

A photograph of a busy Wellington street. In the foreground, a white car is driving towards the camera. To its left, a grey car is also visible. In the middle ground, a green bus with 'Dunedin Park' on its destination sign is moving away. The background shows a hillside covered in colorful houses, with a large green hill in the distance under a clear sky.

TN29 - WELLINGTON TRANSPORT ANALYTICAL TOOLS 2019-21 UPDATE – PUBLIC TRANSPORT ASSIGNMENT

PREPARED FOR GREATER WELLINGTON REGIONAL COUNCIL

July 2023

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TN29 - Wellington Transport Analytical Tools 2019-21 update – Public Transport Assignment

CONTENTS

1.	Introduction	1
2.	Demand	1
2.1	Time periods	1
2.2	Segments	1
3.	Public Transport Network	2
3.1	Modes and vehicles	2
3.2	Link coding	3
3.3	Representation of car access to PT.....	3
3.4	Public transport lines	4
3.5	Bus travel time calibration.....	4
4.	Public Transport Assignment Specifications	9
4.1	Pedestrian access	9
4.2	Car access	10
4.3	Waiting times.....	12
4.4	Boarding times and penalties	12
4.5	In-vehicle travel times.....	13
4.6	Fare	15
5.	Journey Levels	16
5.1	Definitions	16
5.2	Bus	16
5.3	Rail other segment.....	17
5.4	Rail park-and-ride and kiss-and-ride access segments – AM and IP periods	17
5.5	Rail park-and-ride and kiss-and-ride egress segments – PM and ON periods	18
5.6	Airport-related demand	19
6.	Public Transport Crowded Assignment	19
6.1	Definition.....	19
6.2	Vehicle types and capacities.....	19
6.3	Crowding function	22
6.4	Crowded PT assignment tests	25
6.5	Implementation in WTSM	29
7.	Running the PT assignment	29

LIST OF TABLES

Table 3-1: Public transport modes.....	2
Table 3-2: Public transport vehicles	3
Table 3-3: Public transport auxiliary modes	3
Table 3-4: Public transport routes per mode	4
Table 3-5: Bus transit time function parameters	7
Table 4-1: In-vehicle times perception factors.....	13
Table 4-2: Bus to bus transfers as percentage of total bus boardings	13
Table 4-3: In-vehicle times perception factors.....	14
Table 4-4: PT fares (2018\$).....	15
Table 5-1: Journey levels - bus.....	17
Table 5-2: Journey levels – rail other	17
Table 5-3: Journey levels – rail car access (AM and IP)	18
Table 5-4: Journey levels – rail car egress (PM and ON)	18
Table 6-1: Bus vehicle capacity bands.....	20
Table 6-2: Rail vehicle capacity bands	21
Table 6-3: 3-hour period to peak 1-hour factors	24
Table 6-4: Total daily mode share – 2033 test	27
Table 6-5: Total mode share – 2053 test	28

LIST OF FIGURES

Figure 2-1: Rail car access and egress profiles per hour – from HTS 2018	2
Figure 3-1: Dwell times outliers.....	7
Figure 3-2: Bus modelled vs observed travel times	8
Figure 3-3: Travel times on Golden Mile - Northbound	8
Figure 3-4: Travel times on Golden Mile - Southbound.....	9
Figure 4-1: Rail car access catchments.....	11
Figure 6-1: Number of bus services per vehicle class	20
Figure 6-2: AM peak capacities per bus vehicle class – Wellington	20
Figure 6-3: AM peak capacities per bus vehicle class – Rest of region	21
Figure 6-4: AM peak capacities per rail vehicle class – Rest of region	21
Figure 6-5: Comparison of crowding functions	23
Figure 6-6: Comparison of crowding functions	24
Figure 6-7: AM peak V/C by number of segments and length – 2033 Test	26
Figure 6-8: AM peak loading profiles – 2033 test	26
Figure 6-9: AM peak weighted average V/C – 2033 Test	26
Figure 6-10: AM peak V/C by number of segments and length – 2053 Test	27
Figure 6-11: AM peak loading profiles – 2053 test	28

Figure 6-12: AM peak weighted average V/C – 2053 Test28

APPENDICES

- Appendix A Bus travel time comparison
- Appendix B List of attributes and parameters

1. Introduction

This technical note is part of a series documenting the 2019-2022 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 planners.

This note details the public transport assignment within the Wellington Transport Strategy Model (WTSM) and covers the following items:

- Demand segments and representation of the public transport network
- Public transport assignment specifications
- Optional crowded public transport assignment
- Running the model

Throughout this document, mention is made to the Ministry of Transport Household Travel Survey (HTS) which was used to calibrate a number of components of the PT assignment. More detail on this survey and its processing for the project can be found in TN24 – HTS and Mobile Phone Data.

2. Demand

2.1 Time periods

The demand for the public transport assignment is consistent with time periods used throughout WTSM, with assignments carried out for the four following time periods representative of a March 2018 weekday average:

- AM period: 6-9am
- Interpeak (IP) period: 9-3pm
- PM period: 3-6pm
- Overnight (ON) period: 6pm-6am

These four periods total up to a full 24hr weekday.

2.2 Segments

Five different demand segments are assigned separately, each with their own parameters, rules and constraints as further detailed in the remainder of this document. These segments are as follows:

- Bus: any trip including bus but not rail.
- 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: any trip including rail but no car access or egress.
- Airport-related demand: this segment is assigned separately as it does not follow the same rules and constraints as overall demand generated by the trip production model which is represented by the first four segments (see section 5 on journey levels). This segment can freely use any combinations of rail or bus.

The following additional rules apply:

- Rail segments also include the Wellington Cable Car and the East by West cross-harbour Ferry. These were grouped with rail for simplicity as they only represent a small proportion of demand and are 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 P&R and K&R, this can only apply on the leg that is not car-based.

- For P&R and K&R, car access to rail is only permitted in the AM and IP periods, whereas car egress from rail is only permitted in the PM and ON periods. This allows for simplification of the assignment but is also representative of trip patterns observed in the Household travel survey, 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 ON periods (from the alighting station to home). This is illustrated in the figure below, showing time profiles from the HTS.

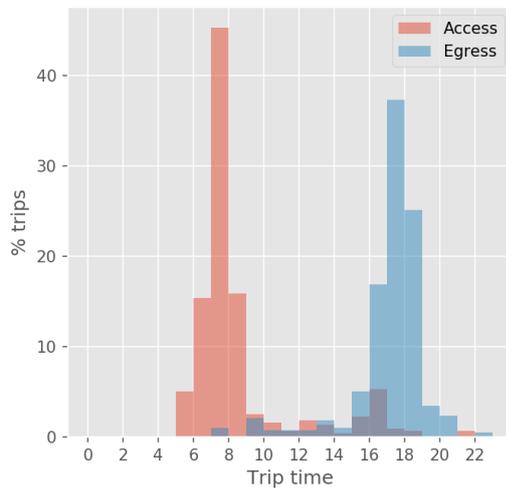


Figure 2-1: Rail car access and egress profiles per hour – from HTS 2018

3. Public Transport Network

This section details the changes made to the 'base' WTSM network i.e. to modes, vehicles, nodes and links. All other parameters and extra attributes used during a public transport assignment are described later in their relevant sections.

3.1 Modes and vehicles

The modes included in the public transport assignment are shown in the following table. This includes three existing modes, but also 3 modes that can be used for forecasting. While any other modes could be added in using the model for forecasting, having these mode pre-implemented will make this process easier.

Table 3-1: Public transport modes

Mode	Mode ID
Bus	b
Rail (including cable car)	r
Ferry	f
MRT	m
New PT mode x	x
New PT mode y	y

The assignment has been setup by default so that new alternatives modes m, x and y are grouped together with bus as they are likely to be more similar to bus than rail in terms of geographic coverage and having a more urban nature. This can however be changed if required.

The vehicles implemented in the model are shown in the following table, together with their ID in the model, light vehicles equivalent in passenger car unit (PCU) and seating and total capacity. How capacities were derived and how they apply in the model is described in Section 6.1. Note that capacities only have an effect in crowded assignments.

Table 3-2: Public transport vehicles

Mode	Mode ID	Light vehicle equivalent	Seating capacity	Total capacity
Rail medium capacity	1	-	310	400
Rail high capacity	2	-	420	630
Ferry	3	-	99	99
MRT	4	5	100	200
New PT mode x vehicle	5	3	80	150
New PT mode y vehicle	6	3	80	150
Bus small	7	3	30	50
Bus medium	8	3	40	60
Bus mixed	9	3	60	80
Bus double decker	10	3	80	95

Finally, the public transport assignment also needs 'auxiliary' modes, that are used for access to and egress from public transport. In transport modelling terms, these are the modes that are used between the origin zone and the initial boarding stop/station, the final alighting stop/station and the destination zone, and between any stops/stations if transfers occur. Auxiliary modes are shown in the following table, along with their speed or time factors (more detail on this can be found in Sections 4.1 and 4.2).

Table 3-3: Public transport auxiliary modes

Mode	Model ID	Speed / time factors
Walk	w	5kph /1.8 (perception)
Park and ride	p	u11 *1
Kiss and ride	k	u12 *1
Station access	s	30kph

While the walk, park-and-ride and kiss-and-ride modes are self-explaining, the 'station access' mode is required to enforce the constraints that apply to the 'Rail Park-and-ride' and 'Rail kiss-and-ride' demand segments. This is detailed in Section 3.3.

3.2 Link coding

The underlying networks used for the public transport assignment are the same ones used for the road assignment. Each time period has a separate network, with road assignment having been carried out so that the networks include information on traffic volumes and travel times.

The main link base attribute that apply to the PT assignment is the link type, with the following links being specific to PT:

- Type 17 = railway
- Type 18 = ferry link
- Type 19 = bus only link (no traffic allowed)
- Type 16 = pedestrian links, including used for access to rail stations

All other link types are used by traffic and can be used by buses.

In addition the link extra attribute @busl is also of importance to identify links including a bus lane (0 by default, 1 if bus lane), as it results in both different travel times being calculated for buses, and bus volumes not being included in the delay calculations in the road assignment as they are not mixed with traffic.

3.3 Representation of car access to PT

Car access to public transport is generally the most complex component of a public transport assignment. Historically in Wellington, two separate approaches have been used.

The previous version of the WTSM had a coarse representation of car access through the use of P-connectors directly linking centroids to rail station nodes. The generalised cost of travelling on the P-connector was estimated during the model development but was not recalculated as part of a scenario run. This also means that there was no accounting for capacity or price, etc. Choice between car (through P-connector) and non-car (through regular connector and walk or bus access) was done through the assignment.

The more recent Wellington Public Transport Model (WPTM) has a detailed PT access logit choice model (including park-and-ride, kiss-and-ride and non-car. This is more detailed and therefore more representative of real access choices, however, is more complex and involves longer runtimes caused by the required matrix calculations.

New functionalities (journey levels) have been introduced in EMME which has resulted in a new approach being used for representing car access to rail. This approach is detailed in Section 5.

In terms of base network, this has resulted in the following changes compared with the network used by the previous version of WTSM:

- The P-connectors have been removed.
- The "dummy" node used for each rail station to connect to the P-connector has also been removed. These are all the nodes that were numbered 303XX where XX represents the station number.
- The new auxiliary modes 'p' (park-and-ride), 'k' (kiss-and-ride) are added to all links usable by car (this mode change carried out automatically during the model run) and mode 's' (for station access) has been added to links between each station and the surrounding road/pedestrian network.

3.4 Public transport lines

Public transport lines were obtained from processing the 2019 General Transit Feed Specification (GTFS) data. 2019 data was used to represent the post Public Transport Operational Model (PTOM) network and services, as using 2018 data would have led to the model being out-of-date compared to current networks (see Section 4 in 'TN15 –w WTPM Update' for more detail).

The EMME Modeller tool 'Import from GTFS' was used to import the PT lines. While this tool simplifies the network by merging lines which follow very similar routes and stopping patterns with only minor variations, a further simplification was done manually. The resulting number of routes per line is shown in the following table.

Table 3-4: Public transport routes per mode

Time period	Bus	Rail	Ferry
AM period	171	19	3
Interpeak period	151	13	4
PM period	168	19	4
Overnight period	136	13	3

Note: Rail includes 2 cable car lines (one for each direction).

The GTFS import tool also imports the headway (average time between service during the time period) for each line.

