SHARED MOBILITY SIMULATIONS FOR AUCKLAND METHODOLOGY
Luis Martinez
(with Olga Petrik, Francisco Furtado and Jari Kaupilla)

WELLINGTON, NOVEMBER, 2017
- Modelling Framework
- Shared modes specification
- Processing input data
- Synthetic mobility dataset generation
- Focus group and stated preference survey
- Setting shared mobility infrastructure
- Shared mobility simulation model
- Model results assessment
## Shared modes specification

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

Index

- Data requirements
- Public transport network GTFS file
- Land use data
  - Census data (population, employment)
  - Location of public services (e.g. hospitals) and education facilities
  - Activity location (Points Of Interest – POI)
- Household travel survey:
  - Reasonable sample size (between 0,5 to 2% of citizens or trips)
  - Geocoded trip extremes and time of travel
  - Detailed mode choice recording (legs of each journey)
Processing input data

Data requirements

- Road network ( routable and with attributes to compute dynamically travel times, e.g. capacity, free flow speed)
- Public transport network GTFS file
- Land use data
  - Census data (population, employment)
  - Location of public services (e.g. hospitals) and education facilities
  - Activity location (Points Of Interest – POI)
- Household travel survey:
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  - Detailed mode choice recording (legs of each journey)
Processing input data
Definition and study area boundaries and spatial resolution

Study area
- The study area boundaries should include any location that has a significant mobility relation

Spatial resolution
- Setting a regular square grid that would treat any study area location more uniformly
- This spatial resolution is used to land use assessment and assessing the transport modal choices between every origin-destination pair in the study area
- The resolution can be simple or compound with adaptive resolution to less active zones
- Only cells with a building footprint, a road network node or any POI inside the grid are preserved
Processing input data
Household Travel Survey

- Data for 3 years from the travel survey
  - 2011/2012
  - 2012/2013
  - 2013/2014
- Trips with trips extremes inside the study area and assigned to the spatial grids
- Personal weights from the survey were reweighted to convert the coefficient value in an average 2013 travel statistical expansion factor
- Reported travel time, departure time, trip purpose and transport mode of each trip leg are saved
- Original data were processed and prepared for two models
  - Revealed mode choice model
  - Synthetic population mobility seed
Trips are combined into journeys

Journey is a series of consecutive trip legs with purpose ‘change mode’ plus one following trip leg with the final purpose of the journey

The mode of a journey is defined in the following way:

- Soft modes (if no motorized modes were used only walk, cycle, scooter)
- Private Car(car/motorcycle driver or passenger, if no PT modes were used)
- Train (if Train was used and no Private Car)
- Ferry (if Ferry was used and no Train or Private Car)
- Bus (if only bus was used for PT trip legs and no Private Car)
- PT + Private Car (if both private transport and PT were used)
- Journeys with plane, taxi and ‘others’ modes are dismissed for now

Other characteristics are calculated for journeys (travel time, in-vehicle travel time, access/egress time, ODs, etc.)
Processing input data
Land use and activity data collection

- Census data (2013)
  - Population
  - Employment
- OpenStreetMap
  - Points of interest or Amenities from OpenStreetMap
- Official land use information
- Buildings footprint
  - OpenStreetMap
Processing input data
Road network validation

- Spatial correction
  - Ensure spatial connectivity of links and node and correct topology
  - Network length and frequency of intersections in the network
  - Compute logical *intersections* (buffer of 30 m of each node within a continuous buffer)

- Attributes
  - Number of lanes
  - Free flow speed
  - Capacity (hourly)

- The network consolidated has:
  - 46 650 links
  - 23 133 nodes
  - 17 441 intersections
Processing input data
Public Transport (GTFS)

- Extract all tables from GTFS file and concatenate databases
  - Each operator may specify the services differently (schedule based or frequency based)
  - Detailed geolocation of stops and transfers is relevant to estimate access/aggress but also transfers in the network (transfers file might be available but not fully complete sometimes)

- Data of the location of centroids grids is added to the GTFS database to generate the source/destination of the shortest paths to be computed

- An R model was created to generate a “Super-Network” that contains
  - the original public transport links (maintaining the same mode code) - morning peak hour
  - Connectors of centroids to centroids and to public transport stops/stations within 2 km
  - Generate transfers between stops within 250 m
  - Costs of the links (integrated or not integrated fare system)
Processing input data
Spatial data geocoding

- Land use data
  - Census data on population and employment
    - Split by census tracts to grids proportionally to area in active cells
  - POIS
    - OpenStreetMap: Count by trip purpose classified into (Restaurants and Bars, Recreational, Commerce and Stores, Offices, Hotels, Education Centers, Hospitals and Shopping Centers)
    - Official information: health, education
- Household Travel Survey
  - Residential location
  - Trip Extremes
- Public transport network
  - Connect public transport stops/stations to grids
A shortest path algorithm was programmed in Java to generate the attributes of all private car or public transport using the road network and public transport “Super Network” between all grids of the study area.

The modes transfer weights and mode preferences weights were established to ensure extracting the best solution for a specific mode (e.g. penalty to the non bus links).

