TN28 - WELLINGTON TRANSPORT ANALYTICAL TOOLS 2019-22 UPDATE – ROAD ASSIGNMENT

PREPARED FOR   GREATER WELLINGTON REGIONAL COUNCIL

December 2022

Stantec | JACOBS

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REVISION SCHEDULE

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Stantec Jacobs | TN28 - Wellington Transport Analytical Tools 2019-22 update – Road Assignment | December 2022

Status: Final| Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Greater Wellington Regional Council

TN28 - Wellington Transport Analytical Tools 2019-22 update – Road Assignment

CONTENTS

LIST OF TABLES

Stantec Jacobs │ TN28 - Wellington Transport Analytical Tools 2019-22 update – Road Assignment │   December 2022

Status: Final │ Project No.: 310203597 │ Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

LIST OF FIGURES

APPENDICES

Stantec Jacobs │ TN28 - Wellington Transport Analytical Tools 2019-22 update – Road Assignment │ December 2022

Status: Final │ Project No.: 310203597 │ Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

1.   Introduction

This technical note is part of a series documenting the 2019-2022 update of components of the Wellington Regional Transportation Planning Analytical Tools. The higher-level Analytical Tools are maintained and operated by Greater Wellington Regional Council (GWRC), who are the client for this project. This project is being primarily delivered by Stantec and Jacobs, supported by GWRC transport planners.

This technical note documents the road assignment, including changes to the road network (links), the new intersection modelling, and assignment parameters.

Much of the information reported here also applies to the Wellington Transport Assignment Model (WTAM), which is reported separately in Technical Note 25. In particular, the road network, intersection modelling, and delay functions reported in this technical note are also used in the WTAM.

2.   Specification

2.1   Vehicle Types

Following discussions with the client, the assignment has been changed from vehicle-based to PCUs. PCUs are "Passenger Car Units" and reflect that buses and trucks take up more space than cars. A car therefore has a value of 1, and other vehicle types a higher value to reflect their size. The following PCU values have been used. It is noted that detailed traffic counts to calculate PCU factors was not available and hence the rounded values below have been adopted and applied to the demand matrices.

Table 2-1: PCU Values

Vehicle Type	PCU Value
Cars	1
Heavy Commercial Vehicles	2
Buses	3

2.2   Time Periods

The main time periods are listed in the table below.

Table 2-2: Time Period Definitions

Period	Hours
AM peak (AM)	6-9am
Interpeak (IP)	9am-3pm
PM peak (PM)	3-6pm
Overnight (ON)	6pm-6am

The three hour commuter peaks are split into a peak hour and a residual or shoulder period for assignment. This means there are six road assignments in total, covering:

- AM shoulder, 6-8am

- AM peak hour, 8-9am

- Interpeak, 9am-3pm

- PM shoulder, 3-5pm

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 1

- PM peak hour, 5-6pm

- Overnight, 6pm-6am

The derivation of these time periods is documented in Technical 21: Peak Periods and Vehicle Occupancy.

In the road assignment, all time periods are assigned as an average hour to simplify the intersection modelling, volume-delay functions, and turn penalty functions.

3. Road Network

This 2018 update started using the transport network from the 2013 update of the model. Changes to the road network included to update the network from 2013 to 2018 include:

- Haywards Interchange (SH2/SH58)

- Mackays to Peka Peka (SH1)

- Additional Local Collector Roads around the Porirua Area as requested by Porirua City Council

- General network additions added as needed to suit the more refined zone system

The above changes were determined based on local knowledge.

The User Manual describes road functions by link type, and specifies the free flow speed, capacity, and JA[1] parameter value for each link type. The network has strayed over time from these values, with refinements added since 2001 to improve the replication of observed. An early test was conducted resetting these variables to the values documented in the User Manual, but this was found to significantly invalidate the model. Resetting and cleaning the network was therefore aborted.

No other substantial change in capacities has been incorporated, even though the road assignment will now be in PCUs rather than vehicles. Tests were undertaken and the assignment still converged with the slightly higher PCU-based demand.

The new 819 zone system was connected to the network. The zone system is documented in Technical Note 3 – Zoning. For ease of reference, the external and special generator zones are tabulated below.

Table 3-1: External and Special Generator Zones

Generator Name	Zone Number
State Highway 1 Northern External	2261
State Highway 2 Northern External	2271
Centreport Container Terminal	2281
Interisland Ferry Terminal	2291
Bluebridge Ferry Terminal	2301
Airport, flight-related travel	2311

Other changes have been made to the transport network for the public transport (PT) system including park-and-ride. These are documented in Technical Note 29: PT Assignment.

4. Intersections

4.1 Approach to Intersection Modelling

Prior to this update of the model, intersection capacities were reflected albeit simplistically. This was considered appropriate for a strategic model with a relatively coarse zone system. In principle, intersections were modelled:

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[1] Delay parameter in Akcelik volume-delay curves

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 2

- Traffic signals, assuming each arm ran in a dedicated phase

- Priorities, assuming zero delay on the opposed right turn from the major arm

- Priorities, assuming same delay experienced on the minor arm for all turns (left, through, or right)

- In the CBD, all capacities were "fixed" and not recalculated based on changing flows during the assignment. This was due to stability issues.

The significant refining of the model zoning presented an opportunity to revisit and refine the intersection modelling. A new EMME module, JCAT (Junction Capacity Assignment Tool), has been adopted which calculates capacities by turn. While capacities are calculated by JCAT using in-built equations that cannot be altered, delays continue to be calculated through user-specified volume-delay functions (VDF).

Depending on the intersection type, the turn delay will either be calculated as a turn or link attribute. At roundabouts, for example, where all traffic on an approach generally experiences the same delay by definition, the turn delay is calculated as a link attribute. This means that for roundabouts, the time reported for the link includes both link and turn travel time. This is a JCAT requirement and cannot be changed. Link times which include turn delays are clearly outlined in the documentation below.

Intersections are modelled at most locations where traffic gives way. Intersections are not modelled in the following circumstances:

- Where no traffic gives way, for example, a 3 arm intersection with a one-way approach and two one-way exits

- Zone loading nodes. Zones are loaded mid link and not into key intersections

- At some 5 arm intersections, which proved too complex to replicate using JCAT. This is detailed in Section 5.2.

4.2 Intersection Specification

In this section, the attributes required to specify intersections for JCAT are documented.

4.2.1 Intersection Control Type (@type)

The type of intersection control for unsignalized intersections is specified using the node attribute @type.

For signalised intersections, @type is not specified. The @nema attribute values (see section 4.2.3) identify to the software that the intersection is signalised.

Table 4-1: Unsignalised Intersection Control Type, @type

Intersection Type Attribute(@type)	Intersection Type	Used?
1	2-way stop controlled with North-South major street	Yes
2	2-way stop controlled with East-West major street	Yes
3	3-way stop, T-intersection	No
4	4-way stop	Yes (1)
5	Roundabout	Yes
6	Ramp Give Way	No
7	Ramp Merge	Yes
8	Ramp Diverge	No

There is no give way intersection available, but the 2-way stop controlled intersection is considered sufficiently robust for a strategic model, and better than modelling approach capacity only.