3.5 Bus travel time calibration

3.5.1 Methodology

Bus travel times in WTSM are not based on timetable but instead calculated during a model run as a function of network congestion and public transport demand. This approach is consistent with the previous version of WTSM and with the WPTM, and was chosen for the following reasons:

- Analysis of travel times during the development of the WPTM has shown that buses regularly fail to adhere to timetables, especially during peak periods.

- This approach allows capturing the impact of rising delays due to increase in network congestion, and conversely of schemes that might reduce these delays.
- It also avoids having to manually estimate timetables for new services when forecasting, which may introduce a level of bias and can be a complex and time-consuming exercise.

The previous version of WTSM was based on factors applied to car travel times, with a small fixed-time penalty per stop (different in the CBD vs rest of the region, and by time period). A number of issues were however identified with the resulting functions:

- the fixed time penalty per stop meant it did not reflect changes in number of boardings and alightings. This was partly addressed by the different penalties per area and time period but was still a static and coarse approach.
- Due to the time penalties per stop being on the low side, adding or removing stops along a route did not make a significant difference in travel times, leading to express services (with less stops) being only marginally faster than regular services.
- In some cases, the factors applied on car travel times (or free flow travel times for link separated from traffic) led to improvements such as bus lanes or full segregation from traffic returning slower travel times than for standard links with low congestion.

For the new version of WTSM, while the general approach was similar, more weighting was placed on delays related to bus stops themselves, and less on the factors applied to car travel times. The bus travel times are made of the following three components:

- Link travel time, based on car travel times (links and turning delays) with a factor applied to represent slower overall bus speed. These factors are different for regular link, bus lanes, and bus only link (based on free flow speed), and by time period.
- Time penalty constant per stop, to represent the deceleration, acceleration and other delays related to servicing each bus stop, but not including boarding and alighting times.
- A new, variable dwell time, based on the number of passengers boardings and alightings.

While it was expected that the introduction of two separate component for stop-related delays would solve the issues noted above by adding more weight to this component of travel times, parameters resulting from the calibration were sense-checked to ensure these issues would not be replicated.

3.5.2 Supporting data

Real time information was initially not available for the calibration of the functions used to calculate bus travel times. Electronic ticketing machine (ETM) data was first used instead, with data for the whole month of March 2019 used. This dataset and its processing and cleaning is detailed in 'TN15 – WPTM Update'.

The ETM data includes time stamps for all boardings and alightings, which allows calculating the time between successive stops, or dwell times at stops.

It was merged with data from the General Transit Feed Specification, which provides information on bus routes and stop sequences.

Towards the end of the calibration exercise, observed travel times from a new PowerBI dataset was made available through GWRC. This data was used for fine-tuning the approach to calibrate the travel times functions and for the validation of the resulting travel times.

Modelled traffic travel times were necessary for the calibration of travel times functions, as well as public transport patronage for the calculation of dwell times. As the PT assignment was developed in tandem with other components of WTSM and before the full synthetic matrices were not available, observed matrices were used instead:

- For the traffic assignment, these were the matrices developed for the new Wellington Traffic Assignment Model, based on mobile phone data adjusted to match traffic counts. The development of these matrices is detailed in 'TN25 – Wellington Traffic Assignment Model'.
- For the public transport assignment and calculation of dwell times, the matrices were themselves built from demand from the ETM data using the same approach as for the matrices produced for the WPTM (see TN15 – WPTM Update). The new WTSM has different time periods from the WPTM so the same processing was applied but using the new time periods.

While it means the travel times will likely be slightly different from final travel times after a full converged run of the WTSM including demand model, the difference is expected to be minimal.

3.5.3 Calibration

Not all routes were used in the calibration of the bus travel time functions, with a sample of routes selected to provide a good representation of the whole network, including between most areas of Wellington and the region, and the CBD. Both regular and express services were also included.

Travel times extracted from the ETM data were found to be relatively noisy, with many stops presenting very long dwell times. While the source of this issue was not clear, it meant the routes used needed additional sense-checking. In addition, not all stop to stop sequences had observed data, leading to some routes having gaps.

Travel times for the selected routes were plotted and any routes presenting such issues or gaps were removed from the dataset. The final dataset included the following number of routes:

- AM period: 49
- IP period: 45
- PM period: 45
- ON period: 17

Travel times parameters were calibrated as follows:

- The factor to apply to car travel times and the time penalty constant per stop were calculated by using the time interval between the last boarding/alighting at a stop, and the first boarding / alighting at the following stop. A linear regression was applied on the dataset for each time period, with the factor on auto time being the resulting slope and the penalty per stop being the intercept.
- The variable dwell time per stop was based on the time interval between the first and last boarding / alighting at the same stop. Again, a linear regression was used with the resulting slope being the time per boarding/alighting (this was forced through zero so no intercept applying)

Factor on car travel times and penalty per stop

Initially the analysis for link and turn factors and constant per stop looked at times between all stop pairs in the dataset. It returned factors on car times that were smaller than 1 and large time penalties per stop, which was clearly not acceptable.

This was changed to running the linear regression using the complete routes instead, i.e. the travel time along the whole route and summing up the number of stops services, which returned much more sensible results for the AM and PM periods.

The time factor analysis was carried out separately for links with bus lanes and for bus only links (for bus only links, this was using coded free-flow speed and not car travel times). In both these cases the samples were much smaller. The resulting values were considered appropriate for bus lanes but not for bus only links of which there are only a few in Wellington CBD. The factors were therefore manually estimated based on analysis of travel times on bus only sections of the Golden Mile.

Finally, a unique constant time per stop was not found to lead to a good representation of travel times overall. Further analysis led to these times per stop being calculated separately for the Wellington CBD along the Golden Mile, the rest of Wellington, and the rest of the region. The higher values for the CBD are likely due to bus congestion, while values are lower in the rest of the region outside Wellington, as lower levels of traffic result in buses easily moving in and out of bus stops with less delays.

Dwell times

For dwell times, the analysis was impacted by the vary large variations in time between first and last boardings/alightings observed using the ETM. To solve this issue, outliers were removed using the Interquartile range approach (the IQR being the range between the 25th and 75th percentile, all points outside the range between +/- 1.5 IQR were identified as outliers and removed from the dataset). The plot below shows the dwell times per number of boardings (for the AM Period), and the distribution of valid versus outlier data points using this approach.

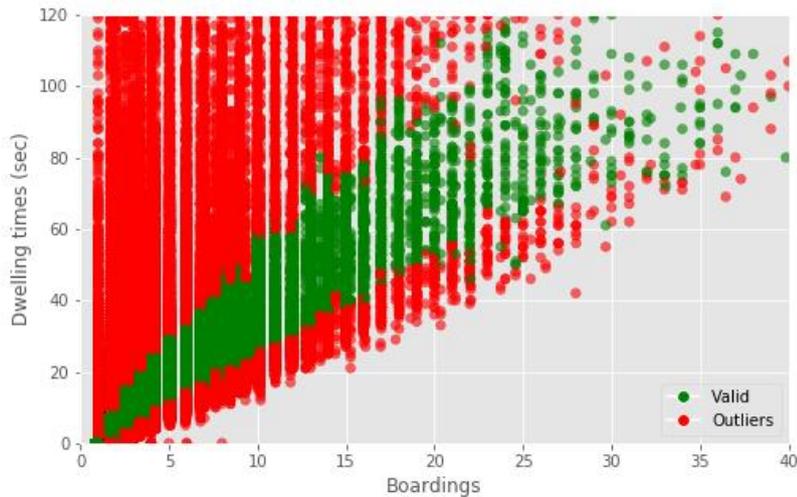


Figure 3-1: Dwell times outliers

Finally the dwell times can be driven by either boardings or alightings, with the latter generally taking less time to process (no paying or presenting concession card to the driver, no time to choose a seat, etc). A linear regression was therefore carried out for both boardings and alightings separately to estimate the relativity between the two leading to a factor of 0.67 (meaning alighters takes in average 0.67 less time than boarders).

The final regression was then carried out using as explanatory variable the maximum of either boarders or 0.67 * alighters.

3.5.4 Results

Results from the linear regressions for factors on car travel times, constant time penalty per stop, and dwell time per boardings/alightings are shown below for the four time periods. Note that for bus only link, the factors apply to free times based on free flow speed and not car travel times.

Table 3-5: Bus transit time function parameters

Period	AM	IP	PM	ON
Factor on auto link times – standard link	1.05	1.18	1	1.05
Factor on auto link times – bus lane	0.85	0.96	0.83	0.96
Factor on auto turn times – bus lane	0.6	1	0.6	1
Factor on free flow speed – bus only link	3.2	3.5	3	3
Constant time per stop – CBD (in seconds)	28	31	28	33
Constant time per stop – Rest of Wellington (in seconds)	13	13	10	12
Constant time per stop – Rest of Region (in seconds)	7	7	7	7
Dwell time per boarding / alighting (in seconds)	3.7	3.7	4.6	4.4

Note: P-value < 0.01 for all parameters except bus lanes and factors on free flow speed for bus only link (not estimated due to small sample).

For factors on auto turn times on links with bus lanes, delays are capped at 1 minutes to avoid long delays for very congested intersections.

The following figures present a comparison of modelled vs observed travel times for the sample of routes used in the analysis, for each time period. It must be noted that since modelled bus travel times are themselves a function of modelled car travel times, the comparison includes both potential error on car travel times and on bus transit time functions parameters.

Results are however acceptable for all time periods for bus travel times calibration, both in terms of r^2 and slope.

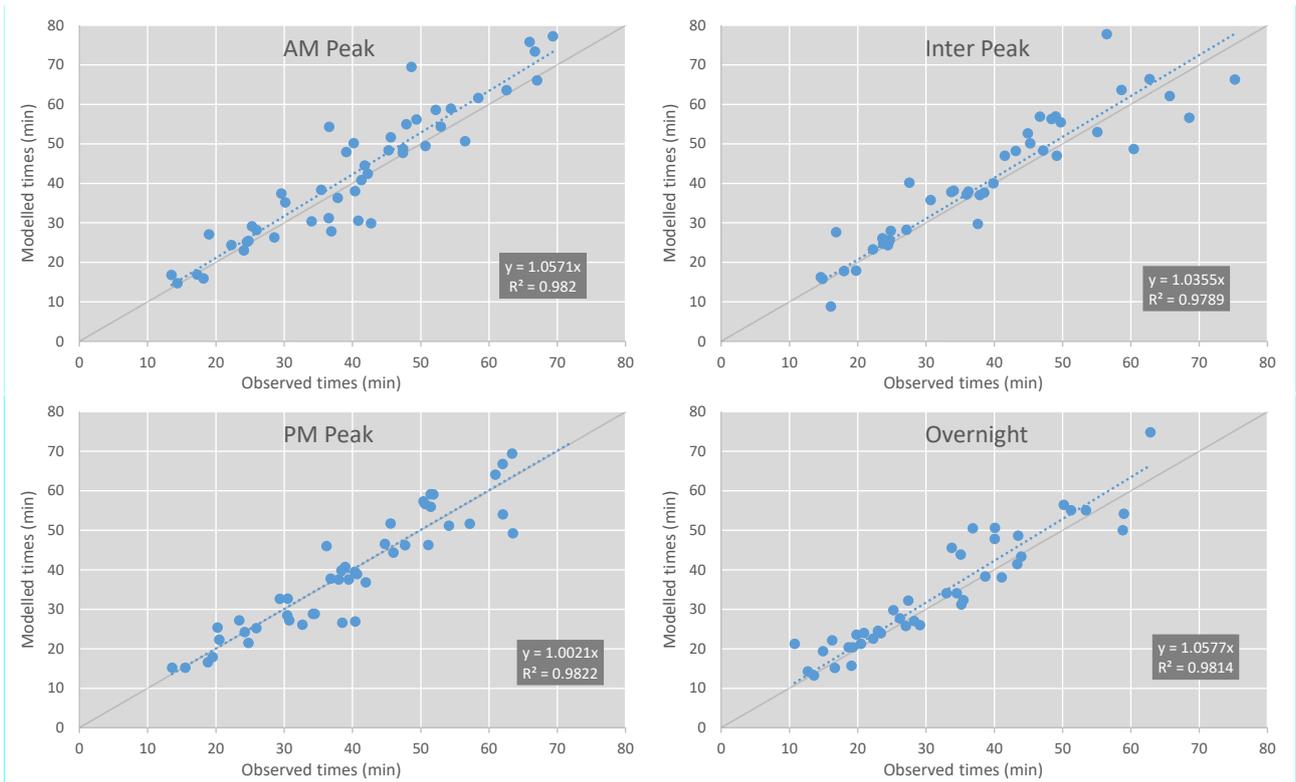


Figure 3-2: Bus modelled vs observed travel times

A table showing the observed and modelled travel times for these services is included in Appendix A.