The resulting table contains:

- travel distances of different transport modes (walk, car, bus, rail, ferry and BRT)
- total travel time
- access/egress time (walk), access/egress time (car)
- total on board time
- transfer time
- number of transfers
- all access and egress public transport stops in the path
Assumptions

- Sample size: 36,314 trips, revealed data generated at 500 grid cell size
- The alternative mode considered are:
  - Walking
  - Private car (as driver) (PC)
  - Rail
  - Bus
  - Ferry
  - PC+ Public transport (PT)
  - Taxi
  - Biking
  - Mode availability function of age and travel characteristics (i.e. age, walking distance, etc.)
Multinomial Logit (Biogeme)

- The model presents a quite good overall calibration of $\rho^2=0.78$, with all variables statistically significant to 0.95 level except PC+PT independent term
- Obtained value of time for car (7.78 NZD) and for PT (4.68 NZD) are sensible
- A transfer penalty is equivalent to 12 minutes on board

<table>
<thead>
<tr>
<th></th>
<th>Walk</th>
<th>Private Car</th>
<th>Train</th>
<th>Bus</th>
<th>Ferry</th>
<th>Car + PT</th>
<th>Taxi</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASC</td>
<td>2.45</td>
<td>4.53</td>
<td>0.533</td>
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<td>-0.224</td>
<td>-0.224</td>
<td>-0.224</td>
<td>-0.224</td>
<td>-0.224</td>
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<td>-0.0491</td>
<td>-0.0491</td>
<td>-0.0491</td>
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<tr>
<td>WT</td>
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<td>-0.0161</td>
<td>-0.0161</td>
<td>-0.0161</td>
<td>-0.0161</td>
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<td>0</td>
</tr>
<tr>
<td>NT</td>
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<td>0</td>
<td>-0.204</td>
<td>-0.204</td>
<td>-0.204</td>
<td>-0.204</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Synthetic mobility dataset generation

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- Introduction
- Model Inputs
- Model workflow
- Outputs of the model
The model uses information from each respondent of the Household Travel survey to:

- Generate a set of persons similar to the respondent (depending on the survey expansion multiplicative coefficient of the person)
- Model the trip chain of each new “virtual person” – preserving the array of trip purposes stated on the survey
- Introduce (relatively small) variations in time and in space distance of each trip (keeping all the other attributes of that trip) – which depend of the origin and destination, the trip purpose and mode used for each trip

The model uses statistical data from the survey to establish constraints and membership fuzzy functions to determine “virtual origin and destination”, attached to the land uses associated with the trip generation of each census track.
Synthetic mobility dataset generation

Model Inputs

- The Household Travel Survey with geocoded trip ends and characterization of the respondents and each trip that they perform (if possible also including trip purpose) with sample coefficients (sampling rate >0.5%)

- A detailed land use database used as seed for trip generation/attraction functions

- A characterization of the trip generation/attraction rates of land use activities for different times of the day and relation with the purpose of the trip (worker, visitor or other)

- A characterization of the travel times in different transport modes and the number of transfers required in public transport between all the census tracts of the study area
For each trip end location the model calls a membership fuzzy function, which
determines the trip end location using a Monte Carlo simulation procedure.
Land use “mass” of trip origin or destination

- The membership fuzzy function is computed for each census tract of the modelling area for each trip. This model is based on a trip generation rate for each type of land use, linked to the trip purpose and the trip departure time.

- Based on the land use distribution of each census tract, the model computes a trip generation rate. These generation rates are then corrected by model correction factors and constraints.
Synthetic mobility dataset generation
Generation of individuals mobility (II)

Transportation probability

- A logistic function (S curve) is calibrated to assess the deviation of travel time for every potential OD pair when compared to the original reported travel time and the number of transfers
  - The number of transfers is set by a rule based approach where the “virtual person” presents a similar mobility by having either the same number of transfers or a maximum variation of 1
  - The probability of travel time similarity is obtained through an S curve where same travel time has higher probability and 15 minutes travel time variation has 0 probability
- The total membership fuzzy function is generated as a product of the land use “mass” and the transportation probability
Transportation probability

- The total mass is converted into a probability density function and a random number is generated to choose the destination of the “virtual user” for the reported trip and a given trip purpose.
- The probability density function when generating an empty set of options restarts the Monte Carlo simulation for the “virtual person” mobility.
- In case of constrained mobility to previous members, previous generation is preserved and ensured that other trips respect the fixed term introduced.
Compatibility analysis of generated journeys and trip chain

- **Structural compatibility:**
  - Same trip purpose, trip mode (walking/biking, private car or public transport), trip home based (yes/no), alone (yes/no)

- **Time compatibility:**
  - Trip starting time interval, trip duration ratio (max 25% difference)

- **Space compatibility:**
  - Distance between origins and destinations (depends on the trip purpose), trip length ratio (max 25% difference)

- The probability of choice of a given census track as destination of a trip is a function of the similarity of distance to origin (in comparison with that reported in the survey), of the distribution of functional areas aligned with the stated trip purpose along with the distance-compatible census track and of the mode-compatibility.
Synthetic mobility dataset generation

Outputs of the model

- The model generates a database with a code for each household, person and trip recording the following information:
  - Trip ID ([T_ID])
  - Grid origin, destination, coordinates ([Grid_o], [Grid_d], [Grid200_o], [Grid200_d], [X_o], [Y_o], [X_d], [Y_d])
  - Seed respondent code ([samno]), Household code ([household_code]), person ([person]) and virtual person ID ([Clone_ID])
  - Trip order ([trip]), Seed journey ID ([journey_ID])
  - Trip purpose ([purpose])
  - Code of the person in which the trip was performed in company of ([company])
  - Original transport mode ([mode]) and transport mode estimated ([mode_est])
  - Departure time ([start_time]), duration ([duration]) and day of the week of trip ([day_of_week])
Focus group and stated preference survey

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.
- 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.
Focus group and stated preference survey
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Focus group and stated preference survey

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- Design of the focus group meetings
- Results of the discussion
- Stated preference survey
Focus group and stated preference survey
Design of the focus group meetings

- 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.
  - Stated preferences survey (taking 10-15 minutes) to understand the respondents’ final perceptions of shared mobility and their potential impact on car ownership.
## Focus group and stated preference survey