There were cases where workarounds were required to describe the intersection to JCAT. This included intersections that were not strictly east-west or north-south orientated, and in particular, there were some 3-arm intersections were the major road was the bend or "L".

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 3

4.2.2 Turning Lanes Available (@lanes)

This attribute is specified differently for traffic signals and unsignalised intersections.

This is a turn parameter.

4.2.2.1 Signals

This attribute describes the number of dedicated and any shared lanes, the latter identified by a specific decimal value which applies only to through movements. This means only through movements can have @lanes with decimals and left and right turns have @lanes values of the total turning lanes regardless of whether it is shared or not. The integer part of @lanes specifies the number of dedicated lanes for the through movement. The decimal part of @lanes specifies lane sharing as shown below.

Table 4-2: Lanes at Signals (@lanes)

@lanes Decimal Component	Meaning
0.1	Single, all shared lane for all movements
0.25	Additional through lane shared with the left turn
0.5	Additional through lane shared with the right turn
0.75	Two through lanes, one of which is shared with the left turn while the other is shared with the left turn

For example, in the following layout, the through turn would be coded as 2.25 for two dedicated through lanes plus a through and left turn shared lane. The left turn would be coded as 1 even though it is shared.
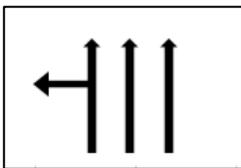

Figure 4-1: Example, @lanes at Signals for Dedicated and Shared Lanes

4.2.2.2 Unsignalised

For 2-way stop controlled intersections, @lanes is not used. The effects of delays to through traffic associated with shared lanes is ignored to simplify the analysis.

For roundabouts and ramps, @lanes is set to the number of approach lanes.

4.2.3 Direction and Approach Codes (@nema)

This attribute defines both the direction and approach of each turn. It is a turn attribute and varies depending on whether the intersection is signalised or unsignalised. The numbering is the same as the Highway Capacity Manual (HCM), Volume 3 Interrupted Flow, Exhibit 18-2 albeit with the orientation rotated.

The @nema values for signalised intersections are shown below. The illustrations are based on north being at the top of the diagrams.

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

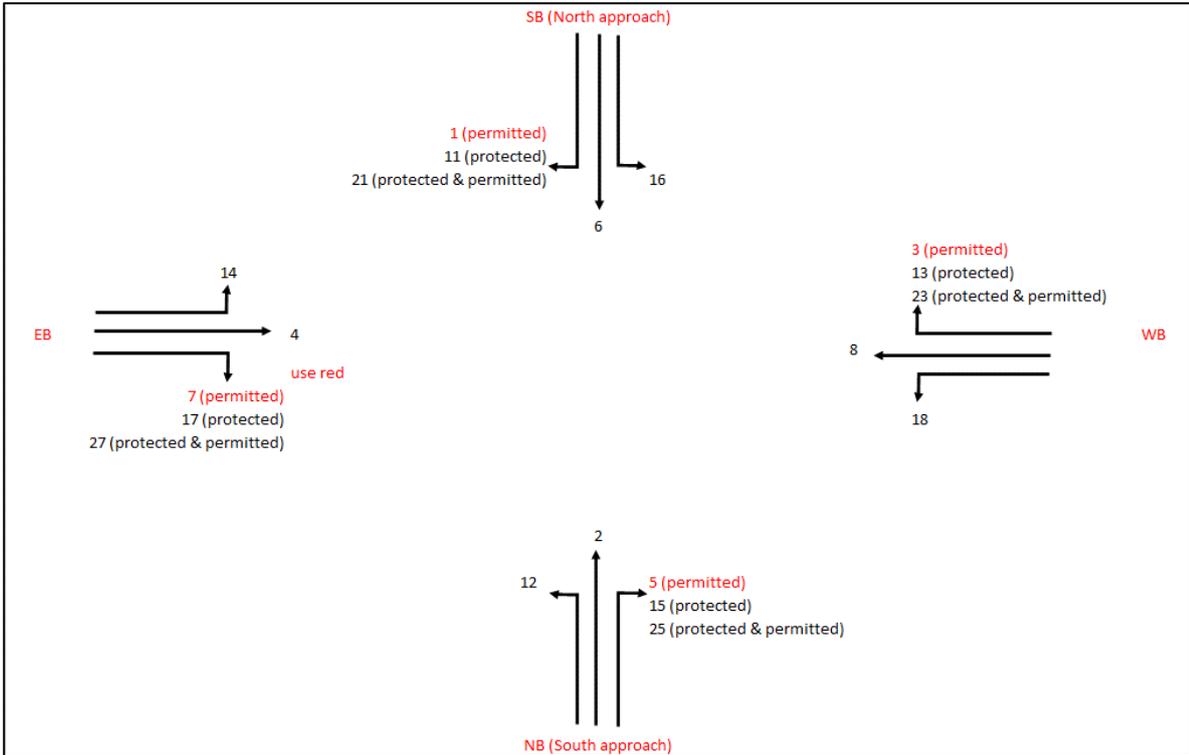Page 4

Figure 4-2: @nema values, Signals

The @nema values for unsignalised intersections are shown below. They use the value for signalised intersections (permitted right turns) multiplied by 10 plus 9.
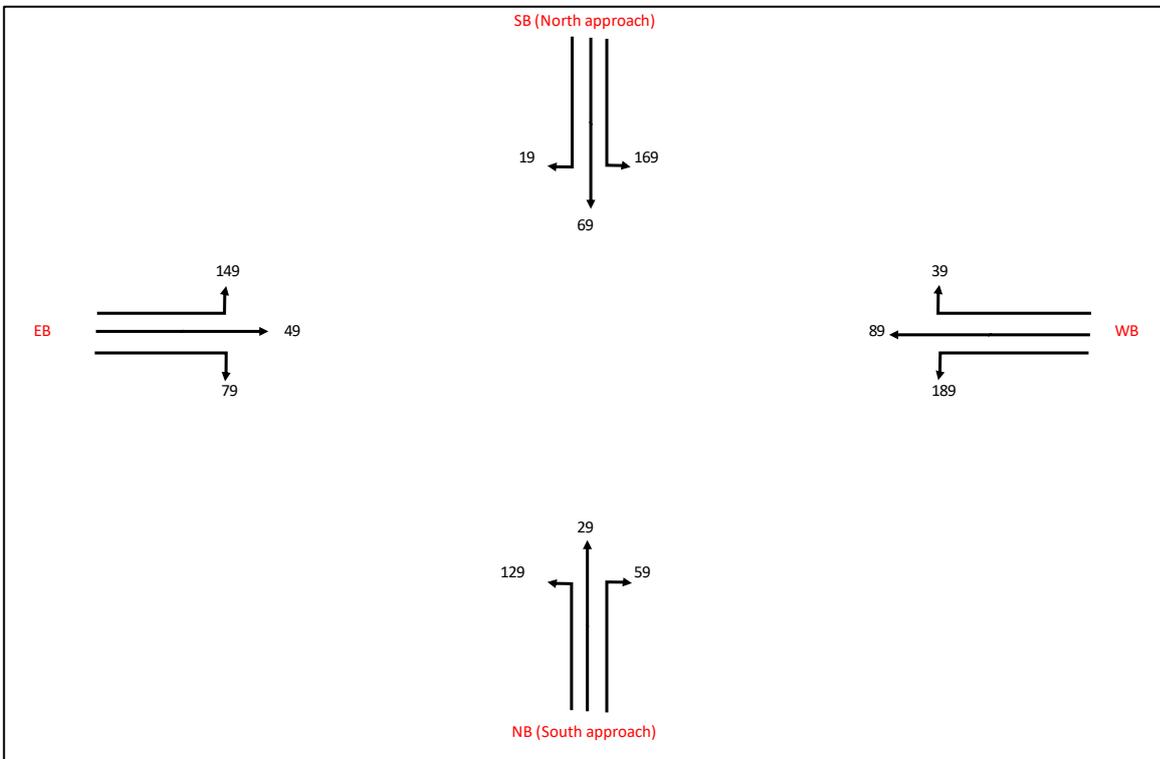

