TN30 - WELLINGTON TRANSPORT ANALYTICAL TOOLS 2019-23 UPDATE – TRIP DISTRIBUTION AND MODE CHOICE

PREPARED FOR   GREATER WELLINGTON REGIONAL COUNCIL

August 2023

Stantec | JACOBS

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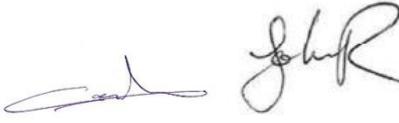
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1.   Introduction

This technical note is part of a series documenting the 2019-2023 update of the Wellington Regional Transportation Planning Analytical Tools. The higher-level Analytical Tools are maintained and operated by Greater Wellington Regional Council (GWRC), who is the client for this project. This project is being delivered by Stantec and Jacobs, supported by GWRC transport modellers.

This note details the development and calibration of the trip distribution and mode choice modules for the Wellington Transport Strategy Model (WTSM). The purpose of these components is to forecast demand matrices for active modes, car and various public transport trips across the Greater Wellington regional area, with trips segmented by purpose.

The note covers the following items:

- Key data inputs and set of definitions
- Forms of models used
- Calibration and validation of the trip distribution model
- Calibration and validation of the mode choice model
- Sensitivity tests

2.   Data Input and Definitions

The main input to the distribution and mode choice models is the set of trip ends (productions and attractions) for each model zone. Here, productions and attractions are defined as follows:

- Trip production: the home end of a home-based trip or the origin of a non-home-based trip.
- Trip attraction: the non-home end of a home-based trip (e.g. workplace, school, shop) or the destination of a non-home-based trip.

Trips across Wellington's transport network are represented by trip matrices that specify the movements of people and vehicles over a 24-hour weekday period.

The other input into these models are the matrices of generalised costs per mode and trip purpose, which are detailed in section 3.2.

Throughout this note, reference is made to the Household Travel Survey (HTS) which serves as the main source of data for models' estimation. More information on this survey and its processing can be found in 'TN24 – HTS and mobile phone data', and a summary is given in section 2.6.

2.1   Trip purposes

In WTSM, trips are segmented by purpose into the following six categories:

- **HBW**: Home-based work (14% of daily trips based on the expanded HTS), this includes both the outbound home to work and inbound work to home journeys as separate trips (as do all home-based trips defined below).
- **HBE**: Home-based education (10%). This is defined as any trip between home and primary, secondary and tertiary education, and includes trips made by the person attending the education facility or any accompanying people.
- **HBS**: Home-based shopping (13%)
- **HBO**: Home-based other (23%)
- **NHB**: Non-home based (34%), excluding for business
- **BSN**: Employer business (6%). This includes business-related trips made to or from home as well as non-home-based business trips.

Separate distribution and mode choice model parameters have been estimated for each trip purpose.

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2.2   Time periods

The WTSM is based on the following four time periods:

- **AM Peak:** 6-9am
- **Inter Peak:** 9am-3pm
- **PM Peak:** 3pm-6pm
- **Overnight:** 6pm-6am

However trip ends produced by the trip production and attraction models are daily, i.e. for an average 24hr weekday. The trip distribution and mode choice models covered in this note also work at a daily trips level, with trip matrices converted to peak period at the subsequent stage of WTSM. These time periods are however described here for reference as they were used as part of the analysis and are mentioned later in this note.

2.3   Modes

The modes represented in the WTSM and therefore in the mode choice model are defined as follows:

- **Private light vehicle:** these include mostly car trips but also a few records of trips by motorcycle and taxi in the HTS (less than 1% of all private light vehicles in each case).
- **Active modes:** mostly pedestrian and cycle trips, but also including mobility (less than 1% of all active modes trips).
- **Bus:** any trip including at least a bus leg but no rail leg.
- **Rail park-and-ride:** any trip including rail and car park-and-ride access to or egress from rail.
- **Rail kiss-and-ride:** any trip including rail and car kiss-and-ride, i.e. drop-off or pick-up to/from rail.
- **Rail other** (called 'rail' in the remainder of this note): any trip including rail but no car access or egress.

The following rules apply for rail trips:

- Rail segments also include the East by West cross-harbour Ferry. This was grouped with rail for simplicity as this mode only represents a very small proportion of demand and is more similar in nature to rail than bus (not impacted by congestion, higher comfort factor).
- All rail-based segments can also include a bus leg. For 'rail other', this could occur either before the rail leg (e.g. for accessing the station) or after (e.g. transferring to bus in the CBD to reach the destination). For rail park-and-ride and kiss-and-ride, bus can only be used on the leg that is not car-based.
- For park-and-ride and kiss-and-ride, car access to rail is only permitted in the AM peak and Inter Peak periods, whereas car egress from rail is only permitted in the PM Peak and Overnight periods. This allows for simplification of the mode choice and assignment procedures but more importantly is representative of trip patterns observed in the HTS, with the very large majority of car access to rail trips occurring in the AM period (from home to the boarding rail station), and car egress from rail trips occurring in the PM and Overnight periods (from the alighting station to home). This is illustrated in the figure overleaf, showing time profiles from the HTS. As can be observed there is a minor proportion of access in the PM peak but this is considered small enough to be omitted without significant impact in regard of the model simplification that this enables.

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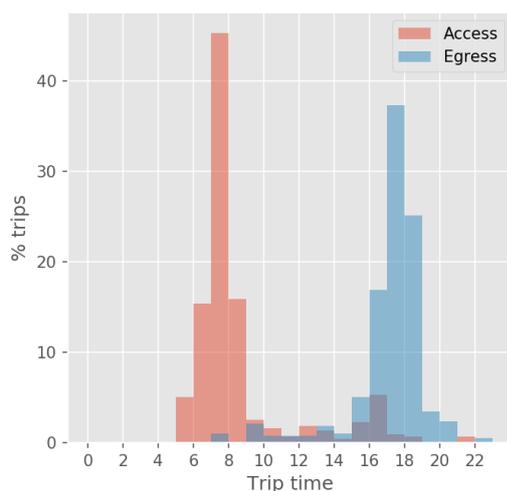
Figure 2-1: Rail car access and egress profiles per hour from HTS

Although the mode choice model is applied to 24hr demand matrices, it was assumed that for home-based purposes all car-based access occurs on the trip from home while all car-based egress occurs on the trip back to home, again borne out by the HTS. As a result, rail park-and-ride and kiss-and-ride segments were not separated into access and egress segments in the mode choice model, with this split occurring at a later stage in WTSM when the resulting demand matrices are factored down to time period and directionality applied[1].

2.4   Car availability

Whilst trips made by households with no cars only represent a small percentage of total demand, car availability does have a larger impact on mode choice as highlighted in Table 2-1 which shows the mode share by car availability and trip purpose from the HTS. For this reason, demand was split by car availability for all purposes, the definition used being:

- **Car:** Trips produced by households which own at least one car (circa 95% of all HTS expanded trips)

- **No car:** Trips produced by households with no car available (5% of all HTS expanded trips)

Table 2-1: Mode shares by car availability and purpose (from HTS)

Purpose	HH type	Active	Car	Bus	Rail other	Rail park-and-ride	Rail kiss-and-ride
HBW	Car	9%	74%	7%	4%	5%	2%
	No Car	47%	25%	22%	5%	1%	0%
HBE	Car	19%	70%	7%	2%	0%	1%
	No Car	48%	29%	20%	3%	0%	0%
HBS	Car	8%	90%	2%	1%	0%	0%
	No Car	44%	35%	18%	3%	0%	0%
HBO	Car	15%	82%	2%	1%	0%	0%
	No Car	50%	41%	8%	1%	0%	0%
NHB	Car	26%	71%	2%	1%	0%	0%
	No Car	58%	33%	7%	2%	0%	0%
BSN	Car	13%	85%	1%	1%	1%	0%
	No Car	54%	31%	16%	0%	0%	0%
Total	Car	17%	77%	3%	1%	1%	1%
	No Car	59%	33%	7%	2%	0%	0%

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[1] See 'TN21 – Time Periods and Vehicle Occupancy'

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2.5 Zones and sectors

The new WTSM zone system has 813 internal zones as well as 2 road externals and 4 special zones for airport, port and both ferry terminals. Only internal zones are included for the trip distribution and mode choice which focus on travel demand internal to the region. For the purposes of estimation and calibration, an 8-sector system has been adopted as shown in Figure 2-2. These sectors are the same as used for the HTS expansion[2]..'
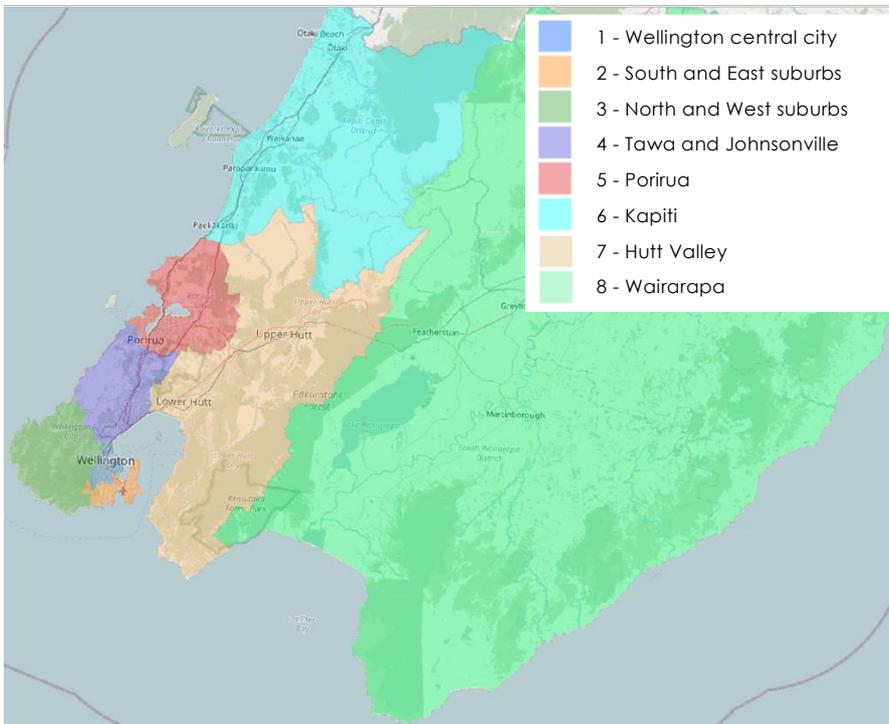
Figure 2-2: Sector zone aggregation

2.6 HTS Summary

The following tables provide some context on the data available in the HTS dataset sample, containing a total of 34,456 trip records (which expanded represent 2,137,169 average weekday trips). Car use is the dominant trip mode, followed by active transport and only 7% of sampled trips are by public transport as shown in Table 2-2.

Table 2-2: Main mode of travel – HTS Sample

Main Mode	Sample	Mode share
Bus	1,572	5%
Car Driver	19,010	55%
Car Passenger	5,780	17%
Cycle	506	1%
Ferry	11	0%
Mobility	21	0%
Motorcycle	144	0%
Pedestrian	6,589	19%
Rail	632	2%
Taxi	191	1%
Grand Total	34,456	

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[2] TN24 – HTS and Mobile phone data'.

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Aggregating the trips into the three main model modes and then reporting by purpose (Table 2-3 and Table 2-4) and sector (Table 2-5 and Table 2-6) highlights the difficulties in segmenting the HTS whilst maintaining enough sample to ensure a statistically valid estimation process.

Table 2-3: Main mode (aggregated) by trip purpose

Mode	HBW	HBE	HBS	HBO	NHB	BSN	Total
Car	3,127	1,490	3,837	6,189	8,601	1,739	24,983
Active	709	547	544	1,385	3,601	282	7,068
PT	808	332	212	290	488	70	2,200
Total	4,744	2,369	4,593	7,864	12,690	2,091	34,351

Table 2-4: Main mode share (aggregated) by trip purpose

Mode	HBW	HBE	HBS	HBO	NHB	BSN	Overall
Car	67%	63%	83%	79%	68%	83%	73%
Active	15%	23%	12%	17%	28%	14%	21%
PT	18%	14%	5%	4%	4%	3%	6%

Note: The total number of trips in Table 2.3 is slightly lower than in the previous table due to a small number of trips not included in any modelled purposes (e.g. having 'Home' as both origin and destination).

In relation to mode by origin sector (origin being the starting point of any trip, which differs from production as defined previously), car is generally dominant except for the CBD, as shown in Table 2-5. Public transport comprises bus, which is strongest in the Wellington suburbs, and rail lines connecting the North (Hutt Valley/Wairarapa and Western corridor) to the CBD. Johnsonville is a suburb of Wellington which has a railway line but also good bus coverage so there is true competition between bus and rail.

The CBD as an origin is high as it includes a large proportion of employment and shopping opportunities in the region, and as a result includes a large amount of non-home-based trips and the return leg of home-based trips.