### Results of the discussion

<table>
<thead>
<tr>
<th>Type of questions</th>
<th>Type of answer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Respondents background</strong></td>
<td></td>
</tr>
<tr>
<td>Respondent profile (residential location within metropolitan area, age, gender, occupation, car ownership and PT usage)</td>
<td>Statistical distribution</td>
</tr>
<tr>
<td>Mobility background</td>
<td>Storylines</td>
</tr>
<tr>
<td>Daily travel pattern, including the main mode used</td>
<td>Storylines</td>
</tr>
<tr>
<td>Main drivers for the mode choice</td>
<td>Storylines</td>
</tr>
<tr>
<td>Factors that would make the respondent to change from car to PT</td>
<td>Storylines</td>
</tr>
<tr>
<td>If the respondent would be willing to move from non-PT (car/taxi) options to the shared services (car users)</td>
<td>Statistical distribution</td>
</tr>
<tr>
<td><strong>Modal preferences and triggers to modal choice</strong></td>
<td></td>
</tr>
<tr>
<td>If the respondent would prefer to use the flexible services. Increase in price which the respondent would accept (bus users)</td>
<td>Statistical distribution</td>
</tr>
<tr>
<td>If the respondent would use a feeder service to arrive to the PT stop (rail/ferry users)</td>
<td>Statistical distribution</td>
</tr>
<tr>
<td>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</td>
<td>Statistical distribution</td>
</tr>
<tr>
<td>The most important characteristics of the shared modes that would make the respondent shift from private modes (car or taxi)</td>
<td>Statistical distribution</td>
</tr>
<tr>
<td><strong>Shared mobility market segmentation</strong></td>
<td></td>
</tr>
<tr>
<td>Acceptable number of passengers when sharing a Shared Taxi</td>
<td>Statistical distribution</td>
</tr>
<tr>
<td>Acceptable number of passengers to share with in a Taxi-Bus</td>
<td>Statistical distribution</td>
</tr>
<tr>
<td>Which of the two shared services the respondent would prefer and why</td>
<td>Statistical distribution</td>
</tr>
</tbody>
</table>
Survey structure and deployment

- A survey was designed including four main components:
  - Personal characterisation
  - Stated preference mode choice (8 games)
  - Mobility characterisation
  - Attitudes towards shared mobility

- The survey was deployed in an online survey tool designated *SurveyHero*
Respondent’s profiles and mobility background

The spatial distribution of respondents is skewed towards the option “close to the city centre” with only one from “the city centre”. It may be that respondents assessment of the city centre is narrow. Age composition presents some balance but with dominance of young people.

The survey was undertaken by 10 males and 9 females. Occupation profile was dominated by full time employees and students.
## Respondent’s profiles and mobility background

<table>
<thead>
<tr>
<th>Activity</th>
<th>Number of weekly trips</th>
<th>Average trip duration (mins)</th>
<th>One most commonly used mode (codes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel to / from work or place of study</td>
<td>129</td>
<td>8.6</td>
<td>Private car - driver (61%), Bus (15%)</td>
</tr>
<tr>
<td>Travel to drop off / pick up children at school or childcare, if trip does not include a place of work or study</td>
<td>22</td>
<td>2.2</td>
<td>Private car (100%)</td>
</tr>
<tr>
<td>Daily shopping (e.g. supermarket)</td>
<td>29</td>
<td>1.93</td>
<td>Private car – driver (75%), Walk (17%)</td>
</tr>
<tr>
<td>Social activity (e.g. visiting friends or family)</td>
<td>41</td>
<td>2.73</td>
<td>Private car – driver (58%), Walk (17%), Private car – passenger (17%)</td>
</tr>
<tr>
<td>Leisure activities (e.g. sport)</td>
<td>26</td>
<td>1.86</td>
<td>Private car – driver (50%), Walk (40%)</td>
</tr>
<tr>
<td>Personal matters (e.g. doctor’s appointment)</td>
<td>16</td>
<td>1.07</td>
<td>Private car – driver (72%)</td>
</tr>
<tr>
<td>Other</td>
<td>12</td>
<td>1.33</td>
<td>Private car – driver (50%)</td>
</tr>
</tbody>
</table>
Attitudes towards shared mobility attributes

- The attitudes were classified into: regular car user, regular bus user, regular rail, BRT or ferry user
- Respondents were asked about
  - Price / Fare of shared mobility modes
  - Accessibility / walking time to stop
  - Lost time with shared mobility modes
  - Ride comfort / Seat availability
  - Number of passengers on board shared mobility modes
  - Number of transfers
  - Feeder service to / from public transport station (e.g. rail, ferry)
Stated preference choice experiments

- An experiment was designed using full factorial design with 8 cards divided into two sub-games
  - A game comparing current transport modes options along with a generic shared mobility option for a generic trip
    - This game had for cards were transport modes were described
      - One related to private car
      - Other with public transport options (bus or rail)
      - A non motorised alternative (walking, cycling)
  - A game comparing the two shared mobility options proposed: Shared Taxi and Taxi-Bus
Focus group and stated preference survey

Stated preference survey

Stated preference choice experiments
Focus group and stated preference survey

Stated preference survey

Stated preference choice (MNL)