The following figures present a comparison of travel times along the Golden Mile between the bus station and the Basin reserve. Modelled times are a good match with observed in all cases.

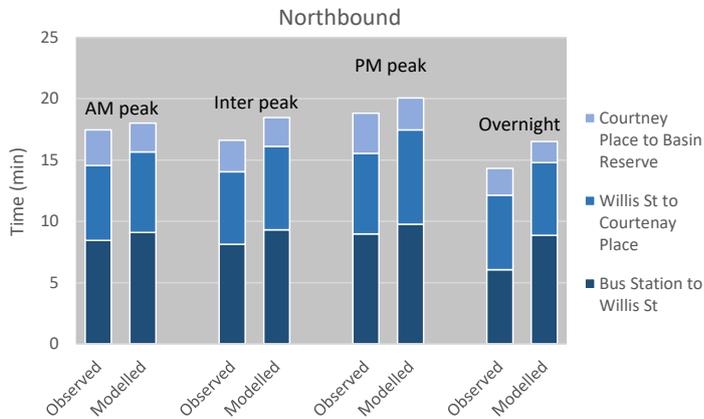


Figure 3-3: Travel times on Golden Mile - Northbound

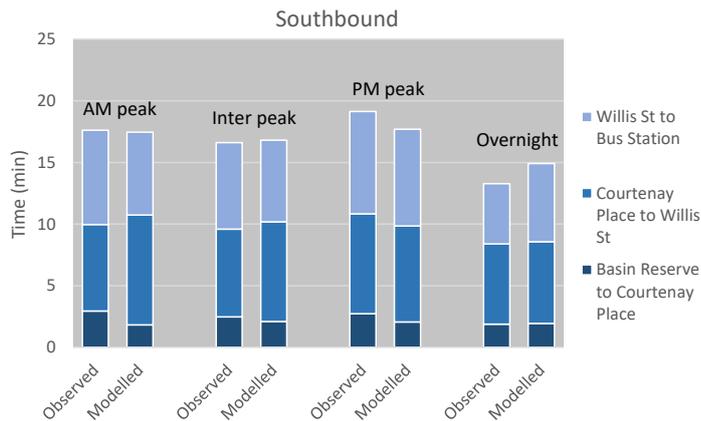


Figure 3-4: Travel times on Golden Mile - Southbound

4. Public Transport Assignment Specifications

A public transport trip includes a number of stages and variables that are captured in the PT assignment and can be summarised as follows:

- Access from origin to public transport initial boarding, by walking or car (auxiliary modes)
- Waiting time
- Boarding time or penalty
- In-vehicle (travelling) time
- Monetary fare, including boarding and per zone costs
- Optionally additional fare, auxiliary, waiting and boarding times if transferring between services
- Egress from public transport to destination using auxiliary modes

For all these components, perception factors and penalties may apply. How these stages are represented and the parameters applied is detailed in the remainder of this section. In many cases, parameters from the WPTM were used for consistency, and because these were based on a thorough review of values used internationally.

The 2018 version of WTSM uses the EMME Flow interface and all parameters used in the PT assignment and described in this section are set in the two associated 'Flow' modules:

- **Initialize PT Assignment:** runs only once per scenario and prepares the networks by applying network changes and setting most attributes required for the PT assignment.
- **PT Assignment:** runs within each main model loop. It recalculates values that are updated between each assignment loop, carries out the assignment and skim a number of output matrices.

A summary table of all parameters and attributes used for all stages of the PT assignment is included in Appendix B for reference.

4.1 Pedestrian access

4.1.1 Speed and perception

The speed for pedestrian access to PT (mode 'w') was set to 5kph. A perception factor greater than 1 is generally applied to time for this mode to represent the perceived inconvenience of walking to/from PT. A value of 1.8 was used for consistency with the WPTM.

4.1.2 Implementation in WTSM

Both walk speed and perception factors are input into the assignment, set in the **Initialise PT Assignment** Flow (**walk_speed** and **walk_perception**)

However due to EMME not being able to apply separate perception factors to different auxiliary modes (in this case walk, park-and-ride and kiss-and-ride), the perception factor could not be applied to auxiliary times as it would apply to all modes. To circumvent this limitation, the perception factor was applied to the speed instead, with walk speed therefore calculated as $5/1.8 = 2.78\text{kph}$ for this mode (this is calculated during a model run based on the input speed and perception factor parameters).

4.2 Car access

4.2.1 Time and generalised costs

Generalised costs for the car leg of a PT trip including park-and-ride or kiss-and-ride include the following components:

- Car travel times
- Car fixed costs, including vehicle operating costs and potentially tolls (not applied in base year 2018 as non-existent)
- Time at station, to represent the time spent parking and walking between car and station platform.
- Parking charge (set to 0 by default as park-and-ride parking was free as per March 2018).

Car travel times

Car travel times are produced from the road assignment carried out before a PT assignment, with car speed saved in a link extra attribute (**@timau**). For the AM and PM periods which have both a peak hour and shoulder assignment, the travel times from the peak hour were saved.

In addition, a perception factor is applied to represent the fact that users are generally more likely to drive to the nearest rail station and maximise the share of the trip spent on public transport. First tests without this factor applied resulted in unrealistic patterns where some users would drive as near to their destination as possible and only board PT for the last short leg. Review of other models has shown that use of such a perception factor is very common for representation of car access to PT to solve this issue, with values as high as 5 being applied. For the WTSM, a value of 2 was shown to be sufficient for both park-and-ride and kiss-and-ride. (This issue has also been addressed through the use of rail station catchments, as described in section 4.2.2)

The final, short link to access the station (needed for representation of car access/egress to PT using Journey levels, as detailed in Section 5) has a fixed speed of 30kph.

Car fixed costs

Car fixed costs are also calculated as part of the road assignment and saved in a separate attribute (**@fcost_iv**). These include both vehicle operating costs and potential tolls (none in the base year). The fixed costs are then divided by car occupancies for park-and-ride and kiss-and-ride car trips. These were extracted from the HTS leading to values of respectively 1.09 and 2.2.

Time at station

The additional time spent parking (for park-and-ride), and walking between the car and the rail platform is represented through a time penalty. The values used were extracted from the HTS, leading to values of 4 minutes for park-and-ride and 3 minutes for kiss-and-ride. While these were based on a small sample and there are limitations in terms of accuracy of reported times for such small intervals, the values were considered realistic and appropriate to use. No meaningful difference was observed between access (car to PT) and egress (PT to car) and the same values were used in both directions.

Parking charge

Finally, the monetary cost of parking at rail station park-and-ride sites is applied through a link attribute (**@pr_charge**). The value must be applied for both inbound and outbound direction, is then converted to generalised time using the value of time, and divided by 2 to split the cost equally between access and egress. This value is set to 0 in the base scenario.

4.2.2 Rail station catchments

In order to ensure that park-and-ride and kiss-and-ride trips to rail stations occur from realistic locations, matrix-based access model (such as the Wellington Public Transport Model) use catchments based on matrix constraints, with what stations can be access from any zone being explicitly defined in matrices. This

is not feasible in the new version of WTSM with the car access/egress legs being represented through assignment.

However, links attributes were used as an alternative to define catchments by banning park-and-ride and kiss-and-ride access at specific locations. This is facilitated by the geography of the Wellington region, being largely made of separate catchments along corridors bounded by hills and water. The resulting catchments are shown in the following figures. No car access to rail trip leg can occur across a catchment boundary.

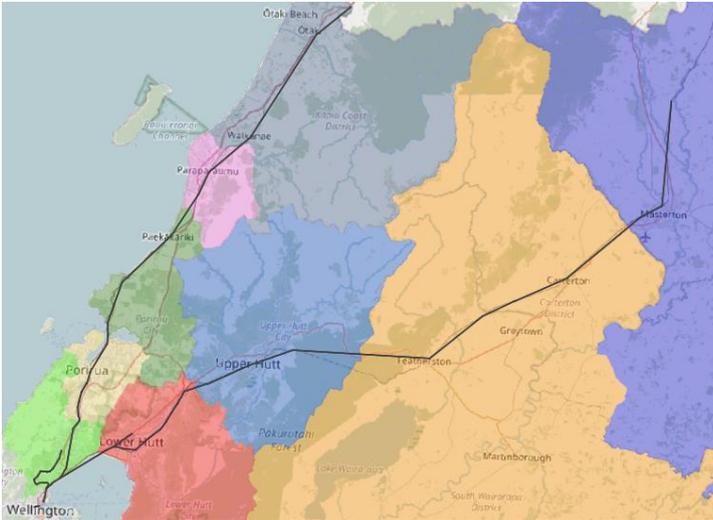


Figure 4-1: Rail car access catchments

4.2.3 Implementation in WTSM

The various costs and perception factors for car access / egress to PT are implemented as follows:

- Car travel times from the road assignment are saved in **@timau** (link attribute), with perception factors set in the **PT Assignment** Flow (respectively **car_pr_perception** and **car_kr_perception**).
- Car fixed costs in generalised minutes are also calculated as part of the road assignment and saved in **@fcost_lv** (link attribute). Car occupancy to convert vehicle costs to person costs are set in the **PT Assignment** Flow (respectively **occ_pr** and **occ_kr**).
- The resulting auxiliary generalised costs are saved in ul1 and ul2 as follows:
 - $ul1 = (@timau * car_pr_perception) + (@fcost_lv / occ_pr)$
 - $ul2 = (@timau * car_kr_perception) + (@fcost_lv / occ_kr)$

ul1 and ul2 are calculated prior to the assignment and used as speed for modes 'p' and 'k'. This is due to the same EMME limitation as for walk access, in order to be able to apply perception factors that are different for each auxiliary mode. Note that in this case the "speed" for these modes is really the link generalised cost.

- Time penalty at station is set in the **Initialize PT Assignment** Flow, respectively in **station_time_pr** and **station_time_kr**.
- Any optional parking charge (in \$) must be applied through the link attribute **@pr_charge**.
- The additional generalised costs associated with using park-and-ride and kiss-and-ride are then stored in a link extra attributes and calculated as follows:
 - $@pr_cost = station_time_pr + @pr_charge / VoT * 60 / 2$
 - $@kr_cost = station_time_kr$

Catchments are modelled through the link attributes **@banpnr**, which is set to 0 by default but 1 for links crossing catchments boundaries. As a result, access modes 'p' and 'k' are not added to these flagged links prior to the PT assignment, disabling car access to rail.

4.3 Waiting times

4.3.1 Effective headway calculations

Effective waiting times are calculated based on the headway (times between services) for each line. The formulation applying to most services is the same one used in the WTPM and is as follows:

- For services with headway \leq 15 minutes:
wait time = $0.5 * \text{headway}$
- For services with headway $>$ 15 minutes:
wait time = $7.5 + 0.22 * (\text{headway} - 15)$

This difference in calculations is to represent the fact that users are more likely to arrive randomly and experience the mean wait time for frequent services, but will time their arrival to minimize wait for services with longer headways.

Using this formulation however was found to lead to car access to rail being too sensitive to wait time, e.g. users would be too likely to drive to a more distant station to use a service with a marginally higher frequencies. Therefore for park-and-ride and kiss-and-ride segments in the AM and IP period (i.e. in the access to PT direction), a revised effective headway was calculated applying only to rail (but not to any subsequent transfer to other modes):

- For services with headway \leq 12 minutes:
wait time = $0.25 * \text{headway}$
- For services with headway $>$ 12 minutes:
wait time = $3 + 0.11 * (\text{headway} - 12)$

A perception factor of 2 is applied to waiting times to represent the perceived inconvenience of waiting for a service, consistent with WPTM. In addition, a factor per mode is also applied to reflect other modal differences, especially reliability. This factor was set to the following values:

- Rail, ferry, cable car: 0.8
- Bus: 1
- MRT, alternate modes x and y: 0.9 (not used in base year)

4.3.2 Implementation in WTSM

Headway calculations are implemented as follows:

- For 'bus', 'rail other' and in the AM and IP periods for 'rail pnr' and 'rail knr', the effective headway is stored in the transit line attribute **@effhdwy** using the default calculations detailed above.
- For 'rail pnr' and 'rail knr' in the PM and IP periods (egress direction), headways are stored in **@effhdwy2**, and are calculated using the alternative formulation with reduced waiting times for rail, but the default formulation for other modes.
- The perception factor on waiting times is set in the **PT assignment** Flow (**wait_perception**) as are the modal factors (**hdwfact_permode**).