Table 2-5: Trips by mode aggregated by trip origin (sector)

Origin Sector	Active	Car	Bus	Rail	Grand Total
CBD	3,538	3,175	650	265	7628
Eastern suburbs	805	2,716	216	7	3,744
Kapiti	441	1,793	17	33	2,284
Lower Hutt	387	2,879	102	72	3,440
North and Western suburbs	252	1,496	108	24	1,880
Petone	130	1,283	33	20	1,466
Porirua	383	3,213	107	74	3,777
Southern suburbs	493	1,514	201	4	2,212
Tawa and Johnsonville	277	1,965	62	80	2,384
Upper Hutt	118	1,080	32	36	1,266
Wairarapa	232	3,480	30	26	3,768
External	60	531	14	2	607
Grand Total	7,116	25,125	1,572	643	34,456

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Table 2-6: % Trips by mode share aggregated by trip origin (sector)

Origin Sector	Active	Car	Bus	Rail
CBD	46%	42%	9%	3%
Eastern suburbs	22%	73%	6%	0%
Southern suburbs	22%	68%	9%	0%
North and Western suburbs	13%	80%	6%	1%
Tawa and Johnsonville	12%	82%	3%	3%
Porirua	10%	85%	3%	2%
Kapiti	19%	79%	1%	1%
Petone	9%	88%	2%	1%
Lower Hutt	11%	84%	3%	2%
Upper Hutt	9%	85%	3%	3%
Wairarapa	6%	92%	1%	1%
External	10%	87%	2%	0%
Grand Total	21%	73%	5%	2%

In terms of trip distribution, Figure 2-3 highlights the movement of people within a sector (the domes that loop back to the same colour) or between sectors (from one colour to another). It can be observed that more than 90% of trips are either within a sector or to/from the CBD. While the high proportion of intra-sector trips is partly determined by the size of the sectors, this does highlight the significance of the Wellington CBD, and the comparatively small amount of trips between other sectors which are geographically quite self-contained due to the regional topography.
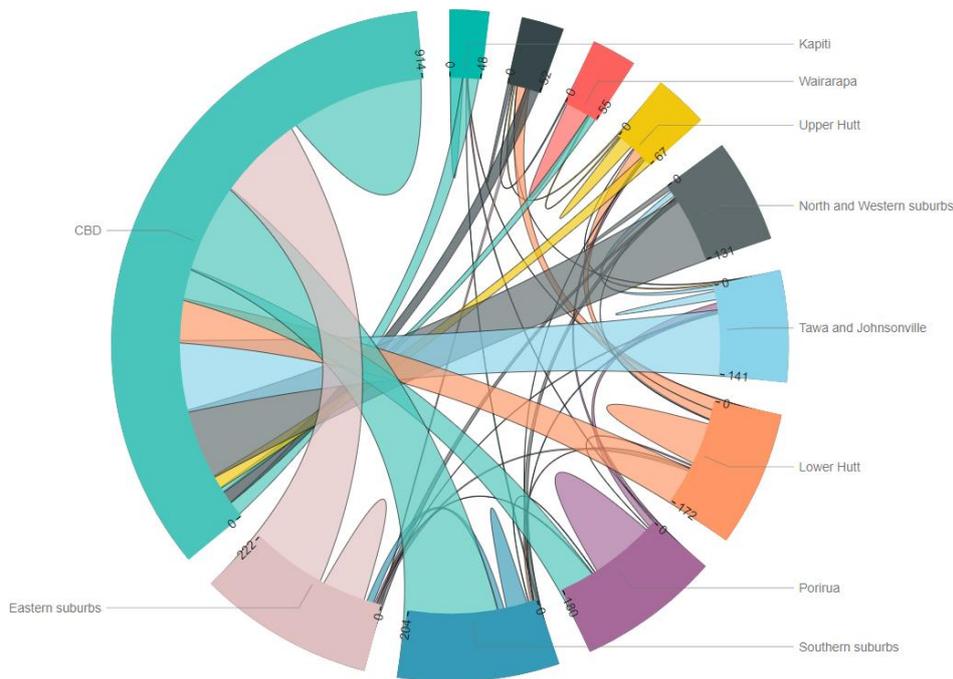
Figure 2-3: Sector to Sector trips

Finally Table 2-7 shows the split of PT trips by access and egress modes in the HTS sample. For bus, non-car based access (mostly walk to bus) is dominant as expected although there are about 5% of bus trips using car to access the bus network. Car access to bus was however not included due to the sparsity of HTS data to calibrate this demand segment, and the small number of trips not being worth the resulting increase in model complexity. This is the same approach as used in the more detailed Wellington Public Transport Model.

Rail trips is more evenly split between non-car (largely walk, with a small amount of bus) and car-based access/egress with respectively 51% and 49% shares. There are few records of ferry trips in the HTS.

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Table 2-7: Public transport trip split by access & egress mode.

PT Mode	Bus	Rail	Ferry	Grand Total
Non-car-based	1,469	315	11	1,795
Park-and-ride Access	32	107	0	139
Park-and-ride Egress	29	92	0	121
Kiss-and-ride Access	23	57	0	80
Kiss-and-ride Egress	15	50	0	65
Grand Total	1,568	621	11	2,200

3. Form of models

3.1 Overall structure

Trip distribution and mode choice models are typically used to forecast the choices of destination and mode made by individual travellers. These models allow for interaction between the choice of destination (i.e. the distribution of trips) and choice of mode.

The order in which mode and destination splits are performed is known as the model hierarchy. The choices can be expressed with three alternative structures: simultaneous distribution and mode choice, pre-distribution mode choice and post-distribution mode choice.
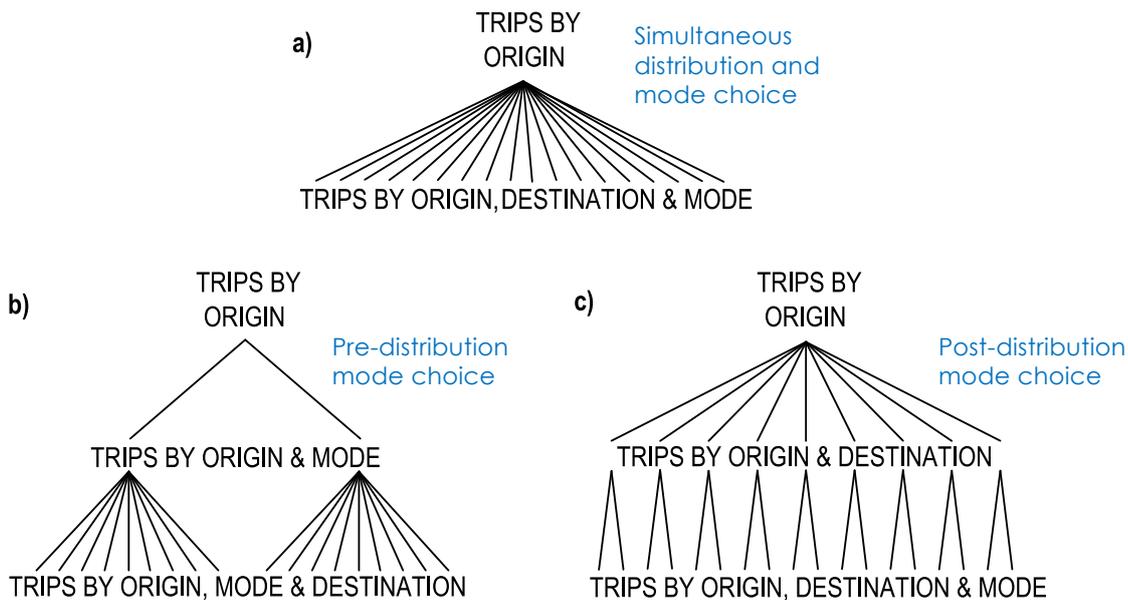
Figure 3-1: Hierarchical choice structures

All three hierarchies were tested and the selected model hierarchy which was found to best suit the WTSM was option c (destination then mode choice), with the mode choice based on a standard nested logit.

The trip distribution model was initially investigated as a logit model but while its overall performance in terms of sectored demand was reasonably good, it resulted in trips being too long. While different approaches and software were used to try to remedy this issue, none led to a satisfying representation of trip length per purpose. It is not clear why this issue occurred, with one possible explanation being the small HTS sample size (<0.6% sample). As a result, a gravity model was alternatively adopted similar to the previous version of WTSM.

More detail on both trip distribution and mode choice models can be found in the remainder of this section. While the trip distribution is applied before the mode split, mode share probabilities for each origin-destination pairs are actually calculated before distribution as the resulting utility logsums are used as an

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input into the trip distribution (see section 3.4). The mode choice model is therefore described before trip distribution in this section.

3.2 Generalised Costs Calculations

The generalised cost of travel is calculated for each origin-destination (OD) zone pair separately per mode and trip purpose, to feed into the distribution and mode choice models. The general approach is standard for a 4-step model, with time components expressed in generalised minutes and monetary values converted into time units using values of time.

Network skims carried out post-assignments are used to extract costs, times, distances and other metrics between each OD pair. The economic input parameters used in the calculations of generalised costs (e.g. value of time, vehicle operating costs, PT fares, etc) are detailed in 'TN22 – Model Input Parameters'.

This section presents the calculations for generalised costs for each mode.

3.2.1 Private vehicles

The formulation to calculate generalised costs (in minutes) for cars for each purpose is as follows:

$$GC_p^{car} = Time + \frac{(Distance * VOC_p + Parking_p)}{VoT_p} + parkTermTime + parkSupplyCap + \frac{Toll}{VoT_{toll}}$$

where:

GC^{car}:	generalised costs for private vehicles
p:	trip purpose
VOC_p:	vehicle operating costs per km for purpose p
VoT_p:	value of time for purpose p
$Parking_p$:	parking charge for purpose p, applied per sector
$parkTermTime_p$:	parking terminal time for purpose p
$parkSupplyCap$:	additional time reflecting demand exceeding supply in the previous iteration when the 'parking constraint' functionality is turned on

The following observations can be made:

- Parking cost calculations are detailed in 'TN7 – Parking'. These costs are currently only calculated for the wider Wellington CBD. Parking costs outside of the wider CBD are not calculated or incorporated in the base model but can be included in scenario forecasting.

- Parking terminal times represent the access time between a parked vehicles and ultimate trip destination (or origin for outbound trips).

- There is currently no road tolling in the Wellington region, but WTSM allows for toll costs to be applied by link. It is important to consider however that as a result the standard value of time will currently be applied to the toll, with no accounting for income segmentation or willingness to pay. This is a simplified approach, which is considered appropriate for investigating the potential high-level impact of tolling and congestion charging on trip distribution and mode choice. However more detailed analysis would be needed for modelling specific tolling schemes and the model should not be used for any estimation of toll revenue or economic assessment. A separate income segmentation module will be developed as part of this project that will partly address these limitations.

- The additional component *parkSupplyCap* has been added to the generalised costs and the model iteratively adjusted as a proxy to represent parking capacity constraint and limit future car trips to specific sectors (especially the CBD area). This is detailed in 'TN7 – Parking'. This function is turned off by default with this component set to 0.

- The generalised costs calculated with this equation are for vehicles and per time period, and are then converted into 24hr costs per person. This is done by applying the same time period and occupancy factors used to convert 24hr person trip matrices to time period vehicles trips (see TN21 – Time Periods and Vehicle Occupancy). The only exception is parking (costs, terminal times and capacity constraints) which are calculated daily and added to the 24hr costs.

- Finally, for intrazonal matrix cells which do not have any time or distance values skimmed from an assignment, a value of half the generalised cost to the closest zone (closest in terms of generalised cost) was used. This is carried out before parking costs and terminal times are added as otherwise these would get incorrectly divided by 2 as well.

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3.2.2 Public transport

Calculations for public transport users generalised costs are a result of improvements made to the EMME PT assignment since the previous version of WTSM was developed, as well as added functionalities that have been implemented in the model since. In particular, 'journey levels' in the assignment allow for a much better and easier representation of varying costs and penalties for transfers versus initial boardings, or between different modes.

The calculation of generalised cost (in minutes) for each purpose is as follows:

$$GC_p^{PT} = \left(IVT * p_{mode}^{ivt} * p_{link}^{ivt}\right) + \left(AuxT * p^{AuxT}\right) + \left(WaitT * p^{WaitT}\right) + \left(BoardT * n^{boardings}\right)$$
$$+ \left(n^{Transfers} * P^{Transfers}\right) + \frac{Fare}{VoT_p}$$

Where:

GC^{PT}:	generalised costs (minutes) for PT users
p:	trip purpose
IVT:	in-vehicle time (minutes)
$p^{IVT}{}_{mode}$:	in-vehicle time perception factor per mode
$p^{IVT}{}_{link}$:	in-vehicle time perception factor per link
$AuxT$:	auxiliary (i.e. access/egress) time (minutes)
p^{AuxT}:	perception factor on auxiliary time (1.8)
$WaitT$:	waiting time (as a function of service headway
p^{WaitT}:	perception factor on waiting time (2
$n^{Boardings}$:	number of boardings
$BoardT$:	boarding time (minutes)
$n^{Transfers}$:	number of transfers
$P^{Transfers}$:	transfer penalty (minutes)
VoT_p:	value of time for purpose p

More information on assumptions regarding the perception factors and how these components are calculated during a public transport assignments can be found in 'TN29 – Public Transport Assignment'.

The following observations can be made:

- In-vehicle time factors were only applied by mode in the previous version of the WTSM initially. A functionality was subsequently added to also specify these factors by link in order to reflect varying levels of service for different sections of a route (e.g., mass rapid transit running with traffic vs running free-flow on a segregated track). As a result the in-vehicle time factor for each segment is a combination of both mode and link. This has been included in the new model, with the default value in the base year scenario being 1 for all links.

- An additional factor (not shown in the equation above) applying to in-vehicle time has also been added to represent crowding and vehicle capacity constraint if using a crowded PT assignment, but turned off by default. More details on crowding penalties calculation can be found in 'TN29 – PT Assignment'.

- Finally, for intrazonal matrix cells which do not have any values skimmed from an assignment, the same value of cost to the closest zone (closest in terms of generalised cost) was used. These were not halved as for short trips most of the cost would be related to auxiliary and waiting times and it would be incorrect to half those.

For car access to public transport, i.e. park-and-ride and kiss-and-ride, the same generalised cost calculations as above apply but the pedestrian auxiliary time is replaced with times and costs associated with the car leg of the trip.

The generalised cost for the car leg of the trip is identical to the car generalised cost equation shown in section 3.2.1, with the following adjustments:

- In this case, parking costs represent the cost of parking at park-and-ride sites (currently free), and apply only to park-and-ride trips and not kiss-and-ride. For sites with both formal and informal parking capacity, a weighted average parking cost would need to be calculated with zero cost for the informal parking spaces and the specified charge for the formal spaces. Sites with significant availability of informal parking spaces will therefore dilute the impact of adding parking charging.

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- Parking terminal times are applied to represent time between parked car (for park-and-ride) or drop-off (for kiss-and-ride) and walking to the stop or rail station.
- An additional component has been added to the generalised costs for park-and-ride to represent parking capacity constraint, as per private vehicle trips. This functionality is turned off by default.