Figure 4-3: @nema values, Unsignalised

December 2022 │ Status: Final │ Project No.: 310203597 │ Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 5

4.2.4 Green Time and Cycle Time at Traffic Signals

Traffic signal phasing is not explicitly coded. Instead, the cycle (@cycle) and green times (@green) are coded for each movement. The software then identifies conflicting movements and adjusts capacities based on the @nema attributes.

Gren and cycle time are specified in seconds. They are both turn based attributes.

4.2.5 Dynamic Link and Turn Capacities

The attributes @lkcap and @tncap hold the dynamically recalculated link and turn capacities respectively.

The default values are 2000 PCUs for a lane on a link and 750 PCUs per turning lane. These are initialised at the start of a model run.

4.2.6 Additional Network Attributes

In setting up the network initially and creating the JCAT-required attributes, the "Prepare for JCAT" tool was used. This tool uses other fields to estimate the essential attributes listed in the preceding sections. The purpose of using "Prepare for JCAT" is that the input is supposed to be more intuitive than the numbered codes that JCAT requires.

These additional fields are not essential for operating the model. They are recorded here for completeness. Now that the JCAT-enabled network has been coded, it is not anticipated that these fields will be further used.

These essential JCAT attributes were derived from the following fields:

- @type derived from #int_type field

- @lanes derived from #lane_config field

- @nema derived from #turn_approach_dir and #turn_dir fields

Where:

- #int_type, is a text string describing the intersection. For example, ES Stop, Signalized, etc. There are specific strings that must be entered.

- #lane_config, is a text string describing the lanes used for each turn. There are up to five slots to describe the lanes. The number of characters entered should equal the total number of lanes available to turn on the approach. This can be greater than the number of lanes on the link (mid block) indicating the presence of extra lanes at the intersection.

- #turn_approach_dir defines the geographic orientation of the turn approach.

- #turn_dir defines the turn direction.

A summary of the information above is provided in the table below.

Table 4-3: Interim Fields for Setting up JCAT Attribute

JCAT Attribute	Interim Field	Description	Attribute Type	Options	Notes
@type	@int_type	Intersection description	Node	NS Stop EW Stop 3-Way Stop 4-Way Stop Roundabout Ramp Yield Ramp Merge Ramp Diverge Signalized	Essential to trigger JCAT preparation
@lanes	#lane_config	Describes lanes on approach used for each turn	Turn	"-" = lane not used D = dedicated lane S = shared lane	• Processed if #int_type is coded • Manually entered

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 6

JCAT Attribute	Interim Field	Description	Attribute Type	Options	Notes
@nema	#turn_approach_dir	Approach orientation	Turn	NB SB EB WB	values not overwritten by JCAT preparation tool
	#turn_dir	Turn direction	Turn	LEFT RIGHT THRU U-TURN	
N/A	#appraoch_direction	Calculated directionality of the link	Link	NB SB EB WB	Always recomputed when Tool run

The Prepare for JCAT tool does not modify the cycle or green times (@cycle, @green). These can be manually specified or estimated using the EMME Signal Generator Tool

4.2.7   Mandatory Fields and Functions

In order for JCAT to work, there are some mandatory fields and functions, which are documented here.

Extra function parameters required by the software are:

- el1, is mapped as @lkcap

- ep1, is mapped as @cycle

- ep2, is mapped as @green

- ep3, is mapped to as @tncap

The following approach controls (see Table 4-4)are triggered by a mandatory link volume-delay function. For ramp merges, it is therefore essential to use volume-delay function number 82, although the form of the equation can be changed.

Table 4-4: Mandatory Link Volume-Delay Functions

Approach Type	Volume-Delay Function	Used?
Single lane minor approach to a 2-way stop controlled intersection	fd80	No
All approaches to a ramp give-way	fd81	No
All approaches to a ramp merge	fd82	Yes

The following turn penalty (delay) function numbers are mandatory.

Table 4-5: Mandatory Turn Penalty Functions

Approach Type	Turn-Penalty Function	Used?
Double lane minor approach to a 2-way stop controlled intersection	fp80	Yes

All link and turn volume-delay functions are specified in Section 5 of this technical note.

4.3   Capacity Equations

Capacity equations are embedded within JCAT and cannot be changed. They are generally from the Highway Capacity Manual (HCM) and the key equations are extracted from the JCAT documentation and summarised.

The following key points are noted:

- In all the capacity equations, the conflicting volume is from the previous iteration.

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 7

- The definition of the conflicting flow is provided in the JCAT documentation. For the conflicting flow, opposing left turns are weighted by a half, opposing right turns are doubled, opposing through traffic on the major arm has no adjustment, while an opposing through movement from a minor arm is weighted by a half. These weights are when the major road has two lanes, other permutations are specified in the JCAT documentation.

- There are further lane sharing equations that are subsequently applied.

4.3.1   2-Way Stop Controlled Intersections

4.3.1.1   Major Street

From the major road, the capacities are "Rank 2" movements from the HCM 2010 Procedures, Volume 3[2].

Right turns from major streets, for one or two opposing through lanes:

$$c = \frac{v_c \, e^{-4.1 v_c/3600}}{1 - e^{-2.2 v_c/3600}}$$

Where:

c =	capacity (PCUs) per hour
v_c =	conflicting volume in previous iteration, PCUs per hour

The value of 4.1 seconds in the equation above is the critical headway, while 2.2 seconds represents the follow up headway. These values can be found in Exhibits 19-10 and 19-11 respectively in the HCM 2010.

Right turns from major streets, for more than two opposing through lanes:

$$c = \frac{v_c \, e^{-5.3 v_c/3600}}{1 - e^{-3.1 v_c/3600}}$$

4.3.1.2   Minor Street

From the minor road, the capacities are "Rank 3" and "Rank 4" movements in the HCM 2010.

$$c = \frac{v_c \, e^{-6.7 v_c/3600}}{1 - e^{-3.7 v_c/3600}} * Q$$

Where:

Q =	probability that all higher ranked movements operate in a queue-free state. Value ranges from 1.0 to 0.73

4.3.2   Roundabouts

The capacity for roundabouts is from the HCM, see Equation 21-1 in Volume 3, HCM 2010.