4.4 Boarding times and penalties

4.4.1 Boarding times calculations

Boarding times and penalties are a combination of node and line values, in order to represent various penalties per modes and facility types. Values used are consistent with times and penalties used in the WPTM. The values used are shown in the following table.

Table 4-1: In-vehicle times perception factors

Mode	Node boarding time	Line boarding time
Rail	1.5	1
Ferry	1.5	1
Bus	2.5	3
MRT / All modes x & y	2.5	1.5

As a result, a PT user boarding a regular bus would experience a boarding penalty of $2.5 + 3 = 5.5$ minutes.

These values can be adjusted for specific nodes in forecasting, for example to represent improved facilities at dedicated interchanges.

Finally a transfer penalty of 10 minutes applies for any transfer between services of any modes, to represent the perceived inconvenience of transferring, consistent with WPTM. The modelled share of bus to bus transfers compared with total bus boardings was checked against the ETM. However no information was available regarding observed transfers between bus and rail. The comparison for bus to bus only is shown in the following table.

Table 4-2: Bus to bus transfers as percentage of total bus boardings

Period	ETM	Model
AM	5.5%	6.4%
IP	7.4%	6.5%
PM	7%	6.4%
ON	6.5%	5.3%

4.4.2 Implementation in WTSM

Boarding times and penalties are all set in the **Initialize PT Assignment** Flow as follows:

- Node boarding times are set using the Flow attribute **board_rail_node** and **board_bus_node**, with the values then applied to the node extra attribute **@boardn**.
- Boarding times per line are set using the Flow attribute **board_line_permode**, with the value then applied to the transit line extra attribute **@boardl**.
- Transfer penalties are set using the Flow attribute **transfer_pen**, with the value then applied to the node attribute **@transferpen**.
- Node boarding and transfer penalties are finally added in a node attribute **@brdtrans**.

4.5 In-vehicle travel times

4.5.1 Bus travel times

The calculations for bus travel times function parameters are shown in section 3.5.

The bus travel times are recalculated within each model loop after the road assignment based on updated car travel times, and are stored for each segment in the segment user attribute **us2**.

For dwell times an initial fixed value of 5 seconds per stops is used for initialisation, with times then also recalculated for each model loop based on boardings and alightings.

4.5.2 Rail and ferry travel times

Travel times for rail (including the cable car) and ferry are not impacted by traffic congestion and are therefore fully based on timetables, with no travel time or dwell time calculations. Timetable-based travel times are stored in the segment user attribute **us1**.

4.5.3 In-vehicle time perception factors

Perception factors are applied to the time spent travelling in-vehicle, to reflect the level of comfort of each mode. The values used are the same ones used in the WPTM for consistency, as shown in the following table, and are applied by line.

Table 4-3: In-vehicle times perception factors

Mode	IVT Factor
Bus	1
Rail	0.88
Ferry	0.5
MRT / New modes x & y	0.9

In addition, perception factors are also applied to links, to reflect varying levels of comfort due to the quality of infrastructure, or PT vehicles travelling separated from traffic on different sections of a route. These factors can be applied separately for bus and for future modes (MRT, new modes x and y). They are all set to 1 in the base year, but can be changed in forecasting. These do not apply to rail and ferry which run separated from traffic and are more consistent along the whole route.

The resulting in-vehicle perception factor for each segment of a route is therefore the product of the line and link perception factors for modes b, m, x and y.

4.5.4 Implementation in WTSM

Parameters used for bus travel time calculations are all set in the Initialize PT Assignment Flow. The values shown in Table 3-5 have been calibrated against observed travel times and are therefore unlikely to be adjusted when running the model. They are however set as follows:

- Time factor on car travel times – standard link: **time_std_perperiod**
- Time factor on car travel times – bus lanes link: **time_busl_perperiod**
- Time factor on car travel times – bus only link: **time_seg_perperiod**
- Time factor on car turning travel times – bus lanes link: **ptime_busl_perperiod** (1 for non-bus lane links)
- Constant time per bus stop for respectively the Wellington CBD, rest of Wellington and rest of region: **stp_cnst_perperiod_cbd**, **stp_cnst_perperiod**, **stp_cnst_perperiod_region**
- Per boarding / alighting dwell time per bus stop: **dwl_perperiod**, with maximum dwell set in **dwl_max**.

The resulting time factors on car travel time are then stored for each link and turn respectively in the @ptspeed and @ptturn segment attributes, and the additional constant time per stop is stored in @stpcnst.

Calculated dwell times based on the number of boardings / alightings are stored in the EMME standard dwt segment attribute.

The EMME transit time function **ft1** is used for bus travel times, set to be equal to segment user attribute **us2**, calculated as follows:

$$ft1 = us2 = (@ptspeed * @timau) + (@ptturn * @pttimau) + @stpcnst$$
 (where @timau is the traffic link time and @pttimau is the traffic turning time)

For links with bus lanes, the turning delay component (@ptturn * @pttimau) is capped to 1 minute.

For bus only links which do not have any traffic, the formulation is as follows:

$$ft1 = us2 = (@ptspeed * length/@v0*60) + @stpcnst$$
 (where @v0 is the free flow speed)

The transit time function **ft11** is used for rail and ferry and is set to be equal to segment user attribute **us1**:

$$ft11 = us1$$
 where us1 is the travel time based on timetable

For in-vehicle time, perception factors are represented in WTSM through the following attributes:

- **@mivt (line attribute):** modal in-vehicle time perception factor
- **@livt_b (and @livt_m, @livt_x, @livt_y, link attributes):** link perception factor, 1 by default.

- **@sivt (segment attribute):** segment in-vehicle time perception factor. Equal to @mivt for rail and ferry. Equal to @mivt * @livt_b for bus.

The modal in-vehicle perception factors (saved in **@mivt**) are an input into the PT assignment (set in the **Initialise PT assignment** Flow). The link perception factors (**@livt_b**, etc.) must be coded manually in the network if different from the default value of 1.

4.6 Fare

4.6.1 Fare values

PT fares are applied both per boarding and per zone crossing, to reflect the 2018 Metlink fare structure. The calculations for these fares is detailed in Section 2.4 of "TN22 – Model input parameters".

While some of the fare products and their related discounts vary between rail and buses, the zones themselves and base fares by zones travelled are identical for both modes. The average fare per zone travelled was calculated for each fare product, weighted using the number of fare zones travelled from electronic ticketing machine (ETM) and rail ticketing data, separately per passenger type (adult or child), mode (bus or rail) and time period, resulting in different average boarding and per zone fares for each time period as detailed in TN22. These are shown in the following table.

Table 4-4: PT fares (2018\$)

Period	Boarding	Per zone crossing
AM	1.53	0.79
IP	1.1	0.58
PM	1.61	0.83
ON	1.54	0.87

Additional fares apply to specific modes and services:

- Cable car: +\$3.5
- Ferry: +\$8.7
- Flyer bus (airport services): +\$8.4

All fares are then converted into generalised minutes using the average value of time detailed in TN22. For the base year 2018, a value of \$11.6 per hour is used,

4.6.2 Integrated ticketing

In March 2018, integrated ticketing was applying for transfers between buses (with the boarding fare not applying for transfers between buses) but not between bus and rail due to different ticketing systems. To represent this, and provide the functionality to apply integrated ticketing or different transfer fares for all modes, two additional parameters are used:

- A "fare from bus" line attribute (**@farefrombus**), set to 0 for bus services (including potential MRT and alternative modes if forecasting) and to the global boarding fare for rail (and cable car and ferry)
- A "fare from rail" line attribute (**@farefromrail**) set to 0 for rail and to the global boarding fare for bus.

Either or both of these attributes can then be set to 0 in forecasting to represent free transfer from one mode to another.

4.6.3 Implementation in WTSM

Fares are represented in WTSM through the following attributes:

- **@fare_board** (node attribute): boarding fare, global value set to all nodes in the network for each time period.
- **@fare_zone** (link attribute): fare zone crossing cost. It is calculated as the fare crossing per zone multiplied by the link attribute **@fzbdx** which represents the number of fare zones boundaries

crossed by a link (0 for most, 1 for links that cross a fare boundary, with a few links crossing more zone one boundaries).

- **@fare_mode** (line attribute): additional cost for cable car, ferry, and Flyer bus services
- **@farefromrail** (transit line attribute): equal to **@fare_board** but only for bus services (incl. MRT and alt modes x and y). To be set to 0 for free transfers from rail to bus.
- **@farefrombus** (transit line attribute): equal to **@fare_board** but only for rail (incl. ferry and cable car). To be set to 0 for free transfer from bus to rail.

All the fare values stored in these attributes are an input into the PT assignment (set in the **Initialise PT assignment** Flow).

The extra attributes **@farefrombus** and **@farefromrail** used to represent intermodal boarding costs can be set to 0 by setting the Boolean parameter **integrated_ticketing** to True.

5. Journey Levels

5.1 Definitions

Journey levels are a new functionality in EMME that enables specifying different generalised costs for PT users depending on the particular sequence of transit and auxiliary modes used along their journeys, as well as enforcing specific mode sequences and transitions.

In the new WTSM, these were specifically used to represent car access to rail, as well as varying boarding time, penalties and fares depending on the type of boarding (e.g. initial vs transfers to represent integrated ticketing).

Five different PT classes are assigned separately with their own journey levels specification, as detailed in this section.

The following observations apply to this section:

- Modes bus, MRT and new modes x and y (b, m, x and y) have been grouped together for clarity and are only referred to as 'bus'. Again, modes m, x and y do not exist in the base network but can be used in forecasting, and potentially changed to be grouped with rail if deemed more appropriate.
- Similarly, ferry has been grouped with rail for clarity.
- Transition rules show how changes of level occur, depending on the next mode being boarded (Refer to the EMME help in the Extended Transit Assignment section for more explanation on Journey Levels.)
- Destination reachable means if the destination of the trip can be reached while at the current level. For all demand class, at least one PT mode has to be boarded which bans trips using auxiliary mode such as walk only.
- Boarding times and costs are shown for each level. 'Global' means that the overall time and costs are used as defined in sections 4.4 and 4.6.

5.2 Bus

This class applies to the 'bus' demand segment (bus only) and includes two levels:

- 0 – not boarded: applies to PT users walking to their first bus boarding stop
- 1 – boarded bus: applies to PT users who have boarded at least one bus.

Table 5-1: Journey levels - bus

Lvl	Name	Transition rules		Boarding times		Boarding costs		Destination reachable
		w	b/m/x/y	Nodes	Segments	Lines	Segments	
0	Not boarded	0	1	<i>global:</i> <i>@boardn</i>	<i>global:</i> <i>@boardl</i>	<i>global:</i> -	<i>global:</i> <i>@fare_board</i> + <i>@fare_mode</i>	No
1	Boarded bus	1	1	<i>@brdtrans</i>	<i>@boardl</i>	-	<i>@fare_mode</i>	Yes

Notes:

- Only the boarding time applies for initial boarding, whereas the transfer penalty is added for additional boardings if already at level 1
- For boarding costs, the fare boarding *@fare_board* only applies for initial boarding and not once at level 1, as integrated ticketing applies.

Other parameters

- Effective headway: **@effhdwy**
- Resulting auxiliary volumes for walk (w) are saved in **@auxbus**

5.3 Rail other segment

This applies to the 'rail other' demand segment (rail and optionally bus, walk access) and includes four levels:

- 0 – not boarded: applies to PT users walking to their first boarding stop or station.
- 1 – boarded bus: applies to PT users who have boarded at least one bus but no train.
- 2 – boarded rail: applies to PT users who have boarded at least one train but no bus.
- 3 – boarded both: applies to PT users who have boarded at least one train and one bus.