3.2.3 Active modes

Generalised costs for the 'active modes' segments are based on the generalised costs for walk and cycle (as described in 'TN23 – Active modes').

For walking trips, the generalised costs are based on walking time with a speed of 5kph being applied and time penalties added to signalised intersections, roundabouts and minor arms of priority intersections. For cycle trips, the same calculations apply with a speed of 15kph, and additional factors added to account for gradient and link attractiveness depending on levels of cycling facilities. A terminal time penalty was also added to represent the time for locking/unlocking bike, walk to destination, etc.

While generalised costs are calculated for both walk and cycle, active modes are represented as a single mode in the mode choice model and these costs therefore need to be combined.

The initially envisaged approach was to apply the percentage of mode share by distance band from the HTS to the respective walk and cycle costs to calculate a weighted average. However because the fast increase in walk generalised costs is counterbalanced by the falling share of this mode as distance increases, as well as the low sample size for cycle trips, this resulted in inconsistent costs.

Instead, a composite generalised cost based on walk and cycle costs is calculated using the following equation:

$$GC_{Active} = \frac{-1}{\lambda} * \ln\left(e^{(-\lambda * GC_{Walk})} + e^{\left(-\lambda * \left(GC_{Cycle} + \frac{\alpha}{(GC_{Cycle}^{\lambda})}\right)\right)}\right)$$

with $\lambda = 0.35$ and $\alpha = 35$.

These parameters were manually estimated to obtain the best representation of generalised costs for short walk trips, longer cycle trips, and smooth transition between the two.

The following figure displays a comparison of walk and cycle costs based on distance (not including potential intersection delays or other factors), along with the 'active' generalised costs calculated both using the weighted averages from the HTS mode share, and the composite cost equation.
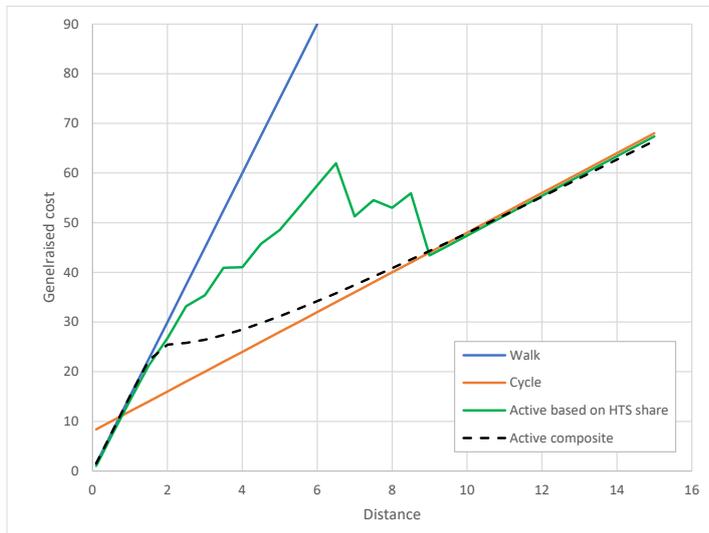
Figure 3-2: Active mode generalised costs

It can clearly be seen that the weighted average using mode share from the HTS results in erratic generalised costs which will be due to the small sample, whereas the composite costs equation returns a much more gradual transition.

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3.3   Mode Choice Model

3.3.1   Structure

The mode choice model structure proposed in the WTSM Scoping Document (TN17, Revision 2) was a nested multinomial logit model, as shown in Figure 3-3.

As mentioned previously, park-and-ride and kiss-and-ride to bus could not be estimated due to low samples sizes with only about 2% of PT trips indicating indirect access to bus stops. It is also known from other data sources and separate studies that non-walk trips to bus represent a very small proportion of demand, and as a result these are also not represented in the separate Wellington Public Transport Model (WPTM) despite it being a more accurate representation of public transport demand.

The adopted structure is shown in Figure 3-4. This nesting structure combines all of the public transport modes into the same nest as they share the same unobserved effect. It is important to note that the nest structure does not imply a decision tree or an ordering of how decisions are made. The proposed nesting structure does not convey a hierarchical decision-making process but is essentially the empirical method that best describes observed behaviours of transport users (while also eliminating the independence of irrelevant alternative violations at the nesting level).
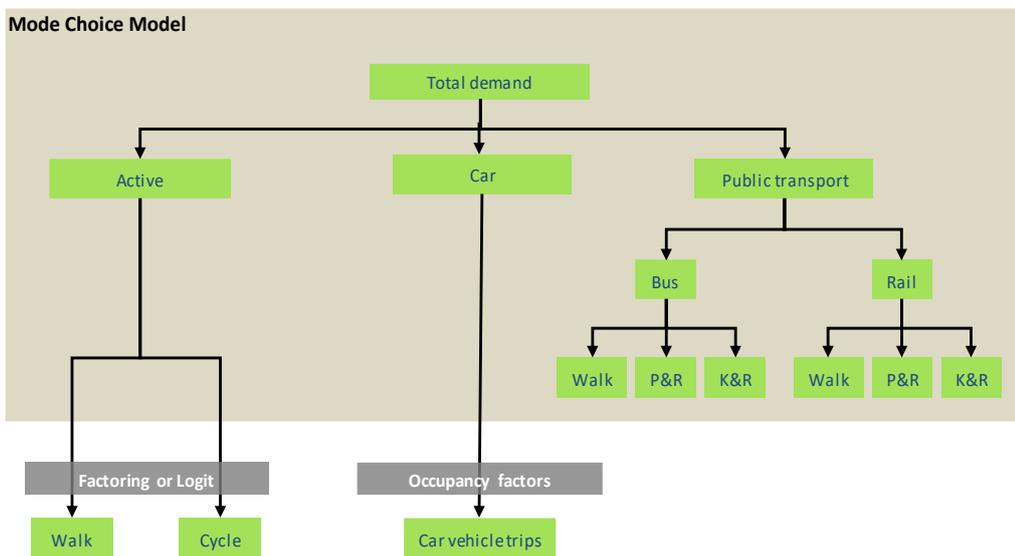
Figure 3-3: Initial mode choice structure
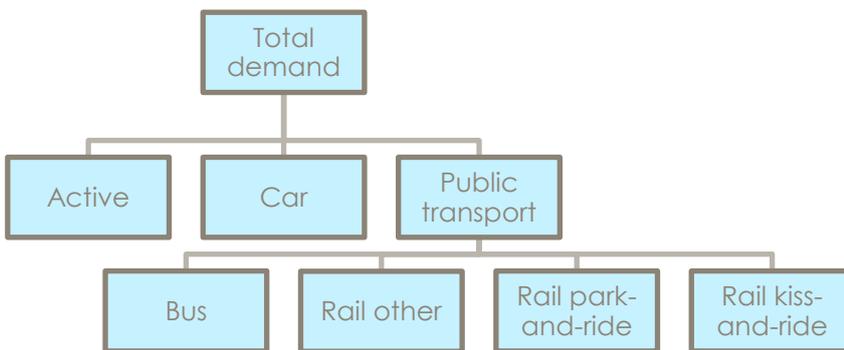
Figure 3-4: Final mode choice structure

As can be observed, the adopted mode choice model only produces active mode demand as a whole, and not split into walk and cycle. This split however occurs at a later stage in a separate active mode demand module, as described in 'TN23 – Active modes'.

Similarly, the mode choice demand model produces total private light vehicle (i.e. car) <u>person</u> trips and does not split demand into car drivers and passengers. Person trips are later converted into <u>vehicle</u> trips

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using occupancy factors per trip purpose and time period, as described in 'TN21 – Peak periods and vehicle occupancy'.

3.3.2 Utilities formulation

At the foundation of discrete choice models are the concepts of utility and utility maximisation. Discrete choice models estimate the probability of an individual making a given choice amongst a set of alternatives. Associated with each alternative is a utility, representing the satisfaction that an individual will experience should they choose that alternative. The behavioural rationale of choice models is that individuals will choose the alternative that they believe maximises their utility.

Relating the above to the mode choice, travellers are presented with various modal alternatives, and it is assumed that they will choose the one they believe will result in the maximum utility. For each alternative, the utility is defined as a function of the generalised cost of travel, as shown below:

- For car and public transport (including bus, rail, rail park-and-ride and rail kiss-and-ride):

$$U^{m,p,c} = \beta^{m,p,c} . GC^{m,p,c} + \sum_m ASC^{m,p,c}$$

Where GC is the generalised cost, m is the mode, p the trip purpose and c the car availability.

- For active modes:

$$U^{m,p} = \beta^{m,p} . GC^m$$

The variables $\beta_i^{m,p,c}$ are model coefficients specifying a traveller's sensitivity to cost. These coefficients are negative because, as the cost of a given alternative reduces, the utility increases. A lower cost and higher utility will result in an increased probability of the alternative being chosen.

A model with utility functions based on generalised cost alone is often incapable of reproducing some of the characteristics of observed trip patterns. This is usually because the generalised costs do not capture all the attributes that affect an individual's choice (e.g. service reliability, security, personal taste, habits and so on). In cases where it is believed such an effect causes a significant discrepancy between the observed and synthesised trip matrices, additional alternative-specific constants (ASC) are included, as represented in the above equation. Active modes in the adopted model form do not have ASCs as values for all other modes were calculated relative to this segment.

3.3.3 Mode choice equations

PT conditional probabilities

The utilities then feed into the mode choice calculations. First, the conditional probability of using each mode m within the PT nest are calculated as follows:

(Note: p c notations have been removed from that point on for clarity)

$$P^m/pt = \frac{e^{\frac{U^m}{\lambda_{pt}}}}{e^{\frac{U^{bus}}{\lambda_{pt}}} + e^{\frac{U^{rail}}{\lambda_{pt}}} + e^{\frac{U^{pnr}}{\lambda_{pt}}} + e^{\frac{U^{knr}}{\lambda_{pt}}}}$$

The logsum of PT utilities is also calculated to feed into the upper-level mode choice, using the following equation:

$$Logsum_{pt} = \ln\left(e^{\frac{U^{bus}}{\lambda_{pt}}} + e^{\frac{U^{rail}}{\lambda_{pt}}} + e^{\frac{U^{pnr}}{\lambda_{pt}}} + e^{\frac{U^{knr}}{\lambda_{pt}}}\right)$$

Marginal probabilities

The marginal probabilities of using mode m between car or active modes are then calculated as follows:

$$P^m = \frac{e^{U^m}}{e^{U^{active}} + e^{U^{car}} + e^{\lambda_{pt} * logsum_{pt}}}$$

For PT modes the marginal probabilities are defined as follows:

$$P^m = \frac{e^{\lambda_{pt} * logsum_{pt}}}{e^{U^{active}} + e^{U^{car}} + e^{\lambda_{pt} * logsum_{pt}}} * P^m/pt$$

The full logsum including all modes is then calculated, which is later used as input into the trip distribution model:

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$$Logsum = \log(e^{U^{active}} + e^{U^{car}} + e^{\lambda_{pt} * logsum_{pt}})$$

The model calibration process estimates the coefficients and constants that define the utility functions (i.e. the β and ASC parameters) as well as the scaling parameters λ_{pt}. These were estimated using the Python package 'Larch' and based on observed demand matrices build from the expanded HTS. The resulting parameters and model calibration is detailed in Section 5.

3.4 Trip Distribution Model

The trip distribution model converts the daily zonal trip ends into production-attraction matrices, for each demand segment (this being a combination of trip purpose and car availability). Note that because the mode split is carried out post-distribution, all trip ends and matrices at this stage include all mode person trips combined, and the utilities used as input must be a composite of utilities for all modes. For this reason, the logsums of utilities were used, which itself is calculated as part of the mode choice probability calculations as detailed in the previous section.

To clarify, the order of the model choice and trip distribution steps of WTSM is as follows:

- Mode choice probability matrices are computed based on generalised costs per mode and demand segments, and the logsums matrices are calculated.

- The trip distribution model is run using the logsums as friction matrices to convert all-mode person trip ends into production-attraction matrices for each demand segment.

- The mode choice probability matrices are then applied to the resulting person trip demand matrices, producing production-attraction person trip matrices per mode.

For the trip distribution model itself, a standard doubly constrained gravity model was applied for all purposes, based on the following formulation:

$$T_{ij} = P_i * A_j * K_i * L_j * f(Logsum_{ij})$$

Where:

T_{ij}	trips between zone i and j
P_i	productions at zone i
A_j	attractions at zone j
K_i, L_j	balancing factors
$f(Logsum_{ij})$	a deterrence function of the logsum of generalised costs of travel from i to j

The balancing factors K and L are subject to the following constraints:

$$K_i = \frac{P_i}{\sum_i T_{ij}}$$

$$L_j = \frac{A_j}{\sum_j T_{ij}}$$

They are iteratively recalculated during the trip distribution process until convergence is achieved.

The deterrence function f is expressed as follows:

$$f_{ij} = e^{-\alpha.logsum_{ij}}$$

with α the distribution model parameter estimated for each demand segment.

The estimation of the trip distribution model was carried out using the EMME Agent calibration functionality. Demand matrices built from the expanded HTS were used for the estimation, for each purpose and car availability segment (but with all modes included), together with matrices of logsums of utilities generated by the model.

For some segments, different sector-based parameters were estimated when a single parameter could not replicate the observed distribution sufficiently well for the matrix as a whole.

In addition, while the parameters were estimated using trip ends and matrices directly from the HTS, applying these parameters to distribute trip ends generated by the WTSM trip production and attraction models resulted in slightly different patterns. This was likely caused by the sparseness and potential biases of the HTS observed data, as well as an inevitable level of error in the trip production and attraction models. As a result a manual calibration of the parameters was undertaken, with minor adjustments so that

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average trip lengths and generalised costs for the synthetic WTSM matrices were a better fit with observed HTS data. This is a standard approach in the calibration of gravity distribution for strategic models.