- The rho-squared is equal to 0.475
- A hypothesis that the two samples have different variance was rejected
- A mixed-logit model specification allowing to capture correlations within answers of a same respondent was tested but was dismissed due to bringing more complexity with no significant gains in terms of the model goodness of fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>t-test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative specific constant, bike</td>
<td>0.374</td>
<td>1</td>
<td>0.32*</td>
</tr>
<tr>
<td>Alternative specific constant, bus</td>
<td>-4.22</td>
<td>-4.47</td>
<td>0</td>
</tr>
<tr>
<td>Alternative specific constant, rail</td>
<td>-2.9</td>
<td>-1.99</td>
<td>0.05</td>
</tr>
<tr>
<td>Alternative specific constant, shared taxi</td>
<td>-3.84</td>
<td>-8.08</td>
<td>0</td>
</tr>
<tr>
<td>Shared mode being Taxi-Bus, for car users</td>
<td>-0.303</td>
<td>-1.26</td>
<td>0.21*</td>
</tr>
<tr>
<td>Shared mode being Taxi-Bus, for non-car users</td>
<td>0.314</td>
<td>1.14</td>
<td>0.25</td>
</tr>
<tr>
<td>Access time, public transport</td>
<td>-0.0916</td>
<td>-5.43</td>
<td>0</td>
</tr>
<tr>
<td>Access time, shared mobility</td>
<td>-0.11</td>
<td>-5.43</td>
<td>0</td>
</tr>
<tr>
<td>Availability/quality of footpath, non-motorized modes</td>
<td>0.386</td>
<td>2.45</td>
<td>0.01</td>
</tr>
<tr>
<td>Ease of crossing in traffic, non-motorized modes</td>
<td>-1.23</td>
<td>-7.37</td>
<td>0</td>
</tr>
<tr>
<td>Being a car user, shared mobility</td>
<td>-0.974</td>
<td>-1.26</td>
<td>0.21</td>
</tr>
<tr>
<td>Travel cost, car</td>
<td>-0.255</td>
<td>-3.58</td>
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<tr>
<td>Travel cost, public transport</td>
<td>-0.388</td>
<td>-2.99</td>
<td>0</td>
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<tr>
<td>Travel cost, shared mobility</td>
<td>-0.243</td>
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<tr>
<td>Being female, shared mobility</td>
<td>0.547</td>
<td>2.29</td>
<td>0.02</td>
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<tr>
<td>Lost time, shared mobility</td>
<td>-0.0523</td>
<td>-2.69</td>
<td>0.01</td>
</tr>
<tr>
<td>Number of transfers</td>
<td>-0.59</td>
<td>-2.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Congestion charges/tolls, car</td>
<td>-0.399</td>
<td>-6.95</td>
<td>0</td>
</tr>
<tr>
<td>Number of passengers, shared taxi</td>
<td>0.156</td>
<td>1.67</td>
<td>0.09</td>
</tr>
<tr>
<td>Being above 60 years old, shared taxi</td>
<td>0.195</td>
<td>0.56</td>
<td>0.57*</td>
</tr>
<tr>
<td>Riding alone, shared taxi</td>
<td>-0.178</td>
<td>-9.4</td>
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<tr>
<td>Travel time, non-motorized modes</td>
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<td>-13.31</td>
<td>0</td>
</tr>
<tr>
<td>Travel time, public transport</td>
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<td>-5.43</td>
<td>0</td>
</tr>
<tr>
<td>Travel time, shared mobility</td>
<td>-0.0573</td>
<td>-3.99</td>
<td>0</td>
</tr>
<tr>
<td>Waiting time, public transport</td>
<td>-0.0336</td>
<td>-5.43</td>
<td>0</td>
</tr>
<tr>
<td>Living far from the city center, shared mobility</td>
<td>-0.81</td>
<td>-3.38</td>
<td>0</td>
</tr>
<tr>
<td>Being above 60 years old, bus</td>
<td>0.933</td>
<td>2.16</td>
<td>0.03</td>
</tr>
<tr>
<td>Being below 25 years old, bus</td>
<td>2.18</td>
<td>3.75</td>
<td>0</td>
</tr>
<tr>
<td>Being below 25 years old, non-motorized modes</td>
<td>1.65</td>
<td>2.68</td>
<td>0.01</td>
</tr>
<tr>
<td>Being below 25 years old, shared mobility</td>
<td>0.9</td>
<td>1.86</td>
<td>0.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Travel time PT / Access time PT</td>
<td>0.333</td>
<td></td>
</tr>
<tr>
<td>Travel time PT / Travel cost PT</td>
<td>4.716</td>
<td></td>
</tr>
<tr>
<td>Travel time PT / Waiting time (generic)</td>
<td>0.908</td>
<td></td>
</tr>
<tr>
<td>Travel time Shared Mode / Access time Shared Mode</td>
<td>0.521</td>
<td></td>
</tr>
<tr>
<td>Travel time Shared Mode / Travel cost Shared Mode</td>
<td>14.148</td>
<td>$NZ/hour</td>
</tr>
<tr>
<td>Travel time Shared Mode / Waiting time (generic)</td>
<td>1.705</td>
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<tr>
<td>Travel time Shared Mode / Travel time Non-motorized modes</td>
<td>0.257</td>
<td></td>
</tr>
<tr>
<td>Travel time Shared Mode / Travel time Car</td>
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<td>Travel time Shared Mode / Travel time PT</td>
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Ratio of coefficients

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<th>Value of the ratio</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Travel time PT / Access time PT</td>
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<tr>
<td>Travel time Shared Mode / Travel time PT</td>
<td>1.879</td>
<td></td>
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</tbody>
</table>
Setting shared mobility infrastructure
Depots and Taxi-Bus stops

Depots

- Designed as a *Set Cover Problem*
  - The inputs for the depot location problem are:
    - the existing off-street parking facilities geocoded (projected to a road node with at least three movements possible)
    - Road nodes more than 1 km from an off-street parking facility and with at least three movements possible
  - The objective function is minimising the number of depots required by satisfying the constraints:
    1. Minimum distance between generated depots of 1000 m
    2. Every departure road node with demand as source should be less than 10 minutes away
Setting shared mobility infrastructure
Depots and Taxi-Bus stops

Taxi-Bus stops

- Designed as a *Set Cover Problem*
  - The inputs for the depot location problem are:
    - the existing bus stops and heavy public transport stations (rail, ferry and BRT) projected to the closest road node with at least three movements possible
    - Road nodes more than 400 m from an existing bus stops and with at least 3 movements
  - The objective function is minimising the number of stops required by satisfying the constraints:
    1. Minimum distance between generated depots of 300 m
    2. Every departure road node with demand as source should be less than 400 m away
Shared mobility simulation model

Index

- Model framework
- Model inputs
- Characterisation of model agents
- Characterisation of the model environment
- Simulation workflow
- Taxi-Bus planning optimisation model
- Shared Taxi dispatch optimisation model
- Setting shared mobility simulation scenarios
- Model logging and outputs
- Model computational requirements and performance
Four main agents:
- User
- Dispatcher
- Shared vehicles
- Cars

One common simulation environment that coordinates information in the same timeline and communicates the three agents and update traffic conditions that retrieves by information to the dispatcher and vehicle movements.
Shared mobility simulation model