The capacity per entry lane for one circulating lane is:

$$c = 1130 e^{-0.001 v_c}$$

Where:

c =	capacity (PCUs) per hour per approach lane
v_c =	volume (PCUs) of conflicting (circulating) traffic per hour that the approach gives way too in previous iteration

The capacity per entry lane for two circulating lanes is shown below, which is Equation 21-5 in Volume 3, HCM 2010:

$$c = 1130 e^{-0.0007 v_c}$$

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[2] Equation 19-32 in Volume 3, HCM 2010

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 8

It is noted that early versions of the JCAT documentation show the conflicting flow multiplier incorrectly as 0.007.

In the HCM, the equation above is actually for one entry lane conflicted by two circulating lanes, with other equations for two entry lanes conflicted by two circulating lanes. But in strategic modelling, it is necessary to simplify the calculations.

The software determines the number of circulating lanes based on the lanes on each arm (@lanes) and uses the first equation if there is one lane on the approach, and the second if there are two or more. This does mean there may be instances where an approach assumes an incorrect number of circulating lanes. For example, a two circulating lane roundabout, where one approach has a single lane at the stop line. In this example, the capacity on the approach with the single lane will be calculated based on a single circulating lane. These simplifications are not considered a significant issue.

4.3.3 Ramp Merges

The capacity for a highway on-ramp merge assumes that the capacity available is the surplus on the main motorway, capped to a minimum value so that the on-ramp capacity cannot be negative. This is quite simplistic, and adjustments at significant motorway ramp merges may be required during model validation.

$$c_{Ramp} = c_T * N_T - v_T$$

Where:

c_{Ramp} = ramp capacity per hour (PCUs)

c_T = capacity of through highway lanes (assumed at 2000 PCUs per hour per lane)

N_T = number of through highway lanes

v_T = upstream through highway flow, PCUs per hour

4.3.4 Signals

4.3.4.1 Fully Protected

The capacity for fully protected movements that do not give way is shown below, which is Equation 18-15 in Volume 3, HCM 2010:

$$c = s\frac{g}{C} N$$

Where:

s = saturation flow, PCUs per hour per lane

g = (effective) green time, seconds

C = cycle time, seconds

N = number of lanes

The JCAT documentation states[3] that the saturation flow rate is 1900 PCUs per hour per lane for through traffic, 1700 for right turns, and 1600 for left turns.

4.3.4.2 Variable Capacities

The capacity equation for opposed right turns at signals is from the HCM and is:

$$c = \left(\frac{v_0\ e^{-\frac{4.5v_0}{3600}}}{1 - e^{-\frac{2.5v_0}{3600}}} * \frac{g_u}{C} + \frac{2*3600}{C} \right) * N$$

Where:

v_0 = opposing through and left turn traffic volume (PCUS per hour) from previous iteration

C = cycle time, seconds

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[3] The documentation is written for right hand side of the road driving, so all left turns in the JCAT documentation need to be read as "right" and vice versa. This technical note is correct for driving on the left hand side of the road.

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 9

N =	number of permitted right turn lanes (usually 1)
g_u =	green time (seconds) after clearance of initial queue of opposing traffic. This is calculated by:

$$g_u = \left(\frac{g_{0T} * 1900 * N_{0T} - C * v_{0T}}{1900 * N_{0T} - v_{0T}} \right).max.0$$

Where:

g_{0T} =	opposing through green time (seconds)
N_{0T} =	number of opposing through lanes
v_{0T} =	opposing through traffic volume, PCUS per hour

The JCAT documentation includes equations for right turns that have both protected and permitted (opposed) phases, as well as lane sharing adjustments. These are available in the JCAT documentation if required.

4.4 Minimum Capacities

JCAT overwrites the calculated capacity with a minimum value for the link or turn, depending on the intersection type (i.e. roundabout calculations are only link/approach-based). The minimum capacities, which are a global input to the process, are:

- Link capacity per lane per hour, 200 PCUs
- Turn capacity per lane per hour, 50 PCUs

4.5 Calculated Capacities

The capacity equations are shown graphically in the figures below. All capacities reported in this section are PCUs per hour.

The capacities for unsignalised intersections are shown below.
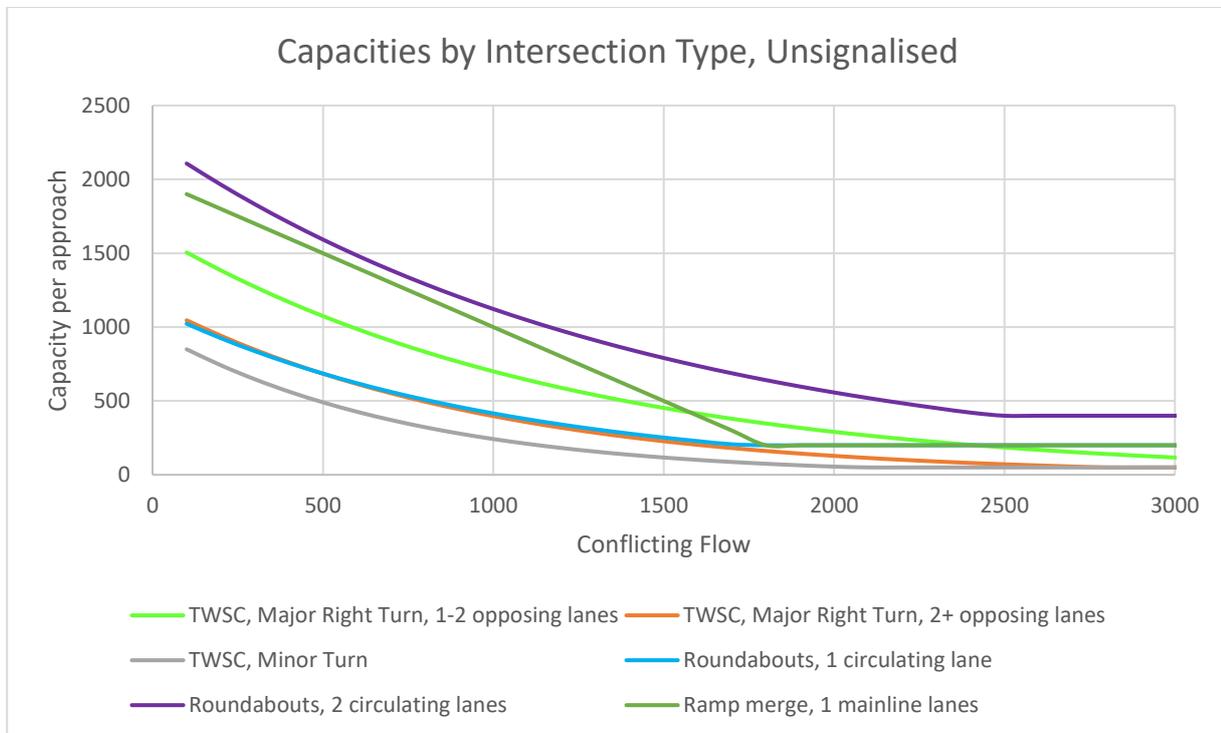
Figure 4-4: Capacities for Unsignalised Intersections

The ramp merge capacity is a linear relationship to the capacity and flow on the mainline. Therefore the ramp merge capacity is per approach, irrespective of the number of lanes on the ramp. This needs to be borne in mind in replicating complex intersections.