4. Trip Distribution Model

4.1 Calibration diagnostics

This section presents the distribution parameters resulting from the estimation and calibration process for each purpose. It can be observed that the parameters differ from standard gravity models for which they are usually negative and smaller in value, whereas they are positive and larger here. This is due to the parameters applying to logsums of utilities and not to generalised costs, i.e. inclusive of modal β and ASC parameters.

For each demand segment, a range of checks of model performance are provided, which include:

- Comparison of the trip length distribution between the model and the observed HTS patterns, both in terms of composite generalised costs and distance for validation. Average and median values are also shown.

- A scatterplot of modelled vs observed sectored demand between all sectors presented in section 2.5. The shaded area on these plots indicates the 95% confidence interval.

- A bar chart showing a comparison of the proportion of intra-sector trips for each sector.

- And further metrics such as percentage of trips to the Wellington CBD and proportion of intrazonal trips (it must be noted that due to the large number of zones and the small size of the HTS sample, observed intrazonal trips are likely to be fewer due to a lack of observations).

These model performance diagnostics are also shown for total demand for each of the trip purposes.

Finally, trip length distributions are presented specifically for trips generated by households with no car available. While these have otherwise been combined with households with car available in these diagnostics due to the low sample size making comparisons difficult, it is important to ensure the resulting trip lengths for these demand segments are a good match with observed patterns.

4.2 Home-based work

The following table presents the trip distribution model parameters (α) for the home-based work demand segment, for trips from household with and without cars available.

Table 4-1: Trip distribution parameters – HBW

Sectors	No car available	Car available
All	2	2.4
Wairarapa to CBD (sectors 8 to 1)		2.9

The figures below show the comparison of trip length distribution, sector-to-sector demand, and proportion of intra-sector trips.

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Figure 4-1: Trip length distribution comparison – HBW

Figure 4-2: HBW sectored trips – observed vs modelled
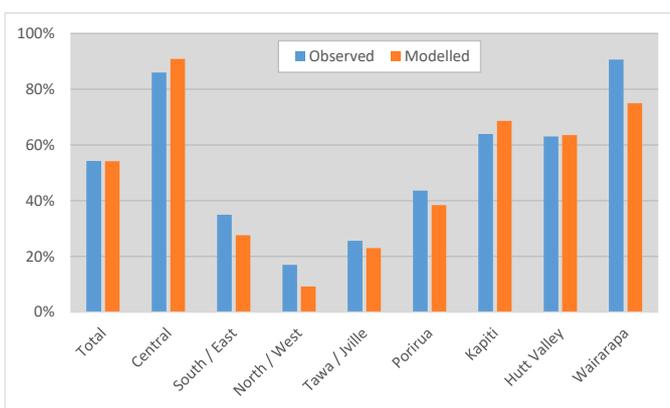
Figure 4-3: Percentage intra-sector HBW trips

The trip distribution comparison shows that the model replicates the distribution well, as well as the average and median of trip distance and generalised costs for home-based work trips.

The sector-to-sector comparison also shows the good performance of the model, with the r-squared indicating a satisfactory goodness-of-fit and all values within the confidence interval.

The percentage of intra-sector trips shows that overall the model replicates observed patterns well. At a sector level, some variation does occur, but the differences are deemed acceptable.

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Finally the table below shows results for two additional metrics: the proportion of trips with attraction in the CBD from four production sectors (aggregated from the original eight sectors due to sample size), and the proportion of intrazonal trips for this demand segment.

Table 4-2: Other Validation Checks – HBW

	Metric	Observed	Modelled
% trips with attraction in Wellington CBD	From/to Wellington CBD	86%	91%
	From/to rest of Wellington	59%	66%
	From/to Porirua & Kapiti	26%	25%
	From/to Hutt Valley & Wairarapa	25%	22%
% Intrazonal		2%	3%

Again, results are overall a close match, with the main exception being the proportion of trips with production in the of Wellington and attraction in the CBD being slightly too high.

4.3 Home-based education

The following table presents the trip distribution model parameters (α) for the home-based education demand segment, for both trips from household with and without cars available.

Table 4-3: Trip distribution parameters – HBE

Sectors	No car available	Car available
Default	6	2.65
Wairarapa to CBD (sectors 8 to 1)		3.7

The following figures present the comparison of trip length distribution, sector-to-sector demand, and proportion of intra-sector trips.

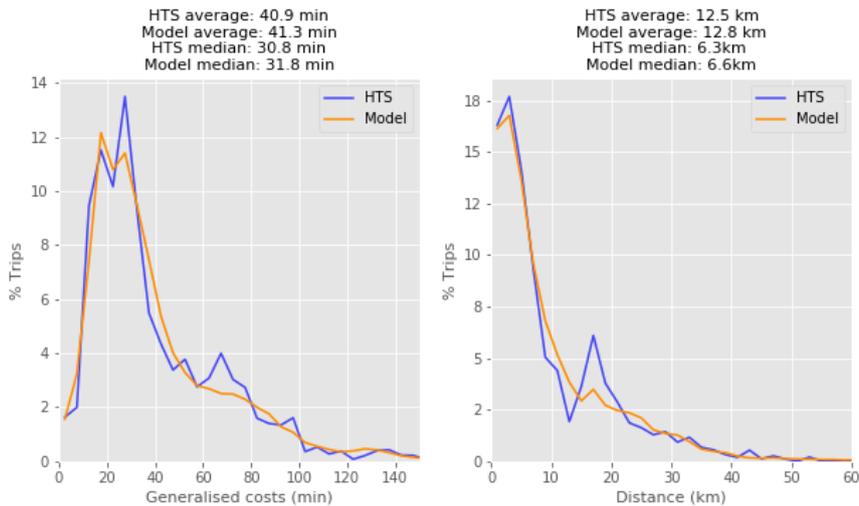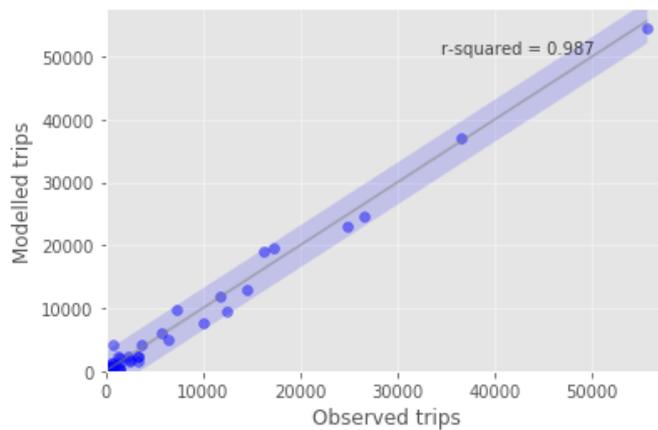Figure 4-4: Trip length distribution comparison - HBE

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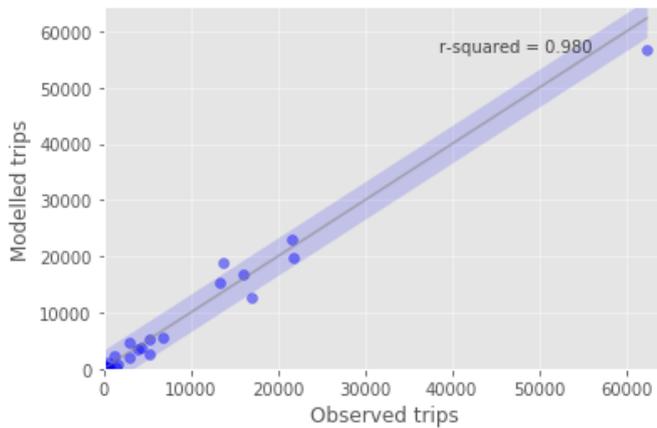
Figure 4-5: HBE sectored trips – observed vs modelled
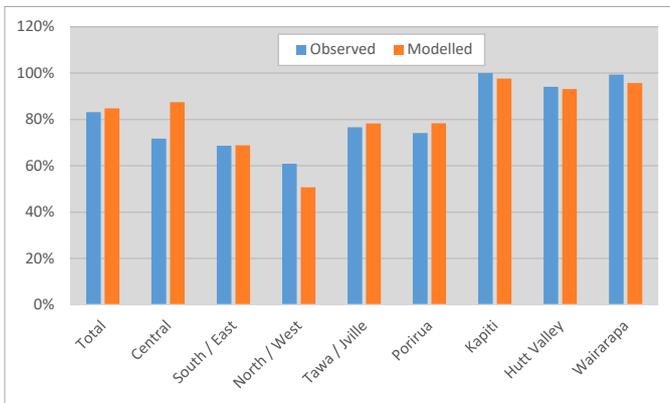
Figure 4-6: Percentage intra-sector HBE trips

Results are overall similar to HBW, with distribution, average and median of modelled trip distance being a good match with observed, and sector to sector comparison showing a suitable goodness-of-fit and most values within the confidence interval.

The percentage of intra-sector trips shows that the model replicates observed patterns well overall and at a sector level.

Finally the table below shows results for the proportion of trips attracted to the CBD from/to four different production sectors, and the proportion of intra-zonal for this demand segment.

Table 4-4: Other Validation Checks – HBE

	Metric	Observed	Modelled
% trips with attraction in Wellington CBD	From/to Wellington CBD	72%	87%
	From/to rest of Wellington	23%	24%
	From/to Porirua & Kapiti	3%	5%
	From/to Hutt Valley & Wairarapa	5%	5%
% Intrazonal		11%	16%

Results are overall a close match, with the main exception being a higher proportion of modelled intra-CBD trips.

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4.4　Home-based shopping

The following table presents the trip distribution model parameters (α) for the home-based shopping demand segment, for both trips from household with and without cars available.

Table 4-5: Trip distribution parameters – HBS

Sectors	No car available	Car available
Default	2.5	1.57
Other TAs to Wellington (sectors 5-6-7-8 to 1-2-3)		1.02

The following figures present the comparison of trip length distribution, sector-to-sector demand, and proportion of intra-sector trips.

HTS average: 18.2 min
Model average: 18.7 min
HTS median: 12.5 min
Model median: 14.3 min

HTS average: 6.0 km
Model average: 6.2 km
HTS median: 2.9km
Model median: 3.6km

Figure 4-7: Trip length distribution comparison – HBS

Figure 4-8: HBS sectored trips – observed vs modelled

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Figure 4-9: Percentage intra-sector HBS trips

The trip distribution comparison shows that the model replicates the distribution well as well as the average trip distance and generalised costs for home-based shopping trips. Modelled median values are slightly higher than observed, due to the model producing circa 5% less short trips (less than 2km). This difference is however largely within acceptable margins of error.

The sector-to-sector comparison also shows the good performance of the model, with the r-squared indicating a suitable goodness-of-fit and most values within or slightly outside the confidence interval.

The percentage of intra-sector trips shows that the model replicates observed patterns well, with the main exception being the Wellington Northern and Western suburbs sector.

Finally the table below shows results for the proportion of trips attracted to the CBD from/to four different production sectors, and the proportion of intra-zonal for this demand segment.

Table 4-6: Other Validation Checks – HBS

Metric		Observed	Modelled
% trips with attraction in Wellington CBD	From/to Wellington CBD	81%	77%
	From/to rest of Wellington	21%	23%
	From/to Porirua & Kapiti	3%	4%
	From/to Hutt Valley & Wairarapa	5%	4%
% Intrazonal		4%	6%

Modelled results are overall a close match with observed for all metrics.

4.5 Home-based other

The following table presents the trip distribution model parameters (α) for the home-based other demand segment, for both trips from household with and without cars available.

Table 4-7: Trip distribution parameters – HBO

Sectors	No car available	Car available
Default	2	1.95

The following figures present the comparison of trip length distribution, sector-to-sector demand, and proportion of intra-sector trips.
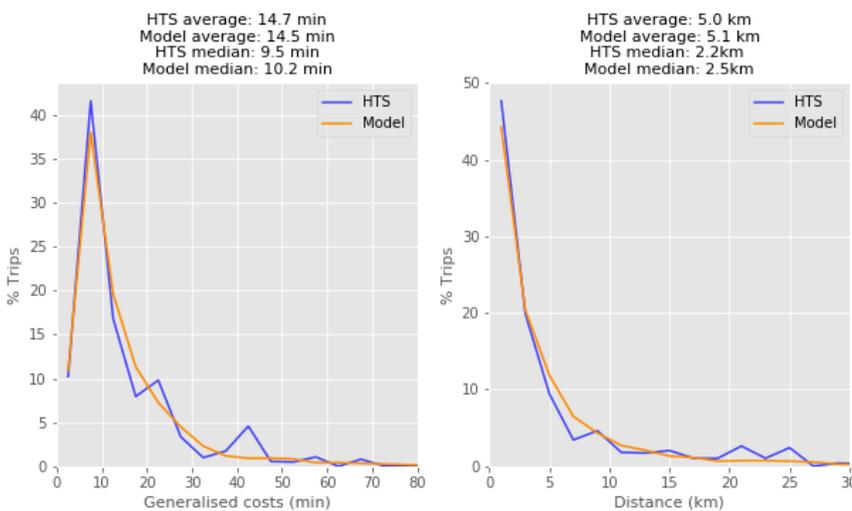
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Figure 4-10: Trip length distribution comparison - HBO

Figure 4-11: HBO sectored trips – observed vs modelled

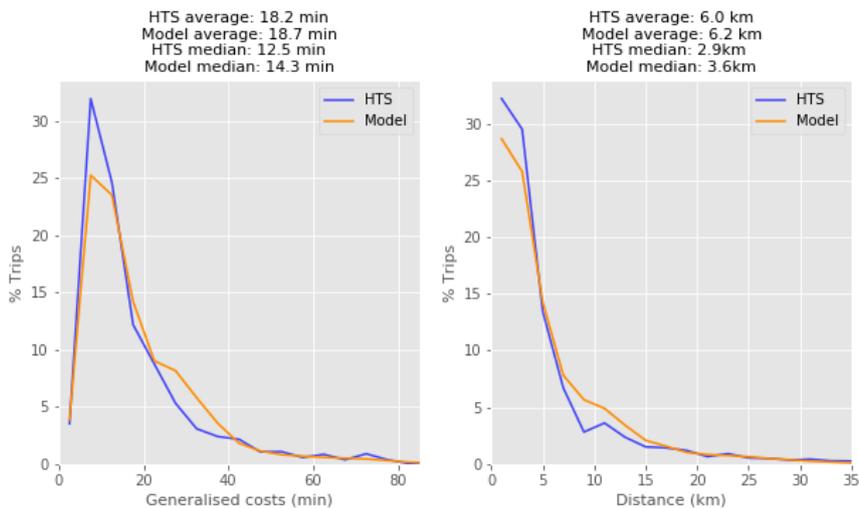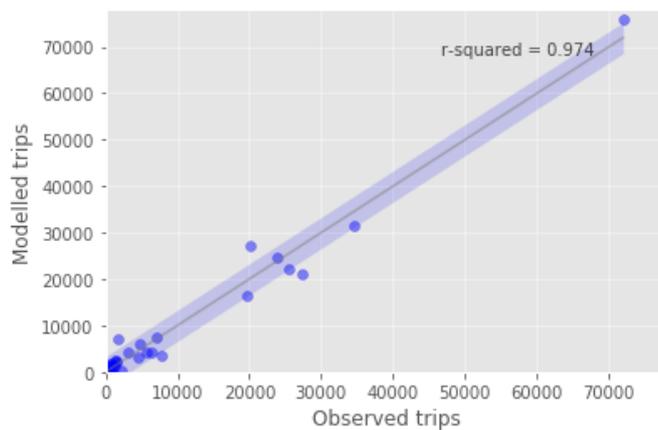Figure 4-12: Percentage intra-sector HBO trips

The trip distribution comparison shows that the model replicates the distribution well, as well as average trip distance and generalised costs for home-based other trips. As for home-based shopping trips previously, modelled median values are slightly higher than observed, again likely due to the model producing fewer short trips, but it is less pronounced for this purpose.