Model inputs

- Synthetic mobility dataset
  - This dataset contains all trips that are made during a weekday with the mode choice when some scenario conditions are met, otherwise the user preserves their current mobility choice
  - Scenario attributes include:
    - Sorting attribute to activate modal diversion (assessing new modal options that can remain unaltered)
    - Boarding and alighting stop in case of feeder services
    - Park and ride station in case of LEZ scenario and if switches to public transport or shared mobility at a Park and ride station

- Road network (links)
  - With free flow speed and capacity

- Road network (nodes)
  - Location of stations, stops and regular pick-up/drop-off points for users
User

- In the simulation environment, a trip is generated when a user requests a departure from a point towards another point. The model accounts for the simulation parameters (resulting from the specification of each shared mode) and accounts for waiting time, detour time and arrival time tolerances that are defined for the model run. The dispatcher then finds, in real time or with the pre-booking, the best possible routing and assigns one of several available vehicle types to carry out the trip in either a shared-taxi or Taxi-Bus mode.

- The user then waits for the vehicle or walks to a specified pick-up location and boards the vehicle. When the vehicle arrives at its destination, the user exits the system and a set of indicators are generated in a trip log so that they can be used for ex-post system evaluation.
Cars

- Car trip are assigned to the network from origin to destination and leave the road network after.
- The agent flow chart is generated at the beginning of the simulation at stays waiting for activating movement at the locate state.
- After that initial state, the car moves with a time step of 0.05 minutes or the travel of the current link of smaller than that time.
- At the end of the path the agent is destroyed and kept information at the user client and logged the aggregate traffic result of each link every five minutes.
Shared mobility simulation model
Characterisation of model agents

Shared vehicles (Shared Taxis)

- The vehicles agent is formulated as a reactive agent that follows the instructions of the dispatcher. Idle cars are in stations spread across the city, and whenever the car is empty and not dispatched to a new trip, it relocates itself to the nearest station.

- Active cars follow the shortest path and minimise travel time for its route assignment taking into dynamically updated link travel times and intersection delays (every 5 minutes).

- The different states represent the vehicles movement and the reset of destination or resting at a shared mobility station.
Shared vehicles (Taxi-Bus)

- Taxi-Buses are vehicles that are by default available at stations and relocate between services if required or stop to idle to the closest station to the last service.
- The system generated potential stops in the study area than can be activated during the day. The location of these stops was constrained by minimum distance between stops (400 metres) and the selection of the road node with greater connectivity in the neighboring area in order to ensure flexible routing for the vehicles (avoid streets with traffic only in one direction or left turning blocking).
- The fleet of cars and minibuses is an output of the simulation by measuring the number of vehicles that are required in the simulation and their relocation dynamics between stations during the day. The minibuses required are differentiated between 8 or 16 seated passenger vans or minibuses.
Shared mobility simulation model
Characterisation of model agents

Dispatcher

- Is an entity that 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 distance-minimisation principle that applies not just to the requesting user but also to those already underway in the same vehicle (ensuring that the user parametric constraints are satisfied).

- The model defines in parallel the dispatching of Taxi-Bus and shared-taxis when both systems are operating. Users launch their requests and preferences that are saved.

- In case of a Taxi-Bus request, they are processed 30 minutes in advance. The dispatcher runs a local search algorithm that tries to maximise the number of passengers assigned complying with the users’ constraints at each step (best match in minibus service that warrant at least 50% occupancy at least in some part of the trip and an average (per kilometre) occupancy rate greater than 25 percent of the vehicle capacity).

- Some users that are not assigned to Taxi-Buses because of these constraints are then re-assigned (upgraded) to the shared-taxi system as real time requests, following the shared-taxi real time booking system automatically performing stop-to-stop services.
Dispatcher

- The shared-taxi dispatching services operate a real time optimisation model that tries to minimise the additional vehicle kilometres generated by each additional user in the system, estimating the minimum insertion Hamiltonian path for each operation vehicle that satisfies all the constraints of passengers already assigned or on-board and the current request.
  - The shared-taxi plate is communicated to the user at least 3 minutes ahead of the estimated boarding time. When 50 percent of the maximum waiting time of that user is reached and no convenient shared-taxi with clients has been found, the dispatcher searches for available empty taxis nearby, and if none is found, it generates an additional vehicle departing from the closest station to serve the user.
- The dispatcher also controls the vehicle movements when idle, ensuring efficient vehicle movements to stations that may require additional fleet soon.
Shared mobility simulation model
Characterisation of the model environment

- Road network
  - Traffic dynamics
- Road network nodes
  - Pick up and drop-off locations
  - Shared mobility stations (Parked idle vehicles)
  - Taxi-Bus stops and heavy public transport stations (rail, ferry and BRT)
  - Park and ride stations for LEZ scenarios
- Grids
  - Collect and retrieve information from/to simulation

Legend:
- LEZ cordon park and ride stations (Larger Boundary)
- LEZ cordon park and ride stations (Smaller Boundary)
- Station (Rail, BRT, Ferry)
- Small LEZ
- Large LEZ
- Rail
- Ferry
- Bus route
Shared mobility simulation model

Simulation workflow

- Shared Taxi dispatch orders
- Taxi-Bus requests
- Log the status and leave the system when arrived

**Time step 0.01 minutes**
- Shared Taxi and Taxi-Bus movements update
- Car movements update
- Taxi-Bus clients upgrade (if not assigned and departure in less than 3 min)