December 2022 │ Status: Final │ Project No.: 310203597 │ Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 10

For unopposed movements at signals, the capacity per lane is shown below against the proportion of effective green time (green time/cycle time).
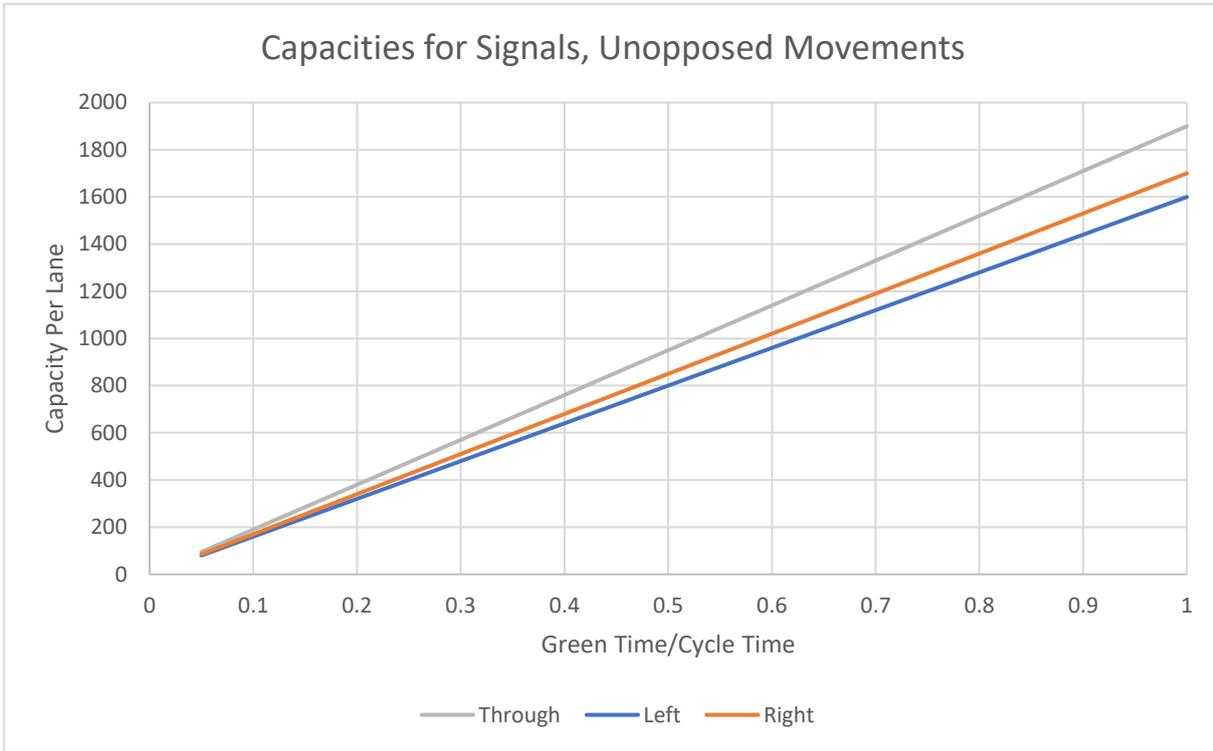

Figure 4-5: Capacities for Signals, Unopposed Movements

The difference between the turning movements is a direct result of the saturation flow for each turn. This reflects that the radius of a left turn is tighter than a right, followed by the right turn having the second tightest radius, and finally the through, with increasing saturation flow by turn respectively.

For opposed right turns at signals, the capacity per lane is shown below against the conflicting flow.
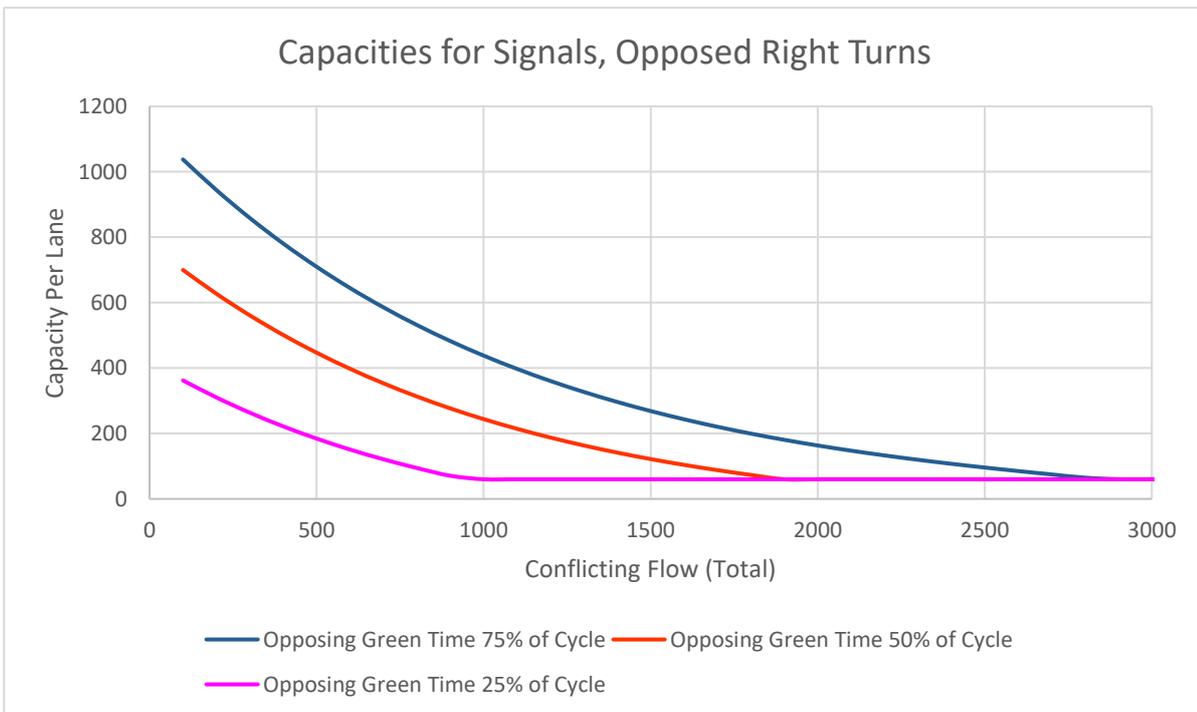

Figure 4-6: Capacities for Signals, Opposed Movements

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 11

This shows that as the proportion of green time for the opposing flow increases, the likelihood of gaps improves, and the capacity per lane is higher for the same conflicting flow.

5. Delay Functions

As noted above, turn capacities are calculated by JCAT using in-built functions from the HCM. These are not accessible to change. The delay on turns is then calculated by applying a user-specified volume-delay function.