The sector-to-sector comparison also shows the good performance of the model, with the r-squared indicating a very good goodness-of-fit and most values within the confidence interval.

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The percentage of intra-sector trips shows that the model replicates observed patterns well overall and at a sector level.

Finally the table below shows results for the proportion of trips attracted to the CBD from/to four different production sectors, and the proportion of intra-zonal for this demand segment.

Table 4-8: Other Validation Checks – HBO

	Metric	Observed	Modelled
% trips with attraction in Wellington CBD	From/to Wellington CBD	71%	75%
	From/to rest of Wellington	24%	29%
	From/to Porirua & Kapiti	5%	4%
	From/to Hutt Valley & Wairarapa	4%	4%
% Intrazonal		8%	11%

Modelled results are overall a close match with observed for all metrics.

4.6　Non-home-based

The following table presents the trip distribution model parameters (α) for the non-home-based demand segment, for both trips from household with and without cars available.

Table 4-9: Trip distribution parameters – NHB

Sectors	No car available	Car available
Default	1.7	1.6
Other TAs to CBD (sectors 5-6-7-8 to 1)		1.05

The following figures present the comparison of trip length distribution, sector-to-sector demand, and proportion of intra-sector trips.
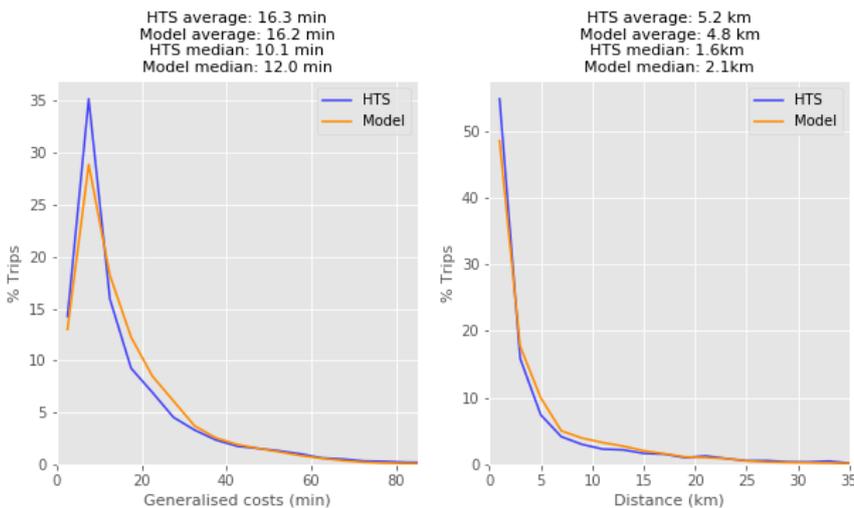
Figure 4-13: Trip length distribution comparison - NHB

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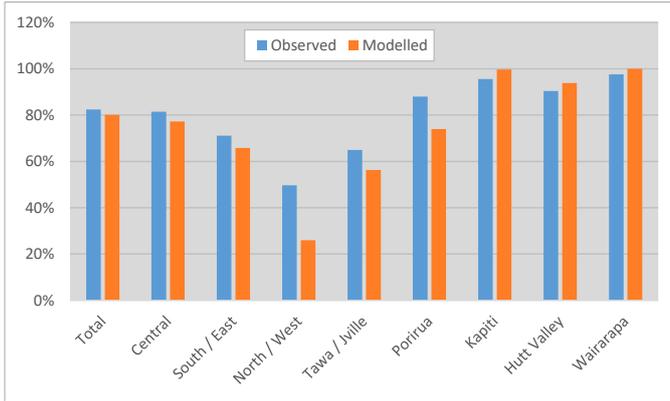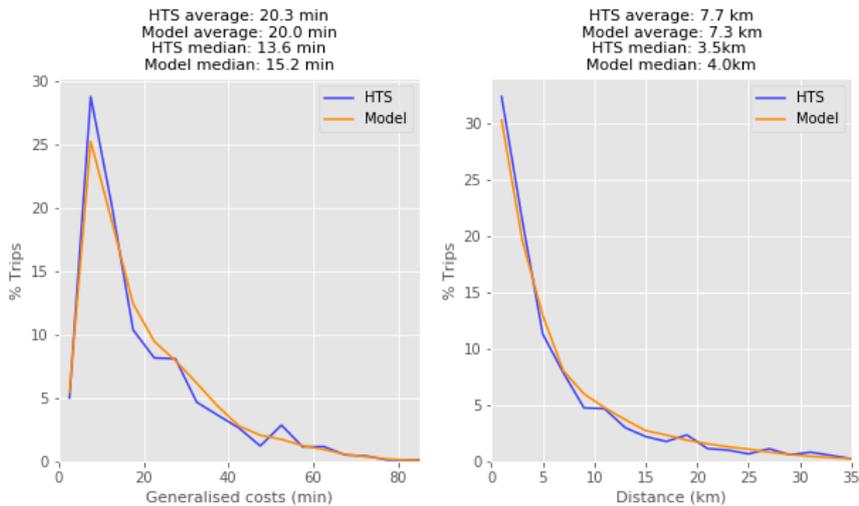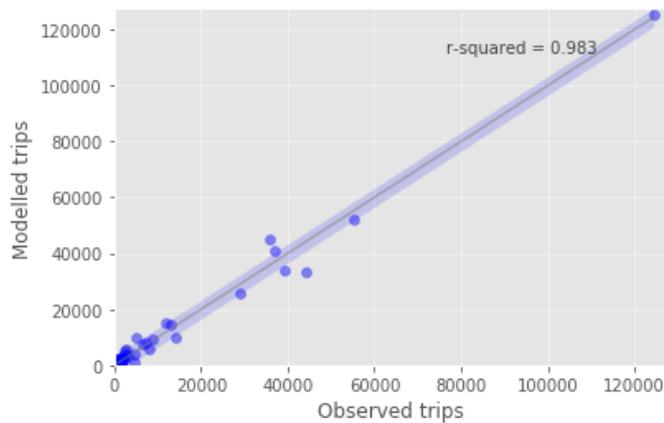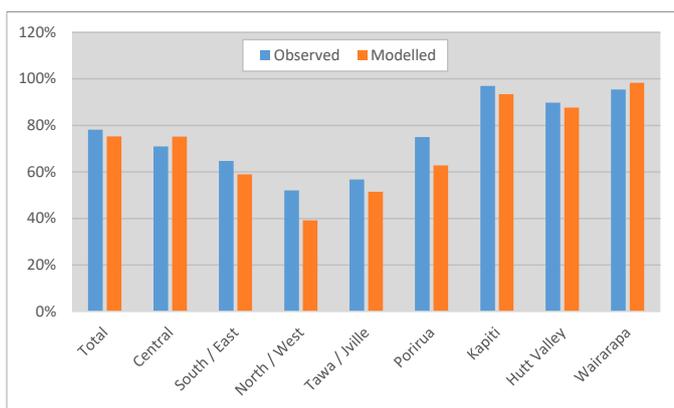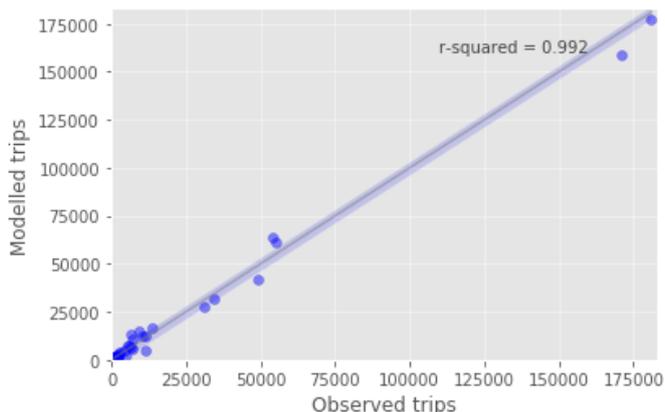Figure 4-14: NHB sectored trips – observed vs modelled

Figure 4-15: Percentage intra-sector NHB trips

The trip distribution comparison shows that the model replicates the distribution well, as well as the average and median of trip distance and generalised costs for non-home-based trips.

The sector-to-sector comparison also shows the good performance of the model, with the r-squared indicating a very good goodness-of-fit and all values being within or just outside of the confidence interval.

The percentage of intra-sector trips shows that the model replicates observed patterns well, with the main exception being the Wellington Northern and Western suburbs where the model tends to underestimate the proportion of intra-sector by circa 20%.

Finally the table below shows results for the proportion of trips attracted to the CBD from/to four different production sectors, and the proportion of intra-zonal for this demand segment.

Table 4-10: Other Validation Checks – NHB

	Metric	Observed	Modelled
% trips with attraction in Wellington CBD	From/to Wellington CBD	80%	76%
	From/to rest of Wellington	18%	20%
	From/to Porirua & Kapiti	3%	3%
	From/to Hutt Valley & Wairarapa	4%	5%
% Intrazonal		16%	15%

Modelled results are overall a close match with observed for all metrics.

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4.7   Business

The following table presents the trip distribution model parameters (α) for the business demand segment, for both trips from household with and without cars available.

Table 4-11: Trip distribution parameters – BSN

Sectors	No car available	Car available
Default		1.1
Rest of region to CBD (sectors 5-6-7-8 to 1)	1	0.7
Intra-sector		0.7

The following figures present the comparison of trip length distribution, sector-to-sector demand, and proportion of intra-sector trips.

HTS average: 23.2 min
Model average: 19.9 min
HTS median: 14.1 min
Model median: 15.8 min

HTS average: 10.4 km
Model average: 8.1 km
HTS median: 3.6km
Model median: 4.3km
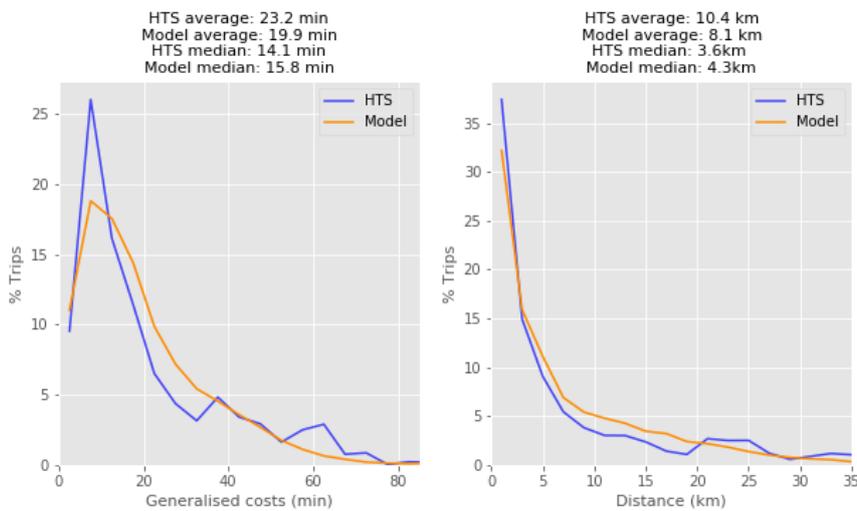
Figure 4-16: Trip length distribution comparison - BSN
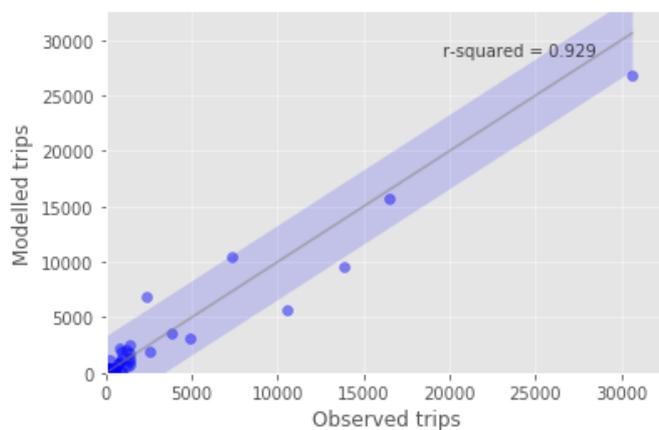
Figure 4-17: BSN sectored trips – observed vs modelled