Table 5-2: Journey levels – rail other

Lvl	Name	Transition rules			Boarding times		Boarding costs		Destination reachable
		w	b/m/x/y	r/f	Nodes	Lines	Lines	Segments	
0	Not boarded	0	1	2	<i>global:</i> <i>@boardn</i>	<i>global:</i> <i>@boardl</i>	<i>global:</i> -	<i>global:</i> <i>@fare_board</i> + <i>@fare_mode</i>	No
1	Boarded bus	1	1	3	<i>@brdtrans</i>	<i>@boardl</i>	<i>@farefrombus</i>	<i>@fare_mode</i>	No
2	Boarded rail / ferry	2	3	2	<i>@brdtrans</i>	<i>@boardl</i>	<i>@farefromrail</i>	<i>@fare_mode</i>	Yes
3	Boarded both	3	3	3	<i>@brdtrans</i>	<i>@boardl</i>	-	<i>@fare_mode</i>	Yes

Notes:

@farefrombus and *@farefrom rail* are used to represent intermodal boarding fare, and can be set to 0 if integrated ticketing applies.

Other parameters:

- Effective headway: **@effhdwy**
- Resulting auxiliary volumes for walk (w) are saved in **@auxrailot**

5.4 Rail park-and-ride and kiss-and-ride access segments – AM and IP periods

This applies to both the 'rail park-and-ride' and 'rail kiss-and-ride' demand segments but only for the car access to PT direction, in the AM and IP periods, and includes four levels:

- 0 – Drive access: applies to PT users driving or being driven (respectively mode p or k) to their first boarding stop or station.

- 1 – Parked: applies to PT users who have reached the station and have switched to mode s to access it.
- 2 – boarded rail: applies to PT users who have boarded at least one train. Note that at this level additional train or bus services can be boarded.
- 3 – banned sequence: used to ban specific sequences of modes as it is not destination reachable.

Table 5-3: Journey levels – rail car access (AM and IP)

Lvl	Name	Transition rules					Boarding times		Boarding costs		Destination reachable
		w	s	p/k	b/m/x/y	r/f	Nodes	Lines	Lines	Segments	
0	Drive access	3	1	0	3	3	-	-	-	-	No
1	Parked	3	1	3	2	2	global: @boardn	global: @boardl	global: -	global: @fare_board + @fare_mode	No
2	Boarded rail / ferry	2	3	2	2	2	@ brdtrans	@boardl	@farefromrail	@fare_mode	Yes
3	Banned	3	3	3	3	3					No

Other parameters:

- Effective headway: **@effhdwy2**
- Resulting auxiliary volumes are saved in:
 - walk (w): **@auxrailot**
 - station (s): **@auxrailpr_s / @auxrailkr_s**
 - car access (p/k): **@auxrailpr_cr / @auxrailkr_cr**

5.5 Rail park-and-ride and kiss-and-ride egress segments – PM and ON periods

This applies to both the 'rail park-and-ride' and 'rail kiss-and-ride' demand segments but only for the car egress from PT direction, in the PM and ON periods, and includes five levels:

- 0 – Walk: applies to PT users walking from their origin to their first boarding stop or station.
- 1 – Boarded bus: applies to PT users who have boarded at least one bus. This is optional, used for passengers transferring from bus to rail.
- 2 – boarded rail: applies to PT users who have boarded at least one train.
- 3 – recovered car: applies to PT users who have picked up their car from the rail station parking (park-and-ride) or been picked up (kiss-and-ride) having gone through the 's' mode station access link.
- 4 – banned sequence: used to ban specific sequences of modes as it is not destination reachable.

Table 5-4: Journey levels – rail car egress (PM and ON)

Lvl	Name	Transition rules					Boarding times		Boarding costs		Destination reachable
		w	s	p/k	b/m/x/y	r/f	Nodes	Lines	Lines	Segments	
0	Walk	0	4	4	1	2	global: @boardn	global: @boardl	global: -	global: @fare_board + @fare_mode	No
1	Boarded bus	1	4	4	1	2	@ brdtrans	@boardl	@farefrombus	@fare_mode	No

Lvl	Name	Transition rules					Boarding times		Boarding costs		Destination reachable
2	Boarded rail / ferry	4	3	4	4	2	@ brdtrans	@boardl	@farefromrail	@fare_mode	No
3	Recovered car	4	3	3	4	4	-	-	-	-	Yes
4	Banned	4	4	4	4	4	-	-	-	-	No

Other parameters:

- Effective headway: **@effhdwy**
- Resulting auxiliary volumes are saved in:
 - walk (w): **@auxrailot**
 - station (s): **@auxrailpr_s / @auxrailkr_s**
 - car access (p/k): **@auxrailpr_cr / @auxrailkr_cr**

5.6 Airport-related demand

This demand segment is used exclusively to assign flight-related public transport demand from and to Wellington airport, with the demand matrices being generated by the dedicated airport model.

It is identical to 'Rail other' with the only exception being that Level 1 (Board bus) is destination reachable. As a result passengers can reach their destination boarding buses, trains or a combination of both.

6. Public Transport Crowded Assignment

6.1 Definition

A significant added functionality for the new WTSM is the addition of the representation of public transport crowding, to account for the impact of capacity constraints on destination, mode, and route choice, and to reflect the benefits from higher frequencies or new vehicles and modes with higher capacity.

This functionality is optional and the model can run both a standard or crowded assignment (also called congested assignment in the Emme software).

6.2 Vehicle types and capacities

For a PT crowded assignment, it is necessary to know the capacity of PT vehicles as defined in the model, including both seating and total (i.e. seating plus standing).

However, many PT routes use a mixture of vehicles during each time period, for example some bus routes in Wellington use both standard and double decker buses, or some rail services may use a variable number of cars.

As only a single vehicle type can be allocated to a particular service in EMME, and to limit the number of vehicles being used and resulting complexity in the assignment, a number of "virtual" vehicle classes were created to aggregate the various mixes of real vehicles used into capacity bands.

Information on vehicle types and capacities was sourced from Metlink, which fed into the assumptions used to define these modelled vehicle classes.

6.2.1 Buses

A dataset showing the vehicle type and total and seating capacities for every single scheduled trip throughout an average weekday was provided by Metlink. From this, the average capacities per bus service were calculated, for each time period.

Four bands were defined, with each band including all services below a certain total capacity threshold. These thresholds were defined manually, aiming to break down services into logical categories and taking into account level of service standards and typical loads provided by Metlink.

For each band the average seated and total capacities were calculated, which are shown in the following table:

Table 6-1: Bus vehicle capacity bands

Vehicle class	Average seating cap	Average total cap
Small	30	50
Medium	40	60
Mixed	60	80
Double Decker	80	95

It can be observed that this breakdown replicates well the observed tendency for higher capacity vehicles (mostly double-deckers) to have mostly seated capacity compared with smaller vehicles.

Every bus service was finally allocated a vehicle class based on its average total capacity. The figure shows the resulting number of services per vehicle class.

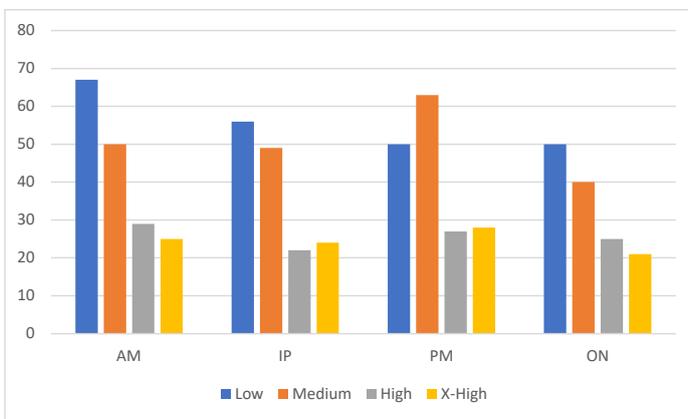


Figure 6-1: Number of bus services per vehicle class

The figures below show the total capacities provided per vehicle class in the AM peak, including the class vehicle capacity and service frequencies.

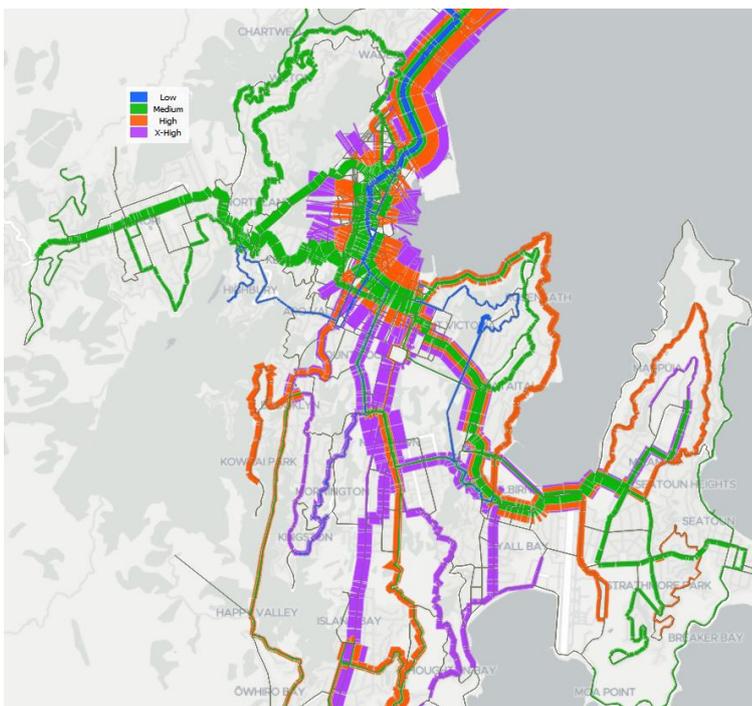


Figure 6-2: AM peak capacities per bus vehicle class – Wellington

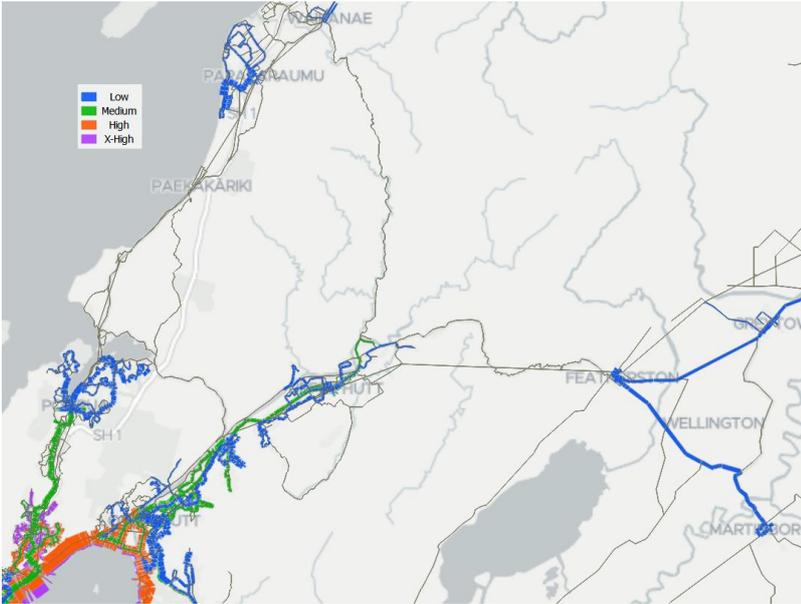


Figure 6-3: AM peak capacities per bus vehicle class – Rest of region

6.2.2 Rail

A similar approach was used for rail, based on the average number of cars per service and capacities per car information provided by Metlink.

Only two vehicle classes were defined due to the lower variations in rail capacities compared with bus, as shown in the following table.

Table 6-2: Rail vehicle capacity bands

Vehicle class	Max total threshold	Average seating cap	Average total cap
Medium	450	310	400
High	-	420	630

The resulting total capacities provided per vehicle class in the AM peak are shown in the following figure.

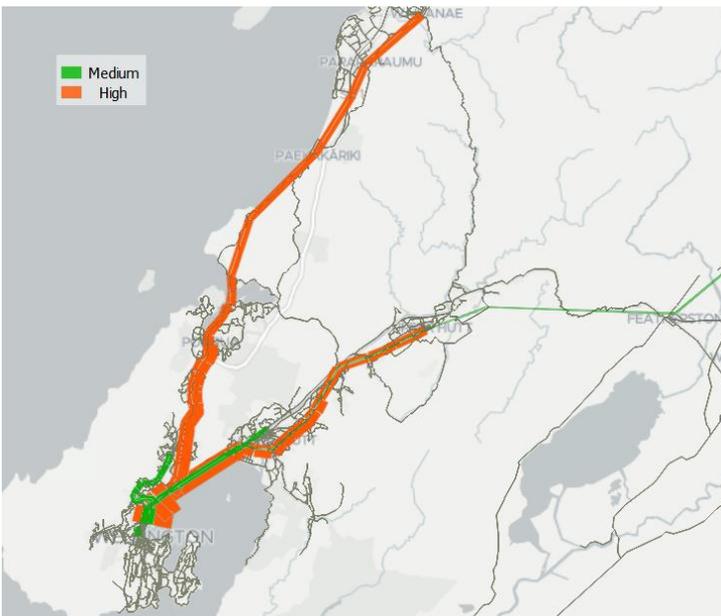


Figure 6-4: AM peak capacities per rail vehicle class – Rest of region

6.2.3 Other modes

Ferry capacity has been set to 99 total and seated, the capacity of East by West diesel ferries in March 2018, assuming that all passengers can be seated.