Link and turn volume-delay functions (VDF) are reported in the following sections.

Also as noted previously, for some intersection control types, the turning delay is calculated and applied on a link basis. This applies to:

- Roundabouts

- Ramp merges

- Single lane minor arm approaches to 2-way stop controlled intersections

For the above control types, all traffic on the approach experiences the same delay (or is modelled as such). While it does complicate interpretation of the link travel time (TIMAU) and the turning travel time (PTIMAU) attributes, this is hardwired software functionality that could not be changed.

To correctly calculate delays for links/turns with dedicated bus lanes, the bus preload volumes are set to zero in the delay function. This allows for the fact that the buses are in the bus lane and not using the general traffic lanes. The bus preloads are therefore calculated and stored in variables 'el8' for links and 'up3' for turns, and will have a zero value if there is a bus lane present.

5.1 Link Delay Functions

The following link volume-delay functions are used:

- VDF 16, all roads aside from those listed below

- VDF 17, congested sections of motorway

- VDF 20, roundabouts. This contains both link and turn time combined

- VDF 82, ramp merges. This is also link and turn time combined

For intersection types where every turn has the same conflicting flow (for example, roundabouts and ramp merges), the turning delay is an approach-based calculation and incorporated in the link time variable, TIMAU.

5.1.1 Standard Link Delays (VDF 16)

The standard road volume-delay equation (VDF 16) uses an Akcelik function. This is shown below using the syntax typical in the literature:

$$ t = t_0 \left\{ 1 + 0.25 \, r_f \left[z + \sqrt{z^2 + \frac{8 \, J_A \, x}{Q t_0 \, r_f}} \right] \right\} $$

Where:

t =	average travel time per unit distance, in seconds per km	
t_0 =	free flow travel time per unit distance, in seconds per km	
J_A =	Akcelik delay parameter	
q =	demand (arrival) flow rate, in PCUs per hour	
Q =	capacity, in PCUs per hour per lane	
x =	q / Q =degree of saturation	
z =	x - 1	
r_f =	Tf / t_0, i.e. ratio of flow (analysis) period (in hours) to minimum travel time	

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 12

Translating this into minutes per link (rather than per kilometre) and using the EMME model variables, the same equation can be written as:

$$t_{16} = length * ul1 \left\{ 1 + 0.25 * \frac{60}{ul1} \left[\left(\frac{volau + el8}{ul2} - 1 \right) + \sqrt{\left(\frac{volau + el8}{ul2} - 1 \right)^2 + 8\, ul3\, \frac{(volau + el8)/ul2}{ul2/lanes}} \right] \right\}$$

Where:

t_{16} =	average travel time on the link, in minutes, calculated by VDF 16
length =	link length, in kilometres
ul1 =	free flow travel time, in minutes per kilometre
ul2 =	capacity, PCUs per hour
ul3 =	J_A
volau =	volume on link, PCUs per hour
el8 =	bus volumes, PCUs per hour
lanes =	number of lanes on link

The resulting congested speeds are shown below for a range of J_A values, with the associated saturation flow and free flow speeds. It is noted that in the model there are many more curves, as links have a range of capacities per lane and free flow speeds having drifted from the specification in the User Manual over time.
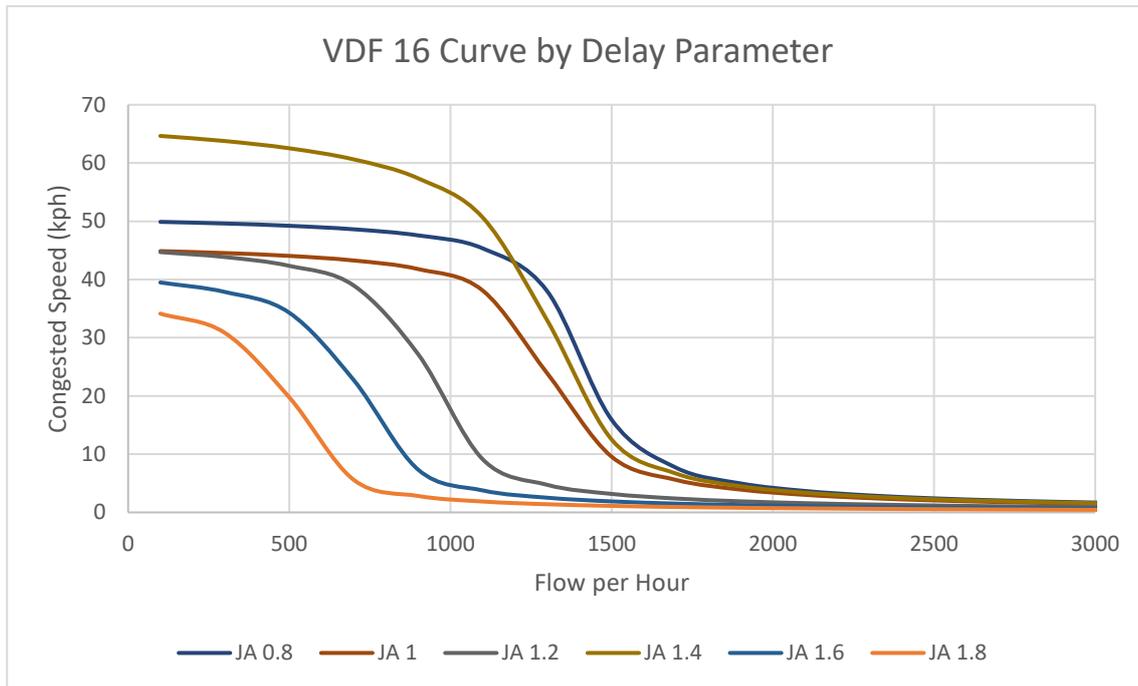
Figure 5-1: Congested Speeds, VDF 16

5.1.2 Motorway Link Delays (VDF 17)

The volume-delay equation for motorways (VDF 17) uses the Modified Davidson function and is:

$$t = t_0 \left\{ 1 + 0.25\, r_f \left[z + \sqrt{z^2 + \frac{8\, J_D\, x}{r_f}} \right] \right\}$$

Where:

J_D = Davidson delay parameter

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 13

Translating this into minutes per link and using the EMME model variables, the same equation can be written as:

$$t_{17} = \text{length} * ul1 \left\{ 1 + 0.25 * \frac{60}{ul1} \left[\left(\frac{\text{volau} + \text{el8}}{ul2} - 1 \right) + \sqrt{ \left(\frac{\text{volau} + \text{el8}}{ul2} - 1 \right)^2 + 8\, ul3\, \frac{(\text{volau} + \text{el8})/ul2}{60/ul1} } \right] \right\}$$

Where:

t_{17} = average travel time on the link, in minutes, calculated by VDF 17

ul3 = J_D

The Akcelik function (VDF 16) was already used in WTSM, while the Modified Davidson function (VDF 17) has been introduced to represent the delays on motorways when flow reaches capacity. This was reported in Technical Note 5: Travel Time Analysis.