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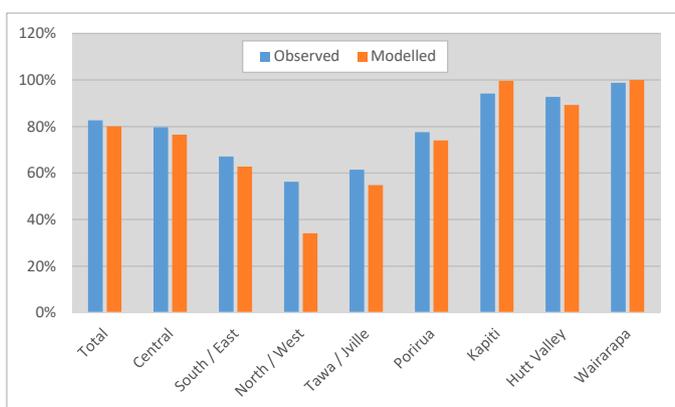
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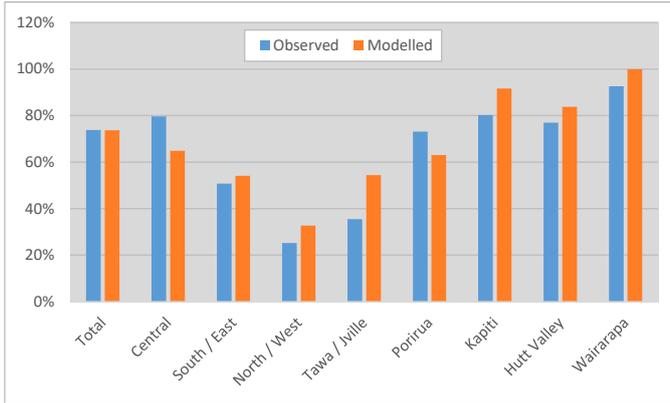
Figure 4-18: Percentage intra-sector BSN trips

The trip distribution comparison shows that the model replicates the distribution appropriately well, as well as average and median of trip distance and generalised costs for business-related trips. Results are however not as close as for other purposes, with the modelled lower average and higher median underlining the difference in profile, with less modelled short trips but more longer trips.

This is a result of the difficulty in modelling trips of different nature that are grouped into this purpose due to the small sample size, including home-to-business and business-to-business, as well as "blue collar" trips which are likely to be longer and occur in the whole region, and "white collar" trips likely to be shorter and occurring in the Wellington CBD and other regional centres. The differences are however deemed a necessary and acceptable compromise.

The sector-to-sector comparison also shows that the model performs well in terms of r-squared with most values being within the confidence interval, but is not as close as other trip purposes.

The percentage of intra-sector trips however shows that the model replicates observed patterns well overall and by sector.

Finally the table below shows results for the proportion of trips attracted to the CBD from/to four different production sectors, and the proportion of intra-zonal for this demand segment.

Table 4-12: Other Validation Checks – BSN

Metric		Observed	Modelled
% trips with attraction in Wellington CBD	From/to Wellington CBD	80%	65%
	From/to rest of Wellington	31%	18%
	From/to Porirua & Kapiti	7%	7%
	From/to Hutt Valley & Wairarapa	10%	8%
% Intrazonal		18%	17%

Modelled results are generally a close match with observed, with the main difference being the proportion of business trips from Wellington (CBD and rest of Wellington) to the CBD that are lower than observed in the HTS.

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4.8 All Purposes

Finally, this section presents the sectored results for all purposes combined, including comparison of sector-to-sector demand, and proportion of intra-sector trips for all trips combined.
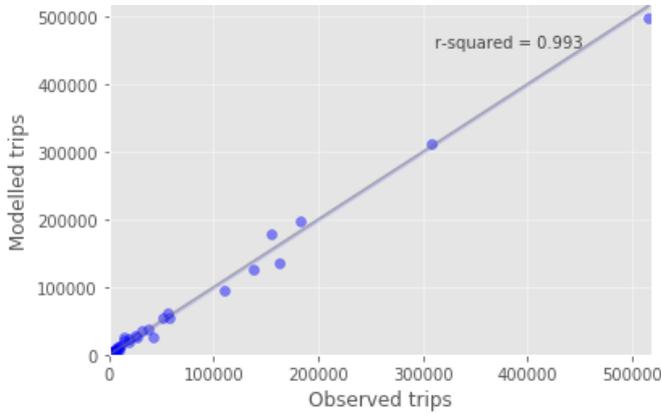
Figure 4-19: All purposes sectored trips – observed vs modelled
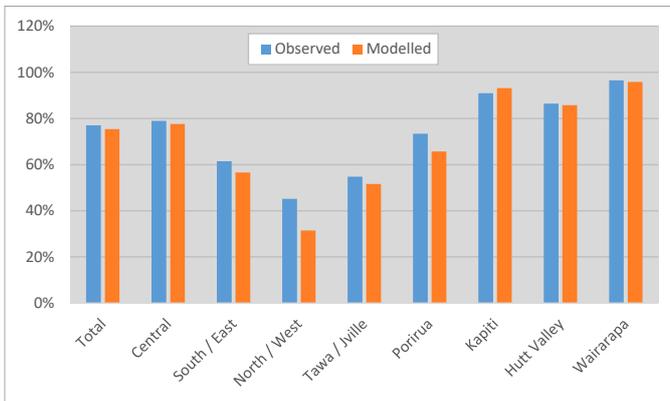
Figure 4-20: Percentage intra-sector all trip purposes

The sector-to-sector comparison shows the good performance of the model for all purposes combined, with the r-squared indicating a very good goodness-of-fit.

Similarly, the percentage of intra-sector trips shows that the model replicates observed patterns well.

Finally the table below shows results for the proportion of trips attracted to the CBD from/to four different production sectors, and the proportion of intra-zonal for all trip purposes combined.

Table 4-13: Other Validation Checks – All Purposes

Metric		Observed	Modelled
% trips to Wellington CBD	From/to Wellington CBD	79%	77%
	From/to rest of Wellington	29%	31%
	From/to Porirua & Kapiti	7%	7%
	From/to Hutt Valley & Wairarapa	7%	7%
% Intrazonal		10%	11%

Modelled results are a close match with observed for all metrics.

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4.9   Households with no car available

The previous sections presented diagnostics of the distribution model calibration by trip purpose including households irrespective of car availability, due to the low sample size for the no car available segment making the comparison difficult on most metrics. However due to the importance of trips with no car available on mode share, especially their increased use of active modes and public transport, it is important to ensure that the distribution of trips for households with no car available is a realistic representation of observed patterns.

The following figures present a comparison of observed and modelled trip distance distribution for each purpose, for trips generated by households with no car only. When looking at the observed patterns from the HTS, the low sample size must be kept in mind that results in small peaks that are caused by a single or very low number of observations.
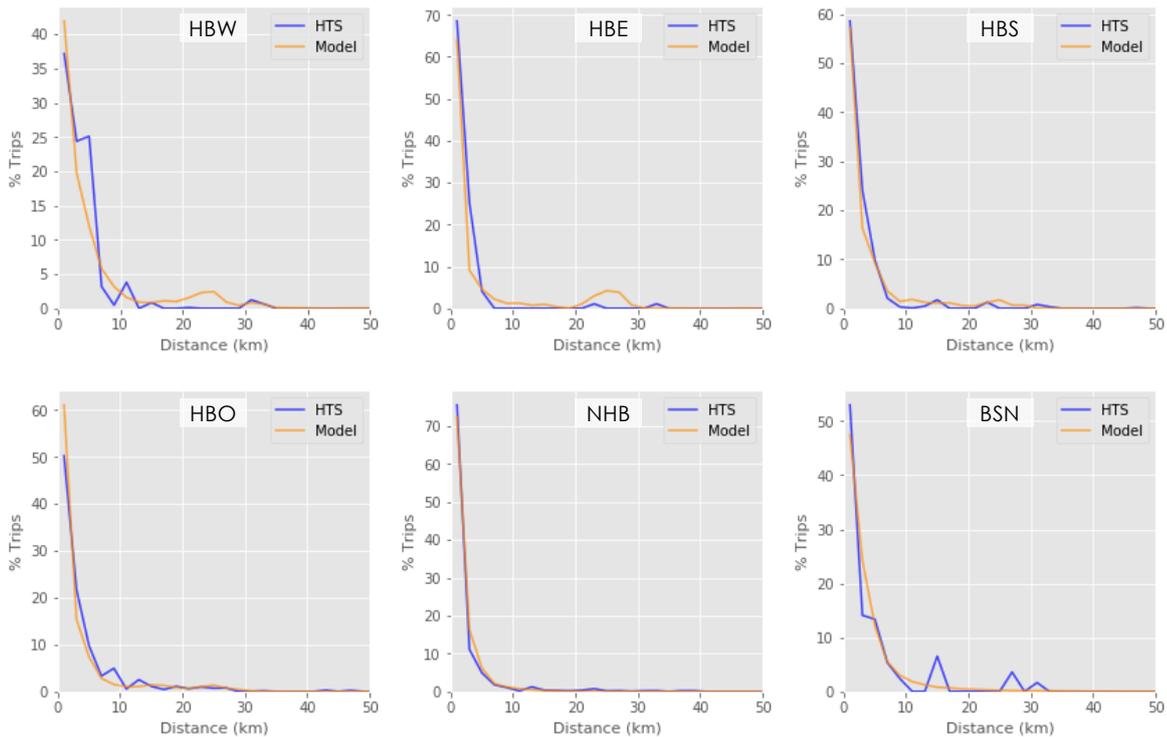
Figure 4-21: Trip length distribution comparison – Trips generated from households without cars

Average and median values from the HTS and the model are shown in the following table.

Table 4-14: Average and median trip lengths for household without cars

Trip purpose	Average length (in km)		Median length (in km)	
	Observed	Modelled	Observed	Modelled
HBW	6.1	7.2	2.8	2.7
HBE	2	5.1	0.9	1.1
HBS	3.2	4.5	1.7	1.5
HBO	4.4	4.9	2	1.3
NHB	2.9	1.7	0.7	0.9
BSN	4.7	4.1	1.8	2.1

The trip length distributions, averages and medians show that the model replicates observed patterns well for trips generated by households without cars. The main differences are the modelled average trip lengths for home-based education and shopping being longer than observed. This is caused by a small number of longer trips in the model skewing the average, with the median length being a much closer match.

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5. Mode Choice Models

5.1 Estimation approach and diagnostics

This section presents the mode choice model parameters resulting from the estimation and calibration process for each purpose.

Various combinations of demand and geographical segmentations were tested for the estimation of the β and ASC parameters. For demand, the best results were found to be obtained by estimating a different β for trips generated by households with a car and those without cars, reflecting differing behaviours depending on car availability.

ASCs were estimated without taking car availability into account, however different values were estimated for trips to/from the Wellington CBD (i.e. with the attraction end in the CBD) vs rest of the region. Applying the same ASC to the whole demand was found to lead to correct modal share at a regional level, but an underestimation of public transport trips with attractions in the CBD and overestimation elsewhere. This geographical distinction allowed a much closer match to the higher public transport mode share to/from the central city. This is likely an indication of limitations in the representation of the competing modes, such as difficulties in parking and limited parking capacity in the CBD that are not captured in the car generalised cost.

Information on the statistical estimation and the model performance are also given for each trip purpose. Whilst exploring the choices between different model structures and specifications, the key outputs from the estimation software (Larch) were log-likelihood, rho-squared and the significance of individual parameters. Valid models should have the following characteristics:

- statistically significant parameter values: t-statistics greater than 1.96 or less than -1.96, in testing for the significance of parameters at the 95% confidence level
- negative values of the mode choice sensitivity parameters (i.e. higher costs result in lower utilities)
- accurate fits to trip purpose mode shares, compared with the expanded HTS

The software also reports the statistical significance using asterisks symbols with the following levels:

- ***: p value ≤ 0.001
- **: p value ≤ 0.01
- *: p value ≤ 0.05
- None: p value > 0.05

Values with at least one asterisk are considered statistically significant.

5.2 Parameters calibration

While the estimation process resulted in overall mode shares that were very close to observed patterns in the HTS, including for trips from/to the CBD, some differences were observed for specific sector-to-sector movements.

In addition, comparison of the HTS itself with observed public transport patterns from other sources highlighted some discrepancies.

Analysis of bus electronic ticketing machine (ETM) data indicated that mode share resulting from the HTS led to an underestimation of patronage compared with observed bus boardings, as shown in the following table comparing the resulting bus daily patronage based on the expanded HTS and on bus electronic ticketing data[3].

Table 5-1: Table 5 1: Daily bus patronage comparison

	HTS	ETM	Difference
Daily bus trips	81,687	89,375	9%

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[3] Processing of this data is detailed in TN15 – WPTM Update

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In addition, comparison of the various rail mode shares by access type against passenger surveys from 2011[4] (carried out for the development of the Wellington Public Transport Model) and 2017[5] showed that the share of rail kiss-and-ride trips in the HTS appeared too high compared with these surveys, with the other two rail modes comparatively low, as shown in the following table.

Table 5-2: Rail access mode share comparison

Access mode	HTS	2011 Survey	2017 Survey
No car access	51%	54%	48%
Park-and-ride	32%	38%	45%
Kiss-and-ride	17%	8%	7%

Note: The 2017 survey covers the AM peak only, which explains the higher share of park-and-ride access trips due to the higher proportion of commuting trips.

These biases are likely a result of the small HTS sample size and in this case, the model matching the HTS would lead to noticeable difference with other information on observed patterns.

To resolve both issues, some of the *ASC*s were altered through a manual calibration exercise, to provide an improved representation compared with these other data sources while still providing a reasonably close match with the HTS overall.

The adjustments were targeted to be minor and impacting as few *ASC*s as possible. Checks were also made that the *ASC*s used did not have significant impact on the mode choice sensitivity, with the resulting model elasticities reported in section 6.