Some capacities for MRT and alternative modes x and y have been entered (see Table 3-2) but these modes are not used in the base scenario. It is the responsibility of the model users to ensure capacities for these modes are consistent with assumptions when using the model for forecasting new modes.

6.3 Crowding function

6.3.1 Comparison of functions

A review of a range of models using PT crowded assignment was carried out, looking at other models in New Zealand (Auckland MSM and MPT), Australia (including Sydney ETCM, Melbourne VITM) and the UK and Ireland (Kent Strategic Model, Ireland East Regional Model, PLANET Framework Model). This review can be found in a separate note ('Wellington Analytical Tools 2019-21 Update - PT Crowding').

Every model reviewed used crowding functions to adjust perceived in-vehicle times using a factor to represent discomfort and capacity constraints in crowded conditions. The factors are calculated using functions which are related to either the total or sometimes the seated and standing capacities of the vehicles, the demand, and an assumption about the relationship between in-vehicle crowding and levels of discomfort. Factors on in-vehicle times are generally 1 until the demand approaches capacity, and then increase together with demand. The application of this crowding factor increases the perceived in-vehicle time which may cause users to shift to other routes, other modes of PT, or potentially other modes or destination altogether.

Three main functions were found to be in use in most models.

BPR function

the congested term is calculated as:

$$\alpha * (V/C)^\beta$$

where α is the weight of the congestion term, β is the exponent, V is the volume and C is the capacity.

Conical function

The congestion terms is calculated as:

$$1 + \sqrt{\beta^2(1 - (v/c))^2 + \gamma^2} - \beta(1 - (v/c)) - \gamma$$

where $\gamma = (2\beta - 1) / (2\beta - 2)$; the β parameter plays the same role as the exponent in the BPR function.

Capacity ratio and piecewise function (MPT model)

This is the approach used in the Auckland Public Transport model (MPT), adapted from the Sydney and Brisbane models. Crowding functions are based on a capacity ratio – a vehicle-specific ratio of the number of passengers to the number of seats and the total capacity. The capacity ratio is calculated as:

$$CR = 1 + (V - C_s) / C_t$$

where V is passenger volume, C_s is seated capacity and C_t is total capacity.

The function applied to the capacity ratio then takes a piecewise form, increasing slowly or not at all until the seated capacity is reached, and increasing more quickly afterward.

In MPT, the crowding function is as follows, where CF is the crowding factor and CR is the capacity ratio:

- CF = 1.0 if $CR \leq 0.8$ [most seats taken]
- CF = $1 + (0.07/0.2) * (CR - 0.8)$ if $0.8 < CR \leq 1.0$ [1 means all seats taken]
- CF = $1.07 + 1.8 * (CR - 1)$ if $CR > 1.0$

Comparison of functions

The following figures show the profile of all three functions for a vehicle with 40 seating capacity and 60 total. Standard values were used for the conical and BPR functions (0.3 for weight and 6 for exponent) and while the profile would change with different values this comparison provides an indication of the general shape of each curve.

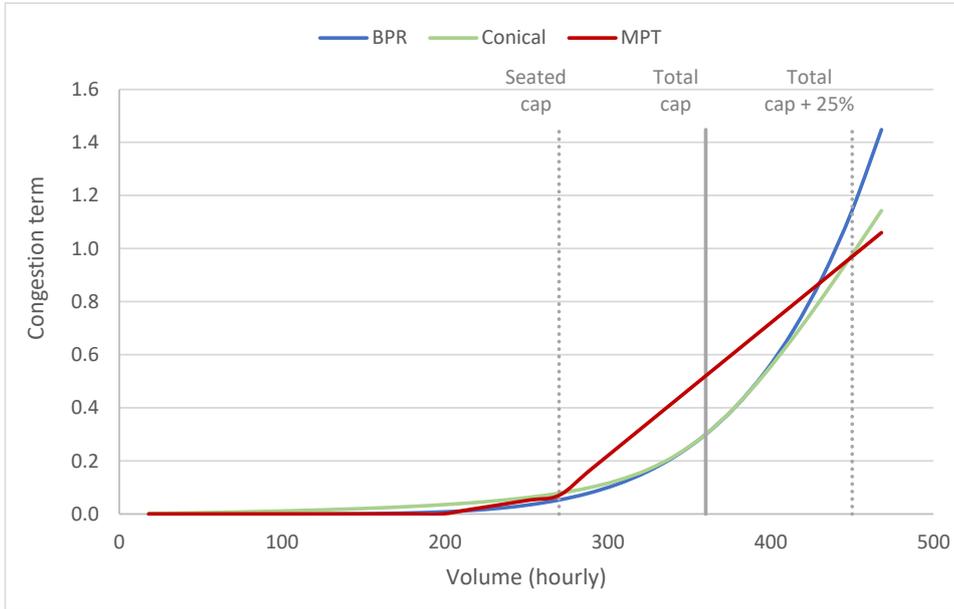


Figure 6-5: Comparison of crowding functions

Both BPR and conical functions only use total capacity and do not explicitly account for discomfort due to standing once seating capacity has been reached. They will also not account for changes in seating capacity if total stays the same. On the opposite, the piecewise function used in MPT does account for it through the use of capacity ratio, however the crowding term rises very quickly once seated capacity is reached. This could be an issue for PT modes that have less seating and more standing capacity, such as most modern light rail vehicles as it would make these modes less attractive.

A modified BPR function was tested which uses the capacity ratio from the piecewise function instead of vehicle total capacity:

$$\alpha * (CR)^\beta$$

This function would allow accounting for both total and seated capacity, while being more gradual than the piecewise function. Comparison between the BPR including capacity ratio, regular BPR and the piecewise function are shown in the following figure, using the same parameters as previously for the last two. For the BPR including capacity ratio, initial values of 0.08 for weight and 6 for exponent were used.

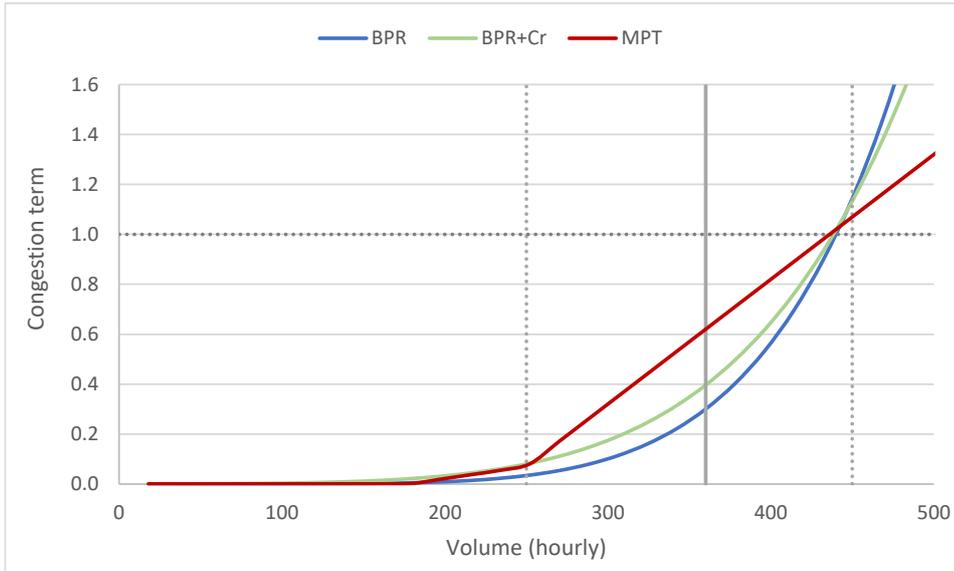


Figure 6-6: Comparison of crowding functions

This function was adopted for the PT congested assignment.

6.3.2 Single hour assignment versus time period demand

Public transport demand during the AM and PM periods (respectively 6-9am and 3-6pm) is mostly concentrated during a single hour, with between about 40% and 55% of demand occurring during the “peak of the peak” hour. As a result, representing the average 3hr demand over 3hr capacities would result in lower crowding discomfort than actually experienced by most PT users during these periods, as well as an underestimation of potential capacity issues.

Running PT assignment for both the peak hour and shoulder periods of the AM and PM periods was considered but was deemed too onerous in terms of added complexity and runtimes. Equally, the option of running the PT assignment for the peak hour only was discarded for two reasons:

- None of the validation data covered a single 1hr period.
- Volumes and other results for the whole period would not be available for analysis and output.

The adopted approach was instead to run the crowded PT assignment with the whole 3hrs period demand, but adjust the capacity and not the demand. Practically, this involves using the period to hour factors not to multiply demand, but instead to divide total capacity for a service (total capacity being equal to vehicle capacity * hourly number of vehicle trips), the end result being mathematically identical.

More details on these conversion factors and how they were calculated are provided in ‘TN21 – Peak periods and vehicle occupancy’, and they are shown in the following table.

Table 6-3: 3-hour period to peak 1-hour factors

Services	AM	PM
Wellington bus	0.55	0.47
Hutt Valley and Wairarapa bus	0.51	0.42
Porirua and Kapiti bus	0.5	0.49
Wellington rail (Johnsonville line)	0.49	0.47
Hutt Valley and Wairarapa rail	0.56	0.41
Porirua and Kapiti rail	0.53	0.4

These factors were allocated to each PT transit line depending on mode and sector covered (most PT services in Wellington start or end in the Wellington CBD, in which case the non-CBD end is used to determine the sector).

6.3.3 Final function form

Following testing, the function used in the PT congested assignment is the BPR function modified to use the capacity ratio (CR) shown in section 6.3.1, with the following parameters:

- α (weight): 0.08
- β (exponent): 8

However for the AM and PM periods two capacity ratio CR were calculated, one for the peak hour and one for the whole period:

$$C_{t_{hour}} = \text{vehicle total capacity} * (\text{peak hour frequency}) / \text{peak factor}$$

$$C_{S_{hour}} = \text{vehicle seated capacity} * (\text{peak hour frequency}) / \text{peak factor}$$

$$CR_{hour} = 1 + (V - C_{S_{hour}}) / C_{t_{hour}}$$

and

$$C_{t_{period}} = \text{vehicle total capacity} * (\text{period frequency})$$

$$C_{S_{period}} = \text{vehicle seated capacity} * (\text{period frequency})$$

$$CR_{period} = 1 + (V - C_{S_{period}}) / C_{t_{period}}$$

The resulting congestion term is based on the weighted average of the two and is calculated as follows:

$$\alpha * (CR_{hour} * \text{peak factor} + CR_{period} * (1 - \text{peak factor}))^\beta$$

The standard BPR function is however also included in the model and can be used for modes for which a lower penalty should be applied to passengers having to stand if only limited seating capacity is provided, for example modern LRT vehicles:

$$\alpha * (V / (C_{t_{hour}} * \text{peak factor} + V / C_{t_{period}} * (1 - \text{peak factor})))^\beta$$

For IP and ON periods, both volumes and capacities for the whole period are used and the standard BPR function with capacity ratio apply:

$$\alpha * (CR)^\beta$$

6.4 Crowded PT assignment tests

6.4.1 2033 Land use

As the base demand did not show significant congestion on the PT network, a first test was carried out running the model with a 2033 forecasted landuse, including an overall 19% assumed growth in population, employment and education rolls compared with the base year 2018. No other changes were made in terms of network and input parameters. This scenario was run both with and without crowded assignment to enable comparisons.

The number of iterations for the crowded PT assignment to reach convergence varied from 11 in the AM peak to 2 in the ON period. The main WTSM demand loop (including trip distribution, mode choice and road and PT assignments) converged in 6 iterations, the same as for the scenario without crowding.

The following figure shows the resulting number of transit line segments and total network length by vehicle/capacity bands for both assignments (all results in this section are shown for the AM peak as it is the period with the highest congestion). Results show a clear reduction in segments over capacity, with no segments higher than 25% over capacity in the crowded assignment.