In the figure below, a VDF 17 curve with a J_D of 0.3 and a free flow speed of 100 kph is plotted against an equivalent Akcelik curve (VDF 16).
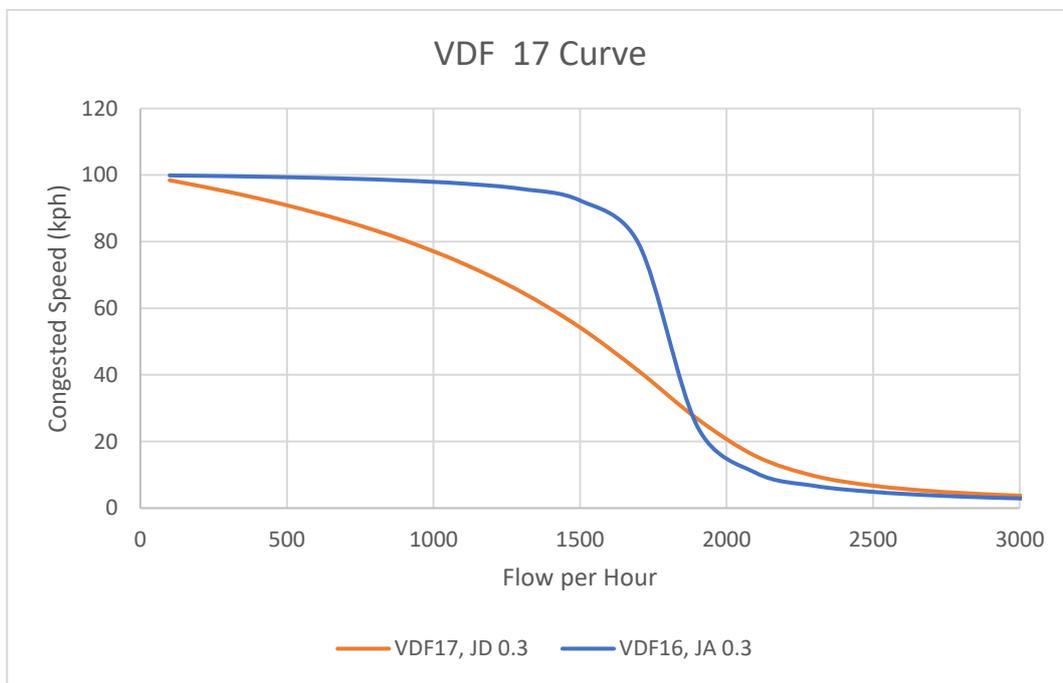

Figure 5-2: Congested Speeds, VDF 17 vs VDF 16

It can be seen that VDF 17 produces slower congested speeds compared with VDF 16 for the same traffic flow.

5.1.3   Roundabout Link and Turn Delays

For roundabouts, the turn delay at the intersection stop line is typically the same for all vehicles, irrespective of whether they are turning left, through or right. This is because the conflicting flow is the same. Hence roundabouts are modelled with an approach delay. Approach delay is a link attribute, and so the congested time on the link (TIMAU) includes time on the link plus delay at the intersection. Delays on roundabout approach links are calculated using VDF 20. This is a two-part Akcelik equation, the first component is the link delay and is identical to VDF 16 (shown in black in the equation below), while the second is the turn delay (shown in red in the equation below), which also uses an Akcelik formulation. Using EMME model variables, VDF 20 is:

December 2022 │ Status: Final │ Project No.: 310203597 │ Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 14

$$t_{20} = \text{length} * ul1 \left\{ 1 + 0.25 * \frac{60}{ul1} \left[\left(\frac{\text{volau} + \text{el8}}{ul2} - 1 \right) + \sqrt{ \left(\frac{\text{volau} + \text{el8}}{ul2} - 1 \right)^2 + 8\, ul3\, \frac{(\text{volau} + \text{el8})/ul2}{ul2/\text{lanes}} } \right] \right\}$$

$$+ \left\{ 0.1 + 0.25 * \frac{60}{ul1} \left[\left(\frac{\text{volau} + \text{el8}}{el9} - 1 \right) + \sqrt{ \left(\frac{\text{volau} + \text{el8}}{el9} - 1 \right)^2 + 8\, ul3\, \frac{(\text{volau} + \text{el8})/el9}{el9/\text{lanes}} } \right] \right\}$$

Where:

t_{20} = average travel time on the link plus turn, in minutes, calculated by VDF 20

el9 = dynamic link capacity calculated by JCAT, in PCUs per hour per link

equal to @lkcap

The default delay experienced at the intersection during free flow conditions has been set as 0.1 minutes (6 seconds).

The application of the second part of the curve (shown above in red) produces the turn delay and is illustrated below for various J_A values (and free flow speeds 45-50 kph) against volume to capacity ratio.
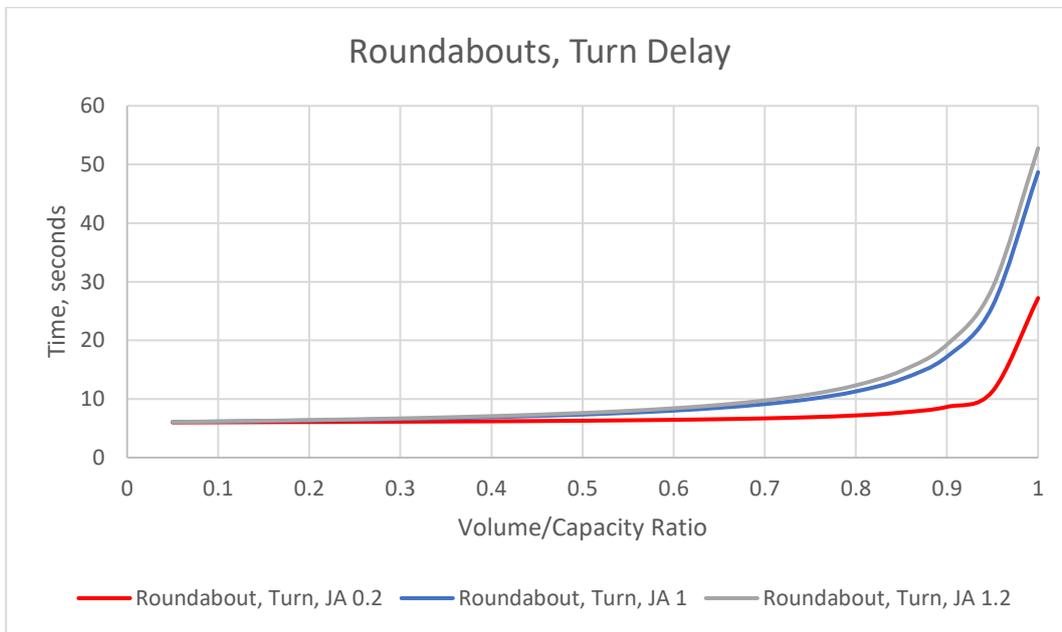

Figure 5-3: Roundabouts, Turn Delays

It was noted in Section 4.3.2 that the capacity calculation for roundabouts with two circulating lanes is extreme (i.e. very low capacities are calculated), but this can be partially offset by specifying a smaller J_A value.

The link travel time for roundabouts is identical to the curves shown in Figure 5-1.