Ultimately the validation of the WTSM as a whole, including its mode choice component, is carried out by comparison with independent data sources such as observed CBD cordon bus patronage or rail guard counts (see TN31 – WTSM validation).

5.3 Parameters estimation

This section presents for each trip purpose the estimated mode choice model parameters, the model performance statistics, and the final calibrated (i.e. manually adjusted) values if changed following manual calibration.

The resulting number of trips and share per mode are then presented.

5.3.1 Home-based work

The following table presents the mode choice model parameters for the home-based work demand segment.

Note that Larch does not report t-statistics (t-stat) values with very large absolute values, these are noted as "<min" (as values are negative in this case) in the following tables, which indicates a very high significance.

For the β parameters, 'ca' means car available and 'nca' no car available.

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[4] See 'TN19 WPTM Calibration and Validation', from the 2011 development of WPTM
[5] Rail Survey 2017 Park and Ride Data Note

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Table 5-3: Mode choice model estimation - HBW

Parameter	Value	t Stat	Significance	Calibrated value
ASC_{bus}	-2.180	-11.15	***	-2.6
$ASC_{bus,to\ cbd}$	-2.180	-14.19	***	Wellington: -1.64, other: -2.02
ASC_{car}	0.700	4.42	***	
$ASC_{car,to\ cbd}$	-0.693	-3.68	***	
ASC_{rail}	-2.200	-10.37	***	
$ASC_{rail,to\ cbd}$	-2.260	-13.78	***	North Wellington: -1.95, Tawa: -1.6, other: -2.2
$ASC_{rail\ pnr}$	-2.830	-12.66	***	
$ASC_{rail\ pnr,to\ cbd}$	-2.460	-14.93	***	North Wellington and Tawa: -2.2, Porirua: -1.8, other: -2.3
$ASC_{rail\ knr}$	-2.830	-12.28	***	
$ASC_{rail\ knr,to\ cbd}$	-2.590	-15.11	***	North Wellington: -3, other: -2.54
β_{active}	-0.089	-18.37	***	
$\beta_{bus,ca}$	-0.013	-5.45	***	
$\beta_{bus,nca}$	-0.014	-5.22	***	
$\beta_{car,ca}$	-0.029	-7.49	***	
$\beta_{car,nca}$	-0.090	-13.45	***	
$\beta_{rail,ca}$	-0.0121	-5.16	***	
$\beta_{rail,nca}$	-0.0128	-4.92	***	
$\beta_{rail\ pnr,ca}$	-0.0133	-4.86	***	
$\beta_{rail\ pnr,nca}$	-0.0184	-4.61	***	
$\beta_{rail\ knr,ca}$	-0.0144	-4.85	***	
$\beta_{rail\ knr,nca}$	-0.128	<min	***	
λ_{pt}	0.141	-31.02	***	

Estimation Statistics	
Number of cases	4,667
Log likelihood at convergence	-3,138
Rho Squared w.r.t. Null Parameters	0.625

The following table shows the observed and modelled number of trips per mode, and the resulting modal share.

Table 5-4: Mode choice model validation - HBW

Mode	Number of trips		Mode share	
	Observed	Modelled	Observed	Modelled
Active	35,333	33,566	12%	11%
Light vehicles	207,975	205,230	70%	69%
Bus	24,714	28,819	8%	10%
Rail	11,203	13,059	4%	4%
Rail PnR	12,958	14,307	4%	5%
Rail KnR	4,486	1,662	2%	1%

The model is generally a close match with observed patterns from the HTS. The main difference in terms of absolute number of trips is for rail kiss-and-ride trips being lower than the HTS, and other rail modes comparatively higher. This is a result of the manual calibration of the ASCs for these modes and was purposefully done to address the observed discrepancy between the HTS and other observed sources of data for these modes, as described in section 5.2.

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5.3.2   Home-based education

The following table presents the mode choice model parameters for the home-based education demand segment.

Table 5-5: Mode choice model estimation – HBE

Parameter	Value	t Stat	Significance	Calibrated value
ASC_{bus}	-4.000	-20.63	***	
$ASC_{bus,to\ cbd}$	-3.17	-12.96	***	Wellington: -2.5, other: -3.57
ASC_{car}	-1.05	-8.41	***	
$ASC_{car,to\ cbd}$	-1.6	-6.36	***	
ASC_{rail}	-4.110	-18.4	***	
$ASC_{rail,to\ cbd}$	-3.200	-11.73	***	
$ASC_{rail\ pnr}$	-6.050	-6.04	***	
$ASC_{rail\ pnr,to\ cbd}$	-4.460	-7.4	***	-4.8
$ASC_{rail\ knr}$	-4.400	-15.5	***	
$ASC_{rail\ knr,to\ cbd}$	-3.090	-10.18	***	-3.3
β_{active}	-0.154	-19.88	***	
$\beta_{bus,ca}$	-0.00639	-3.39	***	
$\beta_{bus,nca}$	-0.0138	-3.37	***	
$\beta_{car,ca}$	-0.0676	-7.66	***	
$\beta_{car,nca}$	-0.186	-8.6	***	
$\beta_{rail,ca}$	-0.00771	-3.26	**	
$\beta_{rail,nca}$	-0.0156	-2.98	**	
$\beta_{rail\ pnr,ca}$	-0.005	-0.48		
$\beta_{rail\ pnr,nca}$	-0.012	-1.17		
$\beta_{rail\ knr,ca}$	-0.0123	-3.02	**	
$\beta_{rail\ knr,nca}$	-0.218	<min	***	
λ_{pt}	0.190	-13.95	***	
Estimation Statistics				
Number of cases		2,334		
Log likelihood at convergence		-1,746		
Rho Squared w.r.t. Null Parameters		0.582		

The β values for rail park-and-ride were not found to be statistically significant, due to the predictably low number of observations for this demand segment. They were however found to lead to sensible results and were therefore kept.

The following table shows the observed and modelled number of trips per mode, and the resulting modal share.

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Table 5-6: Mode choice model validation - HBE

Mode	Number of trips		Mode share	
	Observed	Modelled	Observed	Modelled
Active	41,784	44,689	20%	22%
Light vehicles	140,422	128,491	68%	64%
Bus	17,507	18,676	8%	9%
Rail	3,466	5,732	2%	3%
Rail PnR	444	495	0%	0%
Rail KnR	2,344	1,289	1%	1%

The model is generally a close match with observed patterns from the HTS. The main difference is for rail (non-car access) being higher than the HTS, again this is a result of the parameters calibration process and provides a better alignment with other sources of rail patronage data to solve issues of HTS bias.

5.3.3 Home-based shopping

The following table presents the mode choice model parameters for the home-based shopping demand segment.

No statistically significant ASCs were estimated for car trips.

Table 5-7: Mode choice model estimation - HBS

Parameter	Value	t Stat	Significance	Calibrated value
ASC_{bus}	-3.500	-12.99	***	
$ASC_{bus,to\ cbd}$	-2.6	-12.2	***	-2.2
ASC_{car}	n/a	n/a	n/a	
$ASC_{car,to\ cbd}$	n/a	n/a	n/a	
ASC_{rail}	-3.380	-6.47	***	
$ASC_{rail,to\ cbd}$	-3.440	-5.94	***	-2.5
$ASC_{rail\ pnr}$	-5.340	-5.87	***	
$ASC_{rail\ pnr,to\ cbd}$	-3.900	-4.84	***	-3.6
$ASC_{rail\ knr}$	-8.630	-3.04	**	
$ASC_{rail\ knr,to\ cbd}$	-5.060	-4.91	***	-4.1
β_{active}	-0.161	-32.6	***	
$\beta_{bus,ca}$	-0.0381	-10.42	***	
$\beta_{bus,nca}$	-0.0377	-9.18	***	
$\beta_{car,ca}$	-0.0952	-14.98	***	
$\beta_{car,nca}$	-0.244	-18.84	***	
$\beta_{rail,ca}$	-0.0399	-7.71	***	
$\beta_{rail,nca}$	-0.0553	-9.82	***	
$\beta_{rail\ pnr,ca}$	-0.0462	-6.44	***	
$\beta_{rail\ pnr,nca}$	-1.66	<min	***	
$\beta_{rail\ knr,ca}$	-0.0439	-5.47	***	
$\beta_{rail\ knr,nca}$	-0.0818	-6.35	***	
λ_{pt}	1.00	n/a	n/a	
Estimation Statistics				
Number of cases		4,557		
Log likelihood at convergence		-1,760		
Rho Squared w.r.t. Null Parameters		0.784		

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The following table shows the observed and modelled number of trips per mode, and the resulting modal share.

Mode	Number of trips		Mode share	
	Observed	Modelled	Observed	Modelled
Active	29,237	28,473	10%	10%
Light vehicles	238,507	236,393	85%	85%
Bus	9,035	9,820	3%	4%
Rail	1,468	2,043	1%	1%
Rail PnR	558	673	0%	0%
Rail KnR	396	507	0%	0%

The model is a close match with observed patterns from the HTS for all modes.

5.3.4 Home-based other

The following table presents the mode choice model parameters for the home-based other demand segment.

Table 5-9: Mode choice model estimation - HBO

Parameter	Value	t Stat	Significance	Calibrated value
ASC_{bus}	-4.410	-22.16	***	
$ASC_{bus,to\ cbd}$	-3.04	-19.5	***	
ASC_{car}	-0.722	-9.74	***	
$ASC_{car,to\ cbd}$	-0.878	-6.21	***	
ASC_{rail}	-4.120	-15.89	***	
$ASC_{rail,to\ cbd}$	-2.880	-12.38	***	
$ASC_{rail\ pnr}$	-5.310	-14.57	***	
$ASC_{rail\ pnr,to\ cbd}$	-3.540	-12.9	***	
$ASC_{rail\ knr}$	-5.340	-13.95	***	-5.7
$ASC_{rail\ knr,to\ cbd}$	-3.360	-12.15	***	-3.9
β_{active}	-0.124	-29.46	***	
$\beta_{bus,ca}$	-0.0173	-6.42	***	
$\beta_{bus,nca}$	-0.0236	-7.33	***	
$\beta_{car,ca}$	-0.0449	-7.08	***	
$\beta_{car,nca}$	-0.139	-14.07	***	
$\beta_{rail,ca}$	-0.0189	-5.86	***	
$\beta_{rail,nca}$	-0.0264	-6.45	***	
$\beta_{rail\ pnr,ca}$	-0.018	-5.07	***	
$\beta_{rail\ pnr,nca}$	-0.574	<min	***	
$\beta_{rail\ knr,ca}$	-0.0207	-5.18	***	
$\beta_{rail\ knr,nca}$	-0.0327	-6.21	***	
λ_{pt}	0.296	-12.38	***	
Estimation Statistics				
Number of cases		7,785		
Log likelihood at convergence		-3,610		
Rho Squared w.r.t. Null Parameters		0.741		

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The following table shows the observed and modelled number of trips per mode, and the resulting modal share.

Table 5-10: Mode choice model validation - HBO

Mode	Number of trips		Mode share	
	Observed	Modelled	Observed	Modelled
Active	83,024	82,201	17%	17%
Light vehicles	386,641	390,087	80%	80%
Bus	9,772	9,880	2%	2%
Rail	2,725	3,056	1%	1%
Rail PnR	1,198	1,367	0%	0%
Rail KnR	1,291	621	0%	0%

The model is a close match with observed patterns from the HTS for all modes.

5.3.5 Non-home-based

The following table presents the mode choice model parameters for the non-home-based demand segment.

Table 5-11: Mode choice model estimation - NHB

Parameter	Value	t Stat	Significance	Calibrated value
ASC_{bus}	-3.480	-24.37	***	
$ASC_{bus,to\ cbd}$	-3.870	-33.48	***	
ASC_{car}	0.135	2.75	**	
$ASC_{car,to\ cbd}$	-0.960	-7.41	***	
ASC_{rail}	-4.190	-11.66	***	
$ASC_{rail,to\ cbd}$	-4.530	-12.18	***	-4.0
$ASC_{rail\ pnr}$	-4.480	-8.32	***	
$ASC_{rail\ pnr,to\ cbd}$	-5.320	-7.2	***	-3.5
$ASC_{rail\ knr}$	-4.800	-8.76	***	
$ASC_{rail\ knr,to\ cbd}$	-5.160	-7.69	***	-3.9
β_{active}	-0.114	-36.4	***	
$\beta_{bus,ca}$	-0.0178	-8.12	***	
$\beta_{bus,nca}$	-0.0223	-7.53	***	
$\beta_{car,ca}$	-0.0612	-11.85	***	
$\beta_{car,nca}$	-0.139	-17.45	***	
$\beta_{rail,ca}$	-0.0206	-7.31	***	
$\beta_{rail,nca}$	-0.0276	-6.2	***	
$\beta_{rail\ pnr,ca}$	-0.0285	-6.16	***	
$\beta_{rail\ pnr,nca}$	-1.96	<min	***	
$\beta_{rail\ knr,ca}$	-0.0304	-6.33	***	
$\beta_{rail\ knr,nca}$	-0.0435	-5.44	***	
λ_{pt}	0.823	-1.28		
Estimation Statistics				
Number of cases		12,129		
Log likelihood at convergence		-6,573		
Rho Squared w.r.t. Null Parameters		0.698		

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The following table shows the observed and modelled number of trips per mode, and the resulting modal share.

Table 5-12: Mode choice model validation - NHB

Mode	Number of trips		Mode share	
	Observed	Modelled	Observed	Modelled
Active	198,890	189,826	28%	27%
Light vehicles	486,569	493,349	68%	70%
Bus	18,846	19,041	3%	3%
Rail	4,060	4,325	1%	1%
Rail PnR	1,231	629	0%	0%
Rail KnR	1,365	409	0%	0%

The model is generally a close match with observed patterns from the HTS for all modes, with again the main difference for rail being a result of the parameters calibration providing a better alignment with other sources of data for rail patronage, although the difference in terms of number of trips is very small.

5.3.6   Business

The following table presents the mode choice model parameters for the business demand segment. Due to the small sample size, the β values for rail modes were not estimated split by car availability.

