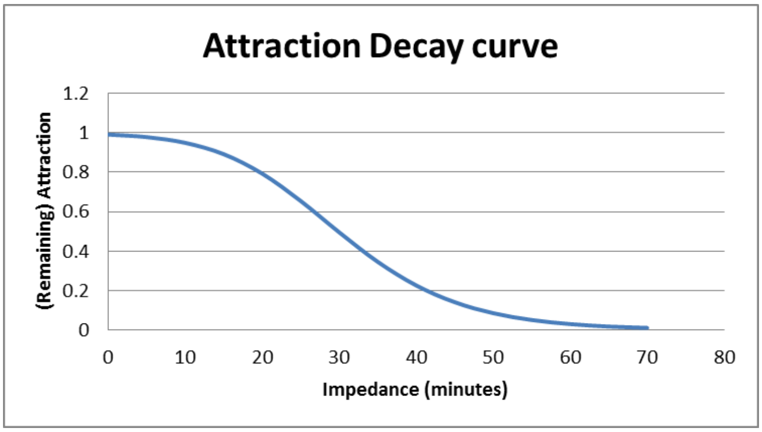
	Auckland	Unit	Source
Car	214.42	g/vkm	Provided by Auckland
Shared Taxi	213.4	g/vkm	Lisbon study (ITF, 2016)
Taxi-Bus 8	255.3	g/vkm	Lisbon study (ITF, 2016)
Taxi-Bus 16	319.1	g/vkm	Lisbon study (ITF, 2016)
Rail	8650	g/vkm	Provided by Auckland
Ferry	1500	g/vkm	Provided by Auckland
Bus	900	g/vkm	Provided by Auckland

Annex 5. Effective access

Effective access is a concept that allows evaluating accessibility levels along a continuum of perception, taking into account not the absolute travel time but the travel time related to a particular origin-destination pair. This provides a better indicator than the absolute travel time since the individual's willingness to go from point *a* to point *b* to carry out an activity usually depends on the remoteness of *a* from *b*. The more the individual needs to travel, the less the destination becomes attractive for carrying out the activity. To account for that, more remote destinations can be penalised by being multiplied by a factor smaller than 1, which decreases as the travel time between the origin and the destination increases. In order to calculate the exact value of the penalty an attraction decay curve can be used (Figure A13), which shows that the attraction reduces non-linearly as the impedance (travel time) grows (Martínez and Viegas, 2013).

In order to calculate the effective accessibility to employment, the number of jobs in each destination grid cell is multiplied by the attraction value provided by the attraction decay curve. For instance, if from the origin cell a destination cell is reached in 40 minutes, then the number of jobs existing in the destination cell is multiplied by 0.2 (which is the attraction penalty in the curve for a 40-minutes travel distance).

Figure A13. **Attraction decay curve**



Annex 6. Inputs for estimation of the costs

Shared mobility costs estimation

Table A4. **Vehicle costs**

Variable	Shared Taxi	Taxi-Bus 8	Taxi-Bus 16
Vehicle type	Toyota Previa	Ford Torneo	Mercedes Benz Sprinter
Purchase costs (NZD)	61 000	61 000	86 020
Useful life (years)	5	7	7
Distance (km) at end of useful life	758 633	347 174	308 436
Residual value at resale (%)	25	25	30
Annual ownership cost (NZD)	9 150	6 536	8 602
Maintenance (NZD)	915	654	860
Insurance (NZD)	366	261	344
Annual fixed cost (NZD)	10 431	7 451	9 806
Fixed cost/km (NZD)	0.07	0.15	0.22

Note: Costs in NZD (New Zealand Dollar).

Table A5. **Labour costs**

Constant parameters independent of vehicle type			
Labour costs based on typical current employment	Gasoline	Diesel	Unit
Monthly salary	2 646		NZD
Social charges	4		%
Gross labour cost/month	2 751.84		NZD
Work days/month	21		
Work hours/day	8		
Gross labour cost per hour	16.38		NZD/h
Maintenance (% of annual ownership cost)	10		%
Insurance (% of annual ownership cost)	4		%
Fuel cost (petrol/diesel)	1.91	1.31	NZD/lt
Road User Charges (RUC)		0.068	NZD/km

Operators profit (margin above system costs for the service provider): 20%.

The back-office costs are equal to an increment of 10% of the labour requirements per vehicle-kilometre.

No costs of the stations were added to the model cost calculations, assuming that no infrastructure is necessary because newly available space can be used from freed up on-street or off-street parking.

Public transport cost estimation

Provided by the Auckland Transport but cannot be disclosed beyond this report usage.

Private car cost estimation

Independent of vehicle type and size

Insurance: NZD 75 plus 4% of annual ownership costs, with a minimum annual value of NZD 180

Maintenance: 10% of annual ownership costs, majored by factor 2 for Shared Taxi vehicles

Percent of annual costs allocated to commuting activity: 80%

Commuting days per year: 220 days

Dependent of the vehicle type and size

Table A6. **Vehicle costs depending on type and size**

Variable	New vehicles			Second-hand
Purchase price (NZD)	15 000	30 000	50 000	5 000
Avg. Life (years)	6	5	4	8
Res. Value at resale (%)	15	30	45	5
Ann. Ownership cost (NZD)	2 125	4 200	6 875	593.75
Insurance (NZD)	180	243	350	180
Maintenance (NZD)	212.5	420	687.5	118.75
Total fixed cost (NZD)	2 517.5	4 863	7 912.5	892.5
Total fix cost commuting (NZD)	2 014	3 890.4	6 330	714

Energy cost estimation for electric vehicles fleet

Energy consumption

Range for 100% charging: 240 km

Range 75% charging: 150 km

Charging time for 75%: 30 min

Charging time for 100%: 2.5 hours

Table A7. **Energy consumption and efficiency**

Variable	Shared Taxi	Taxi-Bus 8	Taxi-Bus 16
Energy consumption of diesel (Kw.h/veh. day)	225.3	97.4	68.0
Tank-to-wheel efficiency, diesel (%)	19.0	19.0	19.0
Tank-to-wheel efficiency, electric (%)	75.0	75.0	75.0

Conversions diesel / Electric Kw.h:

1 KWh = 3.6 MJ

1 lt diesel = 38.29MJ

1 lt diesel = 10.64Kwh

Electricity costs

At the highest power level (41.4 KV.A)

Fixed rate / day / charging unit: 3 NZD

Table A8. **Electricity costs**

Period of day	Variable peak	Variable off peak	Average
Rates/Kw.h	0.20053	0.10053	**0.12053** NZD/Kw.h
Amount of charging (%)	20	80	

Shared Mobility Simulations for Auckland

This report examines how the optimised use of new shared transport modes can change the future of mobility in the Auckland area in New Zealand. Based on computer simulations of different shared mobility scenarios, the study shows that introducing ride sharing and Taxi-Bus services can significantly reduce CO_2 emissions and improve accessibility while lowering mobility costs and improving service quality for users. Most scenarios also reduce congestion and release public parking space for other uses. The simulations show that new shared modes work particularly effectively in tandem with public transport supply such as rail and bus rapid transit (BRT), for which they can act as feeders. A survey and focus groups for the study explored how willing citizens in the Auckland area are to using shared mobility solutions. Together, the findings provide an evidence base for decision makers to weigh opportunities and challenges created by new forms of shared transport services. The work forms part of a series of studies on shared mobility in different urban and metropolitan contexts.

This report is part of the International Transport Forum's Case-Specific Policy Analysis series. These are topical studies on specific issues carried out by the ITF in agreement with local institutions.

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