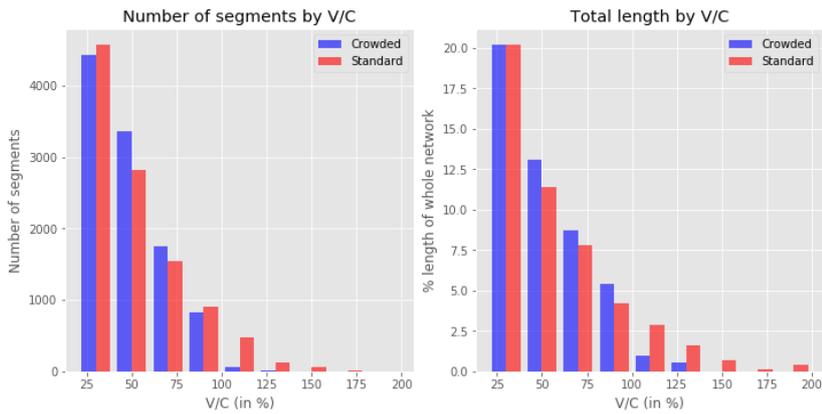


Figure 6-7: AM peak V/C by number of segments and length – 2033 Test

Example of loading profiles for three services that are congested in the standard assignment are shown in the following figure. The level of response varies by services, depending on availability of alternatives.

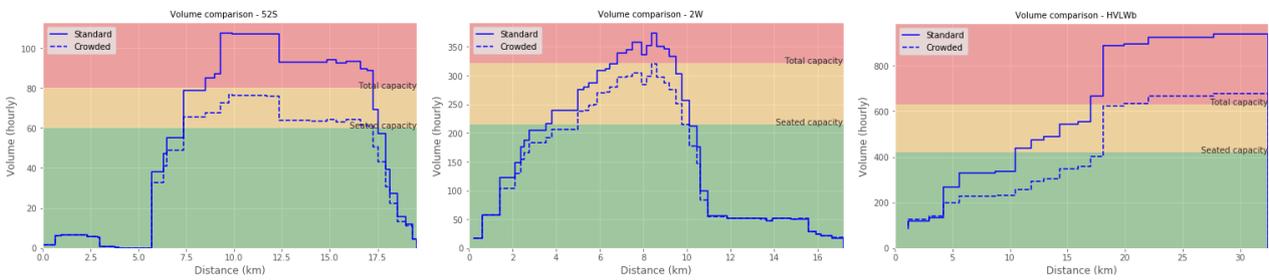


Figure 6-8: AM peak loading profiles – 2033 test

The following figures show the overall volume/capacity ratio on network links, calculated as the average V/C of all segments on a link, weighted by demand per segment. Results are shown for the scenarios with standard and crowded PT assignments.

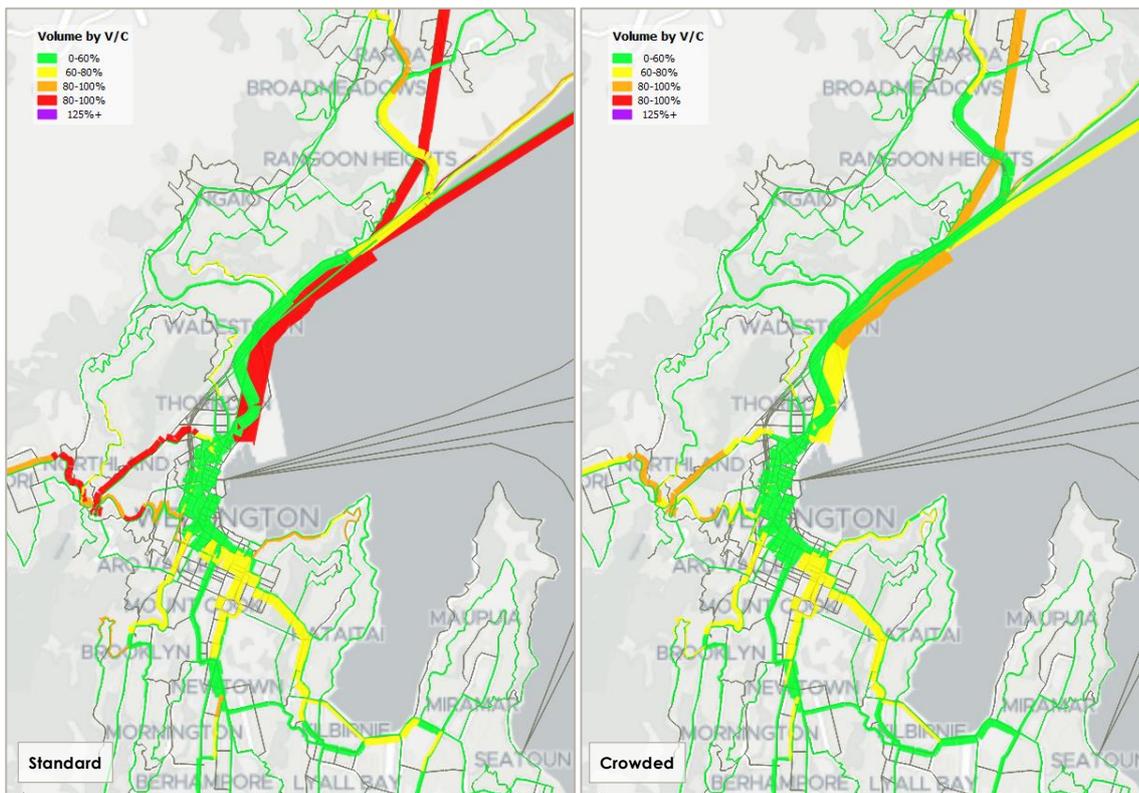


Figure 6-9: AM peak weighted average V/C – 2033 Test

As can be seen the PT crowded assignment leads to a clear reduction in crowding on the network. Finally the impact on mode share is shown in the following table.

Table 6-4: Total daily mode share – 2033 test

Mode	Standard	Crowded	% Difference
Light vehicles	1,869,821	1,871,109	0.1%
Bus	96,945	95,713	-1.3%
Rail	61,467	60,901	-0.9%
Active modes	443,409	443,921	0.1%

The crowded assignment leads to a slight reduction in PT mode share, and corresponding increase for light vehicles and active modes. The reduction is modest however, showing that most of the decrease in congestion occurs during the assignment, caused by a more realistic allocation of demand between services running on the same corridors.

6.4.2 2053 Land use

A further test was run this time with a 2053 land use forecast, with an assumed 41% growth in regional population. Again, no other changes were made in terms of network capacity for both road and public transport, or input parameters. This scenario was run for model testing purpose and to understand how the model would respond in a worst-case scenario with demand likely to significantly exceed capacity, and is not considered a realistic forecast.

In this case, the number of iterations for the crowded assignment to reach convergence reached 30 in the AM peak and 11 in the PM peak. The main WTSM demand loop itself converged in 8 iterations with a standard assignment, but 12 iterations with the crowded assignment, resulting in longer run times.

The following figure shows the resulting number of transit line segments and total network length by vehicle/capacity bands for both assignments. Again the number of segments over capacity reduces, but portions of the network stay overloaded.

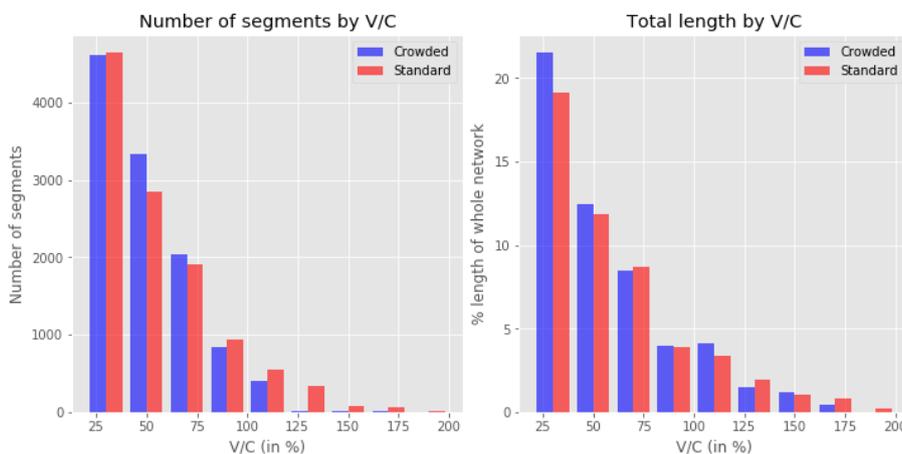


Figure 6-10: AM peak V/C by number of segments and length – 2053 Test

Example of loading profiles for three services that are congested in the standard assignment are shown in the following figure. It can be observed that some services were significantly above capacity with a standard assignment and this is considerably reduced with the crowding function applied.



Figure 6-11: AM peak loading profiles – 2053 test

The following figures show the overall volume/capacity ratio on network links.

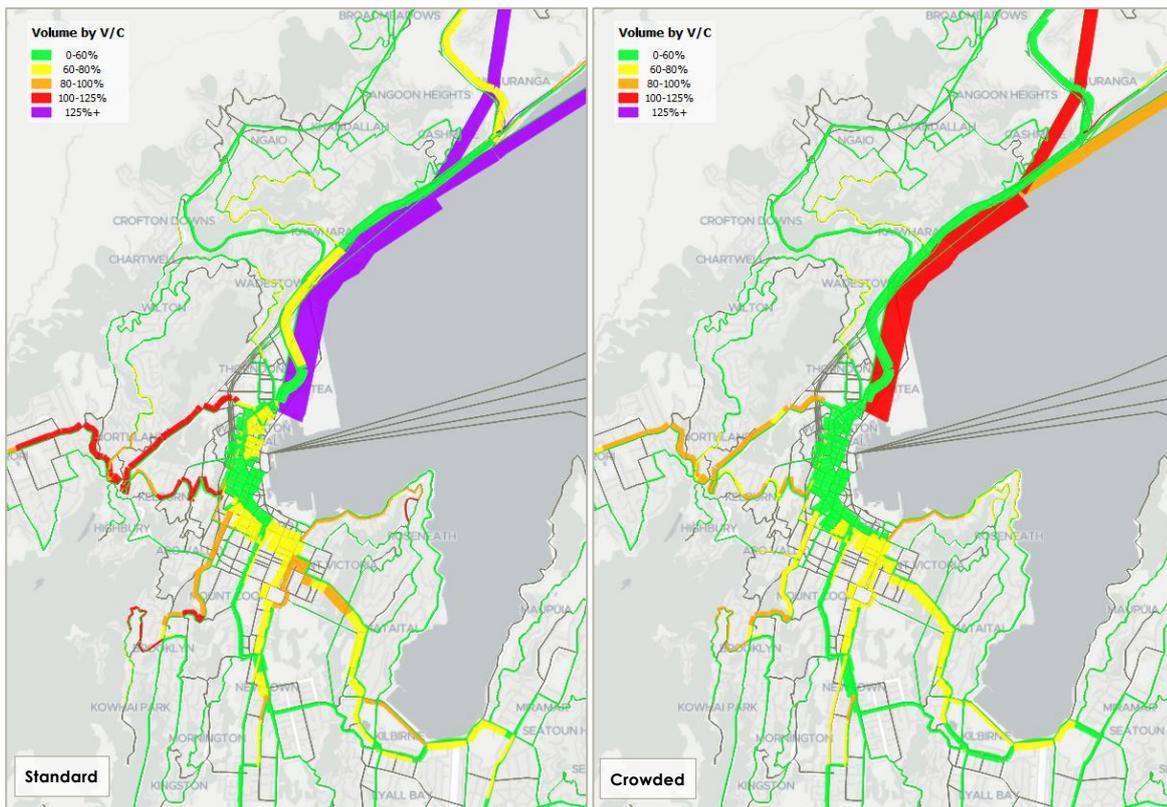


Figure 6-12: AM peak weighted average V/C – 2053 Test

Again, the PT crowded assignment leads to a clear reduction in crowding on the network, although the Kapiti Coast rail line is still over capacity during the AM peak period.

Finally the impact on mode share is shown in the following table.

Table 6-5: Total mode share – 2053 test

Mode	Standard	Crowded	% Difference
Light vehicles	2,179,719	2,182,027	0.1%
Bus	113,457	112,031	-1.3%
Rail	87,246	84,102	-3.6%
Active modes	552,005	554,269	0.4%

The crowded assignment leads to a more marked reduction in PT mode share than in 2033, as demand more significantly exceeds capacity. Potential shift of demand to light vehicles is however constrained as congestion on the road network also increases. As a result, more demand shifts to active modes although this is only for shorter trips for which it is a viable alternative.