Table 5-13: Mode choice model estimation - BSN

Parameter	Value	t Stat	Significance	Calibrated value
ASC_{bus}	-3.500	-7.92	***	
$ASC_{bus,to\ cbd}$	-2.95	-10.88	***	-3.1
ASC_{car}	0.990	6.36	***	
$ASC_{car,to\ cbd}$	-0.683	-3.25	**	
ASC_{rail}	-2.850	-5.23	***	
$ASC_{rail,to\ cbd}$	-2.710	-6.38	***	-3.2
$ASC_{rail\ pnr}$	-15.600	<min	***	
$ASC_{rail\ pnr,to\ cbd}$	-2.320	-4.43	***	-1.0
$ASC_{rail\ knr}$	-5.210	-3.66	***	
$ASC_{rail\ knr,to\ cbd}$	-8.600	<min	***	
β_{active}	-0.118	-13.04	***	
$\beta_{bus,ca}$	-0.0256	-4.25	***	
$\beta_{bus,nca}$	-0.0238	-4.22	***	
$\beta_{car,ca}$	-0.0746	-5	***	
$\beta_{car,nca}$	-0.233	-7.84	***	
β_{rail}	-0.0312	-4.13	***	
$\beta_{rail\ pnr}$	-0.031	-3.93	***	
$\beta_{rail\ knr}$	-0.0282	-2.81	**	
λ_{pt}	0.390	-4.87	***	
Estimation Statistics				
Number of cases		1,988		
Log likelihood at convergence		-720		
Rho Squared w.r.t. Null Parameters		0.798		

The following table shows the observed and modelled number of trips per mode, and the resulting modal share.

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Table 5-14: Mode choice model validation - BSN

Mode	Number of trips		Mode share	
	Observed	Modelled	Observed	Modelled
Active	15,147	12,789	13%	12%
Light vehicles	97,443	91,396	84%	85%
Bus	1,812	2,170	2%	2%
Rail	1,407	623	1%	1%
Rail PnR	598	837	1%	1%
Rail KnR	33	12	0%	0%

The model is generally a close match with observed patterns from the HTS for all modes.

5.3.7 Overall demand

The plot below shows a graphical representation of the resulting modal shares for each trip purpose.
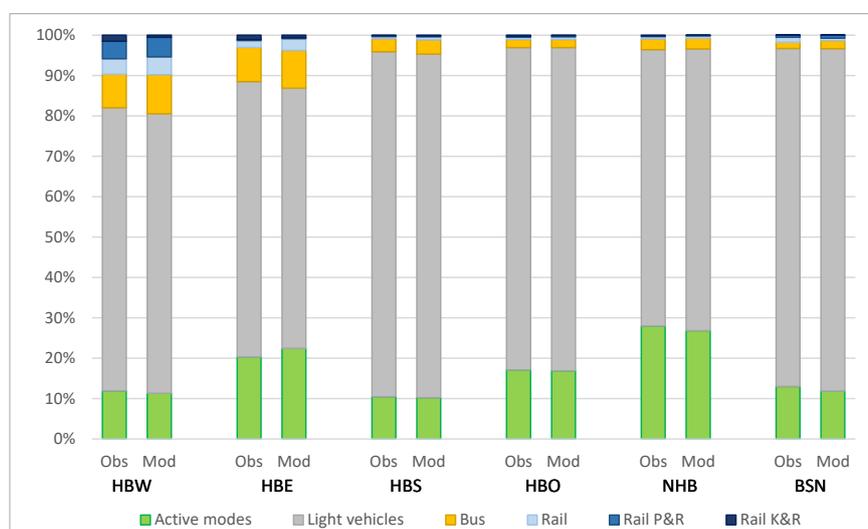

Figure 5-1: Mode share by trip purpose

The following table presents the total number of trips aggregated over all purposes, for both the HTS and the model, and the resulting modal share.

Table 5-15: Mode choice model validation - Total

Mode	Number of trips		Mode share	
	Observed	Modelled	Observed	Modelled
Active	403,415	391,544	19%	19%
Light vehicles	1,557,557	1,544,946	74%	74%
Bus	81,687	88,406	4%	4%
Rail	24,330	28,838	1%	1%
Rail PnR	16,986	18,308	1%	1%
Rail KnR	9,915	4,500	0%	0%

The overall modal shares are very close if looking at total demand including all purposes. In terms of absolute number of trips and as detailed previously, the main difference is a slightly higher amount of bus trips, and more importantly a lower number of rail kiss-and-ride trip and correspondingly higher rail and rail park-and-ride demand. Again while this led to a discrepancy with the HTS, it provides a better match with other sources of data on public transport use in the region, including bus ticketing and surveys of access to rail, and ultimately a better validation for the WTSM.

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5.4 Mode share by car availability

The plot below shows a graphical representation of the resulting modal shares for 'non car available' demand only, i.e. trips generated by households with no car available.

Comparison with observed for this segment is complicated by the very small sample size, as trips from these households represents roughly 5% of the HTS trip records, which itself is a 0.6% sample of regional population. For most purposes, modelled results are however reasonably close to observed.
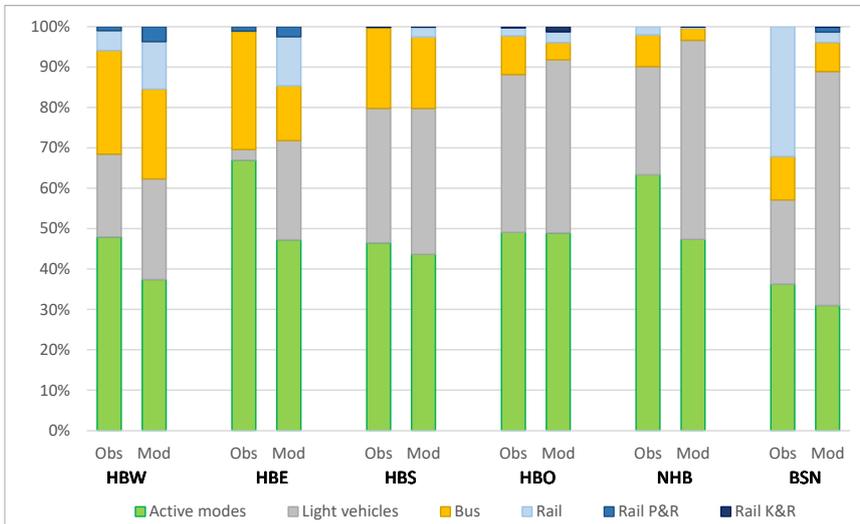

Figure 5-2: Mode share by trip purpose – households with no car available

The two purposes that presents the largest difference in terms of modal share are home-based education and business. It must be noted however that each of these purposes represent a very small proportion of demand and of the HTS sample, representing only 2% of the 'no car available' demand, or 0.1% of the total HTS. The modelled mode shares however appear sensible.

5.5 Mode share for trips to/from the CBD

Results specifically for trips to and from the CBD, i.e. having a trip attraction in the CBD, were reviewed to ensure the mode share for this critical segment of demand was a good match with observed patterns.

The following plot shows the comparison for all trips purposes.
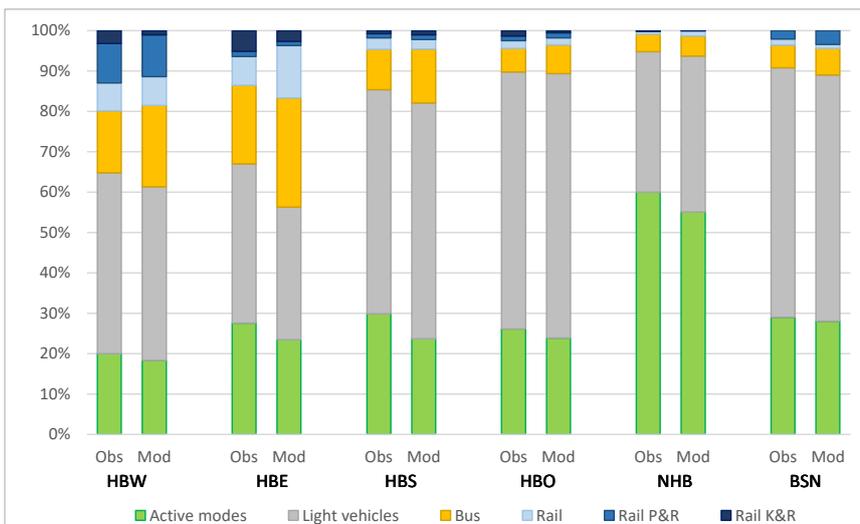

Figure 5-3: Mode share by trip purpose – trip attraction in CBD

Results show that the modelled modal shares are a good match with the HTS overall. Once again, the largest differences are a slightly higher share of bus trips, and a reduction of rail kiss-and-ride to the benefit of other rail modes.

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5.6 Mode share for commuting

Finally, results for the home-based work purpose were compared against observed data[6] for commuting trips. For this comparison it must be noted that the definitions for commuting and home-based work as defined in the model are not the same, e.g. someone dropping kids at school on the way to work would not be classified as home-based work in WTSM, but as a home-based education trip followed by a non-home-based trip. The comparison is however still useful to ensure modelled mode share for trips to work is a reasonably good representation of observed shares.

The following table presents this comparison both for the region as a whole, and for trips with attraction in the CBD only.

Table 5-16: Commuting mode choice model validation - Total

	Source	Active	Car	Bus	Rail
Region-wide	Observed	14%	66%	10%	10%
	Model	11%	69%	10%	10%
CBD Attraction	Observed	16%	50%	16%	18%
	Model	18%	43%	20%	18%

The modelled modal shares for home-based work are a good representation of observed commuting patterns.

6. Sensitivity tests

A number of sensitivity tests were run in the WTSM, which mostly impact on the trip distribution and mode choice stages, to assess the model's response to changes in generalised costs. For this purpose, elasticities of the model to changes in various costs and time input were calculated and compared against the following guidelines and existing models:

- Monetised Benefits and Costs Manual (MBCM), version 1.6.1 June 2023
- Strategic Transport Model Elasticity Guidelines, Victoria Department of Transport, December 2015
- Australian Transport Assessment and Planning (ATAP) Guidelines, M1 – Public Transport, August 2021
- 2001 version of the WTSM
- 2006 version of the Auckland Regional Transport Model (ART)

Some limitations must be kept in mind for this comparison. First, there is a range of formulations to calculate elasticities including arc, point, constant point and reports rarely mention which calculation has been used. In some cases, the resulting values can be quite different depending on the calculation used. Only the Victoria DOT guidelines clarify that they are based on arc elasticities with the following formulation:

$$e = \frac{\log(Q_2) - \log(Q_1)}{\log(P_2) - \log(P_1)}$$

where P is the cost, Q the demand, 1 is before and 2 after the change in cost.

The same formulation was therefore used for the WTSM sensitivity tests for consistency with the Victoria DOT guidelines, but it is unclear what formulation was used for ATAP or the other models.

In addition, the metrics used for demand is also rarely specified (e.g. trips, vehicle-kilometres travelled, etc). Again, the Victoria DOT guidelines do specify the metrics to use, and the same ones were used here for comparison.

Finally, elasticities are likely to differ quite significantly depending on characteristics of the modelled area, especially the availability of alternative modes. The Victoria DOT guidelines indicates that these values are to be interpreted as guidelines rather than rules.

However, this analysis is useful to ensure that the model response to changes in costs is realistic, and ultimately to better interpret output when using the WTSM for forecasting. The sensitivity tests carried out, values from guidelines and other models, and results from the 2018 WTSM are shown in the following table.

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[6] *https://www.nzta.govt.nz/assets/resources/keeping-cities-moving/Wellington-regional-mode-shift-plans.pdf*

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Table 6-1: Sensitivity tests and elasticities

| Test | Guidelines and other models | | | | 2018 WTSM elasticities |
	ATAP / MBCM	Victoria DOT	WTSM 2001	ART 2006	
PT Fares +20%	-0.2 to -0.6	-0.2 to -0.6, PT trips	-0.2	-0.24	-0.26
PT Service levels +20%	0.2 to 0.7	0.2 to 0.6, PT trips	0.1	0.21	0.21
PT In-vehicle time +20%	-0.1 to -0.7	-0.1 to -0.5, PT trips	-0.2	-0.24	-0.32
Car Fuel Cost +20%		-0.15 to -0.3, VKT	-0.4	-0.13	-0.29
Car In-vehicle time +20%		-0.2 to -0.8, car trips	-0.08	-0.06	-0.11
CBD Parking +20%		-0.1 to -0.4, HBW car trips to CBD			-0.43

Results show that the WTSM is within expected ranges from most tests, or slightly outside the range in the case of CBD parking. It can be noted that it sits on the lower end for PT service levels, but upper end for car fuel costs.

The only test for which the model is well outside the range is for the car in-vehicle time change. It can however be observed that both the older version of WTSM and the ART model are also lower than guidelines, even more so than the 2018 WTSM. While it is unclear why this is the case, it could be due to the more car-oriented nature of the Wellington region and Auckland areas. Indeed, the elasticities if looking only at Wellington City which has a higher share of active and PT modes, or even more so for trips to the CBD, are within guidelines.

In addition to these elasticities, changes in mode share were also reviewed in more detail to ensure the response from the model was plausible separately by mode and purpose. While no guidelines apply for this level of detail, all results pointed to the model response being realistic in terms of direction and magnitude.

7. Conclusion

This technical note has detailed the development of trip distribution and mode choice models for the 2018 version of the WTSM.

A number of model forms were assessed with the final models adopted, as a result of their performance and constraints on data available for estimation, being a gravity model for distribution and a nested multinomial logit for mode choice.

Review of statistical performance and validation against observed sources of data, has shown that both models perform suitably well for a strategic model such as the WTSM. In addition, sensitivity tests indicate that the model responds realistically to changes in input costs and times, with resulting elasticities in the expected ranges.

The validation of the model as a whole and hence including the performance of its distribution and mode choice components, against further sources of independent observed data is detailed in 'TN31 – WTSM Validation'.

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