**Time step 0.5 minutes**
- Shared Taxi clients assignment update

**Time step 1 minute**
- Road links travel time update

**Time step 15 minutes**
- Taxi-Bus clients assignment update
- Travel time estimates between road nodes

Dispatcher, Private car, Taxi-bus, Shared Taxi
Method

- The optimisation model is formulated as an heuristic with local search and genetic algorithm operators of aggregate and switch.
- The model is run until convergence criteria in change in the global optimisation minimisation function, model solution constraints and a minimum number of iterations is met.
- The minimisation function is the total vehicle kilometres travelled with a penalty to the vehicle kilometres if a new Taxi-Bus is generated to provide service (3 x factor).
- The constraints to the model are:
  - Clients quality of service specifications on travel linear speed of 15 km/h, walking distance to origin or destination and intended departure or arrival time is not affected more than 15 minutes.
  - All clients have to seated in the type of vehicle generated for the service (minibus seated capacity).
  - Minimum number of clients in a ride party aggregated (clusters) of 4.
  - Minimum average vehicle occupation per km of 40% of the minibus seated capacity.
Inputs and data processing (II)

- The model collects information about the demand and generates Taxi-Bus dispatching orders 30 minutes in advance of the intended departure, presenting from previous iterations solutions still active with fixed solution
  - Each dispatching order has a sub-dispatching order id object containing (gene):
    - The client properties
    - The intended possible departures times are converted to integer 15 minutes slots
    - Each subdispatching order presents a different pair of origin or destination stops that satisfy the walking from/to stops constraint
    - Assigned to the corresponding corridor (18), running in parallel in ‘Divide and Conquer’ heuristic
Shared mobility simulation model
Taxi-Bus planning optimisation model (III)

Inputs and data processing (III)

✓ Each sub-dispatching order generates a neighbouring function with other available orders that satisfy time constraints, measuring:

1. Spatial compatibility (angles for a giving sequence of stops)
2. Time compatibility (as constraint to verify that by design no one is set outside its time boundaries)
3. Mass of compatible clients (S-curve that standardises the weight of boarding clients)
Inputs and data processing (IV)

- The input optimisation corridors are the following:

<table>
<thead>
<tr>
<th>ID</th>
<th>Corridor name</th>
<th>Connected areas</th>
<th># trips</th>
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</thead>
<tbody>
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<td>1</td>
<td>North-Centre, Internal</td>
<td>North-Centre, Internal</td>
<td>615 210</td>
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<tr>
<td>2</td>
<td>North-Centre - Far North</td>
<td>North-Centre, Far North</td>
<td>44 933</td>
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<tr>
<td>3</td>
<td>North - South</td>
<td>North-Centre, South-Centre, Far South</td>
<td>176 210</td>
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<tr>
<td>4</td>
<td>North - West</td>
<td>North-Centre, Far North, West</td>
<td>66 963</td>
</tr>
<tr>
<td>5</td>
<td>To Waiheke Island</td>
<td>All areas to Waiheke Island</td>
<td>6 195</td>
</tr>
<tr>
<td>6</td>
<td>Far North - North-Centre</td>
<td>Far North, North-Centre</td>
<td>43 499</td>
</tr>
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<td>7</td>
<td>Far North, Internal</td>
<td>Far North</td>
<td>334 888</td>
</tr>
<tr>
<td>8</td>
<td>South - North</td>
<td>Far South, South-Centre, North-Centre</td>
<td>176 362</td>
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<td>9</td>
<td>South-Centre, Internal</td>
<td>South-Centre, Internal</td>
<td>1 276 263</td>
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<tr>
<td>10</td>
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<td>South-Centre, West, Far South</td>
<td>167 069</td>
</tr>
<tr>
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<td>South-Centre - Far South</td>
<td>South-Centre, Far South</td>
<td>227 044</td>
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<tr>
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<td>West - North</td>
<td>West, Far North, North-Centre</td>
<td>68 576</td>
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<tr>
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<td>West - South</td>
<td>Far South, West, South-Centre</td>
<td>167 354</td>
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<td>West, Internal</td>
<td>West, Internal</td>
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<tr>
<td>15</td>
<td>Far South - South-Centre</td>
<td>Far South, South-Centre</td>
<td>229 420</td>
</tr>
<tr>
<td>16</td>
<td>Far South, Internal</td>
<td>Far South, Internal</td>
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</tr>
<tr>
<td>17</td>
<td>From Waiheke Island</td>
<td>From Waiheke Island to all areas</td>
<td>3 634</td>
</tr>
<tr>
<td>18</td>
<td>Waiheke Island</td>
<td>Waiheke Island, Internal</td>
<td>1 178</td>
</tr>
</tbody>
</table>
Solving the problem (I)

- The model uses several functions in each iteration to process the model for each corridor and aggregate to the global solution.
- The model uses a concept of classifying potential solutions. The classification is designated *spine*, that places in an array all the *gens* that have the number of potential clients higher or equal than the percentile 10% of the total array.
- The several function triggered in each iteration to update the chromosome are:
  1. Spines aggregation (join)
  2. Non-spines aggregation (join)
  3. Non-spines and non aggregated in previous step (join)
  4. Combine spines (switch and join)
  5. Join weak to spines (switch and join)
  6. Join all non aggregated (switch and join)
Solving the problem (II)

- Dispatchers have to be coordinated to ensure just one sub-request or \textit{gen} is used.
- The optimisation model converges normally between 5 and 20 iteration depending on the problem size for each corridor, having at the strongest peak period around 130,000 \textit{gens} and can take 15 to run the heaviest corridor problem.
- The minibuses created in previous problems and still active are put as available solutions and gens with a chromosome of stops time fixed, being the new solutions a possible append to the previous solution (continue the previous service).
- At the end, all solutions obtained for one corridor are aggregated into one global solutions and results are logged.
  - The model communicates to the passenger the time of boarding and alighting and if requires to add the client request into Shared-Taxi.
  - The model outputs also communicate to each road link that a bus will pass through that link in a specific time slice of 1 minute and is accounted for traffic congestion and travel time update.
Method (I)

- The optimisation model is formulated as a local search algorithm where the dispatcher filters the taxis that are already operating (driving to a first client or with clients already in) that their current location travel time to arrive to the request location are less than the allowed waiting time.

- The model split the problem into 4 levels:
  1. Almost full Shared Taxis (4 or more clients on board)
  2. Taxi with 2 to 4 clients on board
  3. Taxis with 1 client on board
  4. Taxis empty returning to a depot

- The model gives priority to the lowest level solutions to run then (probability of triggering a lower levels if a compatible solution was found at a higher level).