Again, while the changes in mode share are more noticeable, most of the decreased congestion is due to routing changes occurring during the assignment.

This analysis demonstrates that the crowded PT assignment achieves the intended purpose of providing a more realistic representation of public transport demand accounting for capacity constraints, even for scenarios where base demand (without crowding) significantly exceeds capacity.

It must be noted that due to the WTSM nature as a strategic model, capacity thresholds are not represented as absolute limits but through the use of time penalties increasing with V/C ratios. As a result capacities can still be exceeded, in the same way than road capacities can be exceeded for the road assignment. It is therefore important for the model user to monitor transit line loadings for such high growth scenarios and ensure future networks are commensurate with forecasted demand, especially when the road network is also at or above capacity.

6.5 Implementation in WTSM

The congested PT assignment uses the following attributes, in addition to attributes used in a regular PT assignment:

- **@pkcrwd**: line attribute containing the period to hour factor
- **@hdw_hr**: line attribute containing the headway for the peak hour
- **@hdw_prd**: line attribute containing the headway for the whole period
- **@vtype**: vehicles type (necessary to be read in the crowding function as the standard 'veh' attribute cannot be read. This is automatically allocated during a model run)

Other information used is the standard EMME vehicles attributes for seating and total capacities (respectively **vcaps** and **vcapt**).

The congested PT assignment is essentially a wrapper around the regular assignment, which is looped with crowding functions applied in between iterations until a convergence criteria or a maximum of iterations is reached. These criteria have been set as follows:

- **normalised gap**: 0.01
- **relative gap**: 0.001
- **Maximum iterations**: 50

7. Running the PT assignment

After the **Initialise PT Assignment** Flow has been run during the model initialisation, the WTSM PT Assignment itself is run from the **PT Assignment** Flow, called as part of a model run with parameters including:

- Time period: AM, IP, PM or ON
- Assignment type: Initialisation (which uses initialisation matrices based on electronic ticketing data) or Standard (which used synthetic matrices generated by the demand model).
- Crowded: On, Off or Peak-only (i.e. AM and PM periods only)
- Integrated ticketing: True or False. If set to True, the intermodal boarding fares between rail and bus are set to 0.
- Matrix scenario prefix (matid), a prefix being allocated to all matrices generated for this scenario run, throughout the model.

The assignment is based on the EMME Extended Transit Assignment tool (or Congested Transit Assignment if crowding is turned on, which is itself based on Extended Transit Assignment). As mentioned previously, it is run as a multi-class assignment with the 5 following classes:

- bus
- rail park-and-ride
- rail kiss-and-ride
- rail other
- airport-related demand

The journey levels specifications are however different for park-and-ride and kiss-and-ride depending if it is the AM or IP period (car access) or PM or ON periods (car egress), as detailed in Section 5.

Upon completion of the PT assignment, the following processes are run:

- Segment volumes for all five classes are summed up in the respective link attributes **@volbus**, **@volrailpr**, **@volrailkr**, **@volrailot** and **@volairppt** in order to display volumes by demand segment.
- Boardings and alightings for all classes are summed in the segments attributes **@boardings** and **@alightings**.
- An Extended Transit Assignment Matrix Results tool is run to skim the following matrices, for input into the generalised costs calculations:
 - Total impedance
 - Perceived waiting times
 - Average number of boardings
 - Perceived boarding times
 - Perceived total boarding costs
 - Perceived in-vehicle times
 - Perceived in-vehicle costs
 - Perceived auxiliary transit times
 - Perceived auxiliary transit costs
- Finally a path-based analysis is run to extract park-and-ride and kiss-and-ride volumes between origins and first boarding stations in the AM and IP period (between last alighting stations and destinations in the PM and ON). The resulting path file is then read and processed as follows:
 - The station node (300xx) is replaced with the station zone (302xx)
 - The occupancy factors are applied to convert person trips to vehicle trips.
 - The outputs are reformatted as matrices

This results in park-and-ride and kiss-and-ride car matrices including trips between the home and rail station, to be added to the total car matrices during the course of the model run before the next road assignment.



Appendices

Appendix A Bus travel time comparison



Figure A-1 – Bus routes used in comparison



Figure A-2 – Bus routes used in comparison – rest of region

Table A-1 – Bus travel times observed vs modelled (in minutes)

Routes	Direction	AM Peak			Inter peak			PM Peak			Overnight		
		Obs	Mod	% Diff	Obs	Mod	% Diff	Obs	Mod	% Diff	Obs	Mod	% Diff
1	Inbound	69	73	6%	63	62	-1%	62	72	15%	50	52	3%
	Outbound	67	66	-1%	66	56	-15%	64	54	-15%	51	51	-1%
2	Inbound	54	58	6%	49	53	8%	51	66	28%	40	46	15%
	Outbound	52	60	16%	50	49	-1%	52	70	36%	40	43	7%
3	Inbound	42	41	-3%	38	30	-21%	37	39	5%	25	25	-2%
	Outbound	35	37	6%	36	32	-12%	39	43	11%	27	28	2%
7	Inbound	29	26	-8%	22	20	-10%	20	24	19%	15	17	15%
	Outbound	22	24	8%	25	23	-6%	31	34	11%	20	21	7%
14	Inbound	47	47	-1%	45	45	0%	48	50	5%	35	40	15%
	Outbound	46	51	11%	45	49	8%	45	53	18%	34	43	28%
18	Inbound	53	50	-5%	49	41	-16%	54	59	9%	41	33	-19%
	Outbound	48	56	17%	47	42	-10%	50	65	29%	39	34	-11%
21	Inbound	37	29	-20%	16	6	-60%	20	31	54%	21	21	-2%
	Outbound	19	27	43%	17	25	51%	29	39	34%	23	22	-7%
22	Inbound	37	48	31%	24	24	-3%	25	22	-13%	19	19	-1%
	Outbound	24	24	-1%	25	24	-1%	39	30	-21%	22	20	-11%
23	Inbound	40	38	-7%	34	33	-4%	33	25	-25%	27	24	-12%
	Outbound	34	28	-17%	38	27	-29%	40	27	-33%	29	24	-19%
24	Inbound	63	64	3%	69	49	-28%	72	89	23%	63	72	14%
	Outbound	67	69	4%	75	63	-16%	62	64	3%	59	47	-19%
25	Inbound	45	46	3%	42	44	5%	34	36	4%	43	39	-10%
	Outbound	47	48	2%	43	45	5%	36	49	36%	44	40	-10%
30x	Peak	42	47	12%	0	0	0%	46	53	15%	0	0	0%
52	Inbound	49	67	39%	47	56	19%	46	57	24%	37	48	30%
	Outbound	49	55	12%	48	53	11%	51	60	19%	43	47	7%
57	Peak	39	46	17%	0	0	0%	38	44	16%	0	0	0%
58	Peak	40	48	19%	0	0	0%	40	44	8%	0	0	0%
60	Inbound	26	27	5%	24	27	15%	23	29	24%	20	20	-1%
	Outbound	25	28	10%	24	23	-1%	24	24	-2%	19	20	2%
81	Peak	57	49	-13%	0	0	0%	51	57	11%	0	0	0%
110	Inbound	66	69	5%	55	51	-7%	57	52	-8%	53	53	-1%
	Outbound	58	58	-1%	59	62	6%	63	68	8%	59	52	-11%
120	Inbound	43	29	-32%	27	28	5%	26	25	-2%	23	24	5%
	Outbound	25	25	1%	25	28	14%	30	28	-7%	23	24	5%
130	Inbound	41	39	-4%	40	39	-2%	39	39	-2%	34	33	-4%
	Outbound	38	36	-6%	38	36	-7%	41	41	1%	35	31	-12%
160	Inbound	37	28	-25%	36	36	1%	31	34	11%	26	26	1%
	Outbound	30	34	15%	34	37	8%	34	30	-12%	28	26	-9%
200	Inbound	51	45	-11%	60	46	-23%	51	46	-9%	11	21	94%
	Outbound	25	24	-1%	56	74	30%	61	65	7%	16	21	32%
210	Inbound	14	15	1%	15	16	13%	14	16	18%	13	14	11%
	Outbound	13	17	23%	15	15	4%	16	16	0%	14	13	-4%
220	Inbound	41	27	-35%	28	40	44%	38	38	-1%	33	34	2%
	Outbound	30	35	17%	31	35	14%	42	36	-15%	35	30	-16%
260	Inbound	17	17	0%	18	16	-9%	19	17	-9%	17	14	-15%
	Outbound	18	16	-11%	20	17	-14%	20	19	-4%	19	15	-23%

Appendix B List of attributes and parameters

Class	Walk Access		Car Access		Waiting time		Boarding times and penalties			Fares			In-vehicle times		Car Egress		Walk Egress		
	Speed / Perception	Car time	Car operating costs	Time and cost at station	Effective headway	Level	Node time	Line time	Boarding cost	Per zone cost	Extra per mode	Travel time	Perception factors	Car time	Car operating costs	Time and cost at station	Speed / Perception		
Bus						0 - Not boarded	board_rail_node/bus --> @boardn	board_line_permode --> @boardl	fare_board_perperiod --> @fare_board		fare_flyer --> @fare_mode								
	walk_speed walk_perception					1 - Boarded bus	board_rail_node/bus + transfer_pen --> @brdtrans			fare_zone_perperiod --> @fare_zone									
Rail other (and airport-related demand)					headway <-- hdw wait_perception hdwfact_permode --> @effhdwy	0 - Not boarded	board_rail_node/bus --> @boardn		fare_board_perperiod --> @fare_board			Travel time function bus: ft1 (calculated) --> us2 Travel time function rail, ferry: ft11 (timetable) --> us1 Parameters for ft1: time_std_perperiod time_busl_perperiod time_seg_perperiod --> @ptspeed ptime_busl_perperiod --> @ptturn stp_cnst_perperiod stp_cnst_perperiod_cbd stp_cnst_perperiod_region --> @stpcnst dwl_perperiod dwl_max wellgt_dwell_reduc mrt_dwell_reduc --> dwt	Mode: ivt_perception_perperiod --> @mivt Link: --> @livt_b/m/x/y Segment: @mivt * @livt_{mode} --> @sivt Crowded Assignment only: @pkcrwd @hdw_prd @vtype @hdw_hr						
					1 - Boarded bus	board_rail_node/bus + transfer_pen --> @brdtrans	board_line_permode --> @boardl	fare_board_perperiod (0 if IT) --> @farefrombus	fare_zone_perperiod --> @fare_zone	fare_cablecar/ferry --> @fare_mode									
					2 - Boarded rail	board_rail_node/bus + transfer_pen --> @brdtrans		fare_board_perperiod (0 if IT) --> @farefromrail											
Rail park/kiss-and-ride access		travel time<-- @timau car_pr_perception car_kr_perception Catchments @banpnr	link cost<-- @fcost_lv occ_pr occ_kr	Time: station_time_pr station_time_pr Cost: @pr_charge Total: @pr/kr_cost		0 - Drive access													
						1 - Parked	board_rail_node/bus --> @boardn	board_line_permode --> @boardl	fare_board_perperiod --> @fare_board		fare_cablecar/ferry /flyer --> @fare_mode								
						2 - Boarded rail/ferry	board_rail_node/bus + transfer_pen --> @brdtrans		fare_board_perperiod (0 if IT) --> @farefromrail	fare_zone_perperiod --> @fare_zone									
						3 - Banned													
Rail park/kiss-and-ride egress	walk_speed walk_perception				headway <-- hdw wait_perception hdwfact_permode --> @effhdwy2	0 - Walk	board_rail_node/bus --> @boardn	board_line_permode --> @boardl	fare_board_perperiod --> @fare_board		fare_cablecar/ferry /flyer --> @fare_mode								
						1 - Boarded bus	board_rail_node/bus + transfer_pen --> @brdtrans		fare_board_perperiod (0 if IT) --> @farefrombus	fare_zone_perperiod --> @fare_zone									
						2 - Boarded rail/ferry			fare_board_perperiod (0 if IT) --> @farefromrail										
						3 - Recovered car													
						4 - Banned													

hdwfact_permode Parameter in Flow
 hdw EMME attribute
 IT Integrated ticketing
 --> saved to EMME attribute
 <-- read from EMME attribute

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