- The objective function is minimise the insertion distance of an additional client.

- Each client had a different waiting time and detour time constraint to be satisfied.
Method (II)

- This requires computing the shortest compatible Hamiltonian Path for each solution
**Inputs and data processing**

- The model collects information about the demand and generates Shared Taxi dispatching orders in real time, aggregated into an array of dispatch orders that are computed each 0.5 min.

- The solution is considered acceptable if all the constraints are satisfied in the Hamiltonian path sequence and the additional distance generated is lower than 120% of travel distance to the closest depot, that would lead to generate a vehicle.

- The dispatch orders active in the 0.5 minutes time slot are sorted by party size (if any person travels with a dependent or other person with same departure time and departure location) and distance descending.

- The taxi solutions to test are sorted by number on clients on board and the time gap available from the most constrained client. Taxis that have their constraints saturated (available space or detour available for the most constrained clients) are set as occupied and not added the Shared Taxis solution array.
Solving the problem (I)

- The model classifies dispatching orders regarding their constraint in waiting time is close to be reached and a solution has to be found rapidly to satisfy it (urgent) or request still have time slack to improve the assignments if a solution found is not very good for the system (additional vehicle-kilometres generated).

- When a dispatch order is labelled as urgent if no solution is found in a taxi already in the street the dispatcher request an iddle car from the closest depot to became active and ride to the pick up point.

- If the dispatch order is not urgent the optimisation model tries to find a solution sorted by level of Shared Taxi occupancy classification as described before.
Solving the problem (II)

- If a solution is found an assignment is communicated to the user saying a pick up time but not yet the Shared Taxi plate that will pick up him.

- In the next iterations until the pick up time – 3 minutes, the system will try every 0.5 minutes to find a better solution for this user with the real time Shared Taxi locations and occupations. This clients are labelled as temporary dispatch and run as a separate array of the problem.

- 3 minutes before the pick time communicated the client receives the identification of the plate of the Shared Taxi.
Car replacement settings

- Share of car replacement by shared mobility is set as input
- Each client has a column in the input table with the probability of switch to shared mobility
- The list is sorted by this column and the first clients up to the % defined are transferred to shared mobility
Bus replacement settings

- We can transfer to shared mobility services trips than use bus totally or partially
  - Binary variable if preserve or not
- Filter out the trips performed by BRT to be kept
  - BRT systems are identified as bus trips with headway less or equal to 5 minutes
Shared mobility simulation model

Setting shared mobility simulation scenarios

Setting Low Emission Zones (LEZ)

- In the input table of trips (Users) loaded into the model, one column for each LEZ specification, set if that trip is affected by LEZ or not
- if yes, which is the optimal park and ride stations (minimum detour distance from the original route)
- if at the park and ride station the user gets a Taxi-Bus or ride the heavy public transport system (rail or BRT)
Shared mobility simulation model

Model logging and outputs (I)

- The model saves a large set of information during the simulation and at the end of the simulation.
- Logging is considered the saving of information during the simulation that have a time output:
  - Traffic state in each road link (every 15 minutes)
  - Shared Taxi stock and state (e.g. empty, with 1 to 6 passengers, km travelled) (every 5 minutes)
  - Shared Taxi movements (recording each change in state of every vehicle)
  - Taxi-Bus planning optimisation performance for each corridor (every 15 minutes)
- capacity)
Shared mobility simulation model
Model logging and outputs (II)

- Model outputs:
  - The clients output with the detailed information of their travel (e.g. waiting time, on board time, walking distance, detour time, boarded Shared Taxi, boarded Taxi-Bus)
  - The Shared Taxi outputs with the detailed performance of vehicle (e.g. depot generation, initial service, time, time with different number of clients, travelled km)
  - Taxi-Bus outputs with a detailed information of each route (time at each stop, stop sequence, boarding and alighting at each stop and bus capacity)
The model requires a large memory allocation and processors for the parallel computing

- The Auckland model requires for the most demanding case 48 Gb RAM
- The number of processors should be greater than 20 to ensure efficient Taxi-Bus optimisation

All tasks that operate in parallel have to be synchronised before the clock of the simulation advances again
Shared mobility simulation model
Model computational requirements and performance (II)

- The full replacement model (heaviest and longest model) the model takes 27 hours for a simulated day. The time distribution in the different simulation task are:
  - Taxi-Bus optimisation (20-30% - 96 optimization problems with 18 instances simultaneously)
  - Shared Taxi optimisation (10-20% - 2880 optimization problems – 300 instances simultaneously) – assignment synchronisation at the end of each optimisation and reassignment for conflicting assignments
  - Taxi movements (30% - 50 000 000 processes)
  - Cars (10% 10 000 000 processes)
  - Users (5% 15 000 000) – user decisions
  - Logging and outputing (5%)
Model results assessment

Index

- Aggregate analyses
- In-depth performance assessment
  - Parking requirements
  - Changes in heavy capacity modes ridership
  - Accessibility and Connectivity
  - Quality of service
  - Number of vehicles required and average occupancy
  - Cost
  - Electric vehicles
The model results are saved directly during the simulation or imported to SQL.
Most of the results are processed as SQL queries or R scripts that query SQL tables.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Vkm</th>
<th>CO₂</th>
<th>Congestion</th>
<th>Motorised vehicle fleet (equivalent private car vehicles)</th>
</tr>
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<tbody>
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<td>-54.4</td>
<td>-49.1</td>
<td>-92.8</td>
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<td>-3.2</td>
<td>17.7</td>
<td>-0.2</td>
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</tbody>
</table>
Model results assessment

In-depth performance assessment

Parking requirements

- SQL table saves every 5 minutes the parking dynamics

<table>
<thead>
<tr>
<th>Park and ride stations</th>
<th>Arrivals</th>
<th>Departures</th>
<th>Required parking capacity</th>
</tr>
</thead>
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<tr>
<td></td>
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<td></td>
<td>Car</td>
</tr>
<tr>
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<tr>
<td>13</td>
<td>10 393</td>
<td>8 653</td>
<td>0</td>
</tr>
</tbody>
</table>
Model results assessment
In-depth performance assessment

Changes in heavy capacity modes ridership

- SQL query that joins the inputs table and the Users outputs

<table>
<thead>
<tr>
<th>Area</th>
<th>Baseline (pax, thousands)</th>
<th>Scenario 1 (%)</th>
<th>Scenario 6 (%)</th>
<th>Scenario 10 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rail</td>
<td>Bus</td>
<td>Ferry</td>
<td>Rail</td>
</tr>
<tr>
<td>North Centre</td>
<td>0.0</td>
<td>78.4</td>
<td>2.2</td>
<td>0</td>
</tr>
<tr>
<td>North Far</td>
<td>0.0</td>
<td>10.7</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>South Centre</td>
<td>35.2</td>
<td>142.6</td>
<td>10.7</td>
<td>1229</td>
</tr>
<tr>
<td>West</td>
<td>7.0</td>
<td>29.4</td>
<td>0.0</td>
<td>1736</td>
</tr>
<tr>
<td>South</td>
<td>10.9</td>
<td>50.1</td>
<td>0.0</td>
<td>1199</td>
</tr>
<tr>
<td>Waiheke</td>
<td>0.0</td>
<td>0.9</td>
<td>3.6</td>
<td>0</td>
</tr>
<tr>
<td>Total/average</td>
<td>53.1</td>
<td>312.1</td>
<td>16.5</td>
<td>1290</td>
</tr>
</tbody>
</table>
## Model results assessment

### In-depth performance assessment

### Accessibility and Connectivity

- SQL query that joins the inputs table and the Users outputs

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Current car users</th>
<th>Current PT users</th>
<th>Car mode share (%)</th>
<th>PT and shared mobility mode share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Travel time (min)</td>
<td>Total travel time (min)</td>
<td>Waiting time (min)</td>
<td>Access time (min)</td>
</tr>
<tr>
<td>Baseline</td>
<td>17.77</td>
<td>44.42</td>
<td>18.02</td>
<td>11.97</td>
</tr>
<tr>
<td>1</td>
<td>29.00</td>
<td>31.29</td>
<td>9.07</td>
<td>8.05</td>
</tr>
<tr>
<td>2</td>
<td>28.93</td>
<td>48.91</td>
<td>18.24</td>
<td>11.79</td>
</tr>
<tr>
<td>3</td>
<td>24.33</td>
<td>28.60</td>
<td>8.16</td>
<td>8.63</td>
</tr>
<tr>
<td>4</td>
<td>20.18</td>
<td>27.87</td>
<td>7.58</td>
<td>9.01</td>
</tr>
<tr>
<td>5</td>
<td>28.92</td>
<td>29.98</td>
<td>8.68</td>
<td>8.98</td>
</tr>
<tr>
<td>6</td>
<td>20.20</td>
<td>29.11</td>
<td>7.72</td>
<td>9.60</td>
</tr>
<tr>
<td>7</td>
<td>19.09</td>
<td>28.32</td>
<td>6.87</td>
<td>9.40</td>
</tr>
<tr>
<td>8</td>
<td>19.24</td>
<td>28.21</td>
<td>6.83</td>
<td>9.44</td>
</tr>
<tr>
<td>9</td>
<td>18.92</td>
<td>28.25</td>
<td>6.81</td>
<td>9.43</td>
</tr>
<tr>
<td>10</td>
<td>18.56</td>
<td>28.13</td>
<td>6.69</td>
<td>9.52</td>
</tr>
</tbody>
</table>
**Model results assessment**

**In-depth performance assessment**

### Quality of service

- SQL query to Users output table

<table>
<thead>
<tr>
<th>Mode</th>
<th>Scenario 1</th>
<th>Scenario 6</th>
<th>Scenario 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Travel distance (km)</td>
<td>25&lt;sup&gt;th&lt;/sup&gt; perc. Median</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; perc.</td>
</tr>
<tr>
<td><strong>Shared Taxi</strong></td>
<td>&lt; 2 km</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>[2, 5] km</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>[5, 10] km</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>&gt;10 km</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Taxi-Bus</strong></td>
<td>&lt; 2 km</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>[2, 5] km</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>[5, 10] km</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>&gt;10 km</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>6</td>
<td>11</td>
</tr>
</tbody>
</table>
Model results assessment

In-depth performance assessment

Number of vehicles required and average occupancy

- R script that uses data from SQL query to Users output table, Shared-Taxis and Taxi-Buses output tables
Model results assessment

In-depth performance assessment

Cost

- SQL query to Users output table, Shared-Taxis and Taxi-Buses output tables
- The relation with the baseline costs are estimated based on available data or assumptions for cost estimation available at the report

### Cost comparison with Taxi and Public Transport

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Shared Taxi (NZD/km)</th>
<th>Taxi-Bus (NZD/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average taxi trip</td>
<td>PT cost for user</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>169</td>
</tr>
<tr>
<td>6</td>
<td>22</td>
<td>186</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>240</td>
</tr>
</tbody>
</table>

### Cost comparison with private car

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Second-hand car, NZD 5 000</th>
<th>New car, NZD 15 000</th>
<th>New car, NZD 30 000</th>
<th>New car, NZD 50 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>19</td>
<td>37</td>
<td>63</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>14</td>
<td>29</td>
<td>49</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>12</td>
<td>24</td>
<td>40</td>
</tr>
</tbody>
</table>
Model results assessment

In-depth performance assessment

Electric vehicles

- SQL query to Users output table, Shared-Taxis and Taxi-Buses output tables
- The relation with the baseline costs escenario

<table>
<thead>
<tr>
<th>Fleet size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operational costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>
Thank you!

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E luis.martinez@itf-oecd.org

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