5.1.4   Ramp Merge Link and Turn Delays

The final volume-delay function used is for ramp merges. Again, an approach delay is calculated by the software and so the time on the link plus the time merging (i.e. intersection delay) is a composite value stored in the link time attribute, TIMAU. A simple Bureau of Public Works (BPR) form of equation has been used with two elements, the first is the free-flow time on the link (shown in black below) and the second is the delay through the turn (in red below). The equation for VDF 82 in EMME model syntax is:

$$t_{82} = \text{length} * \frac{60}{el6} + \left(\frac{\text{volau} + \text{el8}}{el9} \right)^4$$

Where:

t_{82} = average travel time on the link plus turn, in minutes, calculated by VDF 82

el6 = free flow speed on the link, in kilometres per hour

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 15

The merge/turn delay on the motorway ramps (using VDF 82) is plotted below against volume-capacity ratio on the ramp. This shows the turn element only, which is the part of the equation shown in red above.
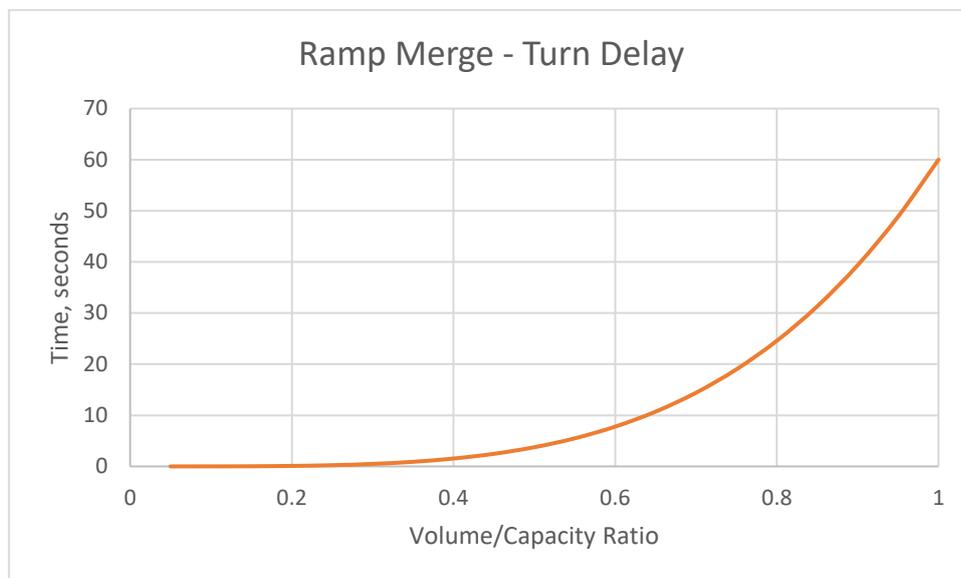

Figure 5-4: Ramp Merge, Turn Delays

5.1.5   Other Functions

In the model, default functions for VDF 80 and 81 have been automatically generated by JCAT and have been retained but are currently not used.

5.2   Turn Delay Functions

The following turn penalty functions (TPF) are used:

- TPF 80 and 83, double lane minor approach (80) and opposed turns from the major road (83), both at 2-way stop controlled intersections

- TPF 81, permissive turns at traffic signals

- TPF 82, protected turns at traffic signals

- TPF 84, fixed input turn capacity for intersections that could not be replicated using JCAT

5.2.1   Priority Intersections

As noted previously, give way priority intersections have been modelled as 2-way stop controlled, as there is no equivalent of a New Zealand give way in the HCM.

For right turns from major arms, TPF 83 is used while a double lane minor approach has TPF 80. The equation for TPF 80 and 83 is identical and shown below. The difference is that the conflicting flows and hence calculated capacities will be different.

The equation for TPF 80 and TPF 83 using EMME syntax is shown below:

$$tp_{80} \ = \ 0.05 + \left(\frac{pvolau + up3}{ep3}\right)^4$$

Where:

tp_{80} =   turn delay, in minutes, calculated by TPF 80

pvolau =   turning volume, PCUs per hour

up3 =   bus turning volume, PCUs per hour

ep3 =   dynamic turn capacity, in PCUs per hour

For a single lane minor approach to a 2-way stop controlled intersection, the turning delay is calculated on the link producing a composite link plus turn time.

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 16

The application of TPF 80 is shown below plotted against volume-capacity ratio.

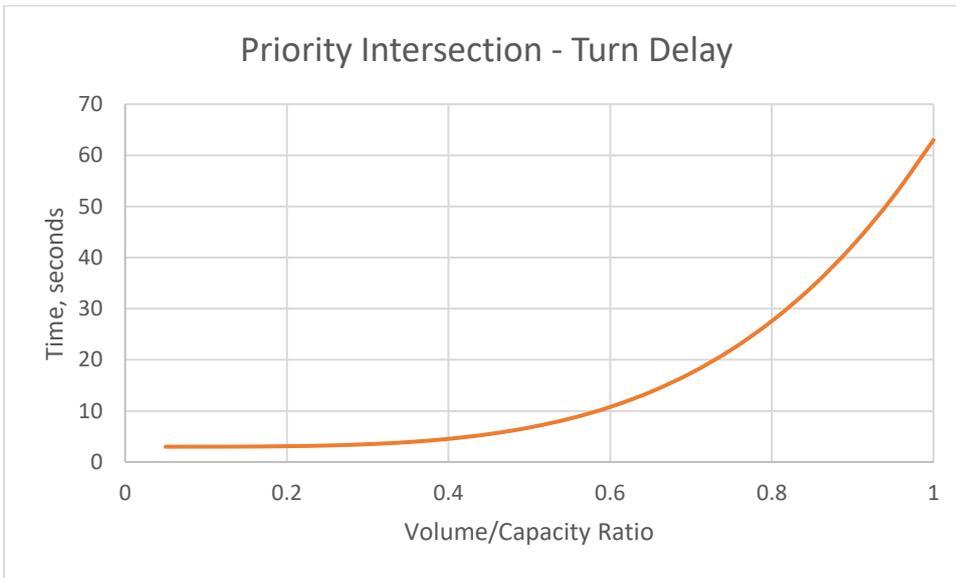

Figure 5-5: Priority Intersection, Turn Delays

5.2.2   Signals

For permissive (i.e. not a protected turn) movements at traffic signals, the following turn penalty function has been used:

$$tp_{81} \ = \ \frac{(\mathrm{ep}1 - \mathrm{ep}2)^2}{120 * ep1} \ * \ \frac{ep3 - {7200}/{ep1}}{ep3} \ + \frac{60}{ep3} \ + \ \left(\frac{pvolau + up3}{ep3}\right)^4$$

Where:

tp_{81} =   turn delay, in minutes, calculated by TPF 81

ep1 =   signals cycle time, in seconds, equivalent to @cycle

ep2 =   phase time at signals for movement, in seconds, equivalent to @green

The delay is a function of volume to capacity, green and cycle time, and capacity. Because of the number of permutations, two graphs are provided below to illustrate the delays. The first graph has capacities per lane of 750 and 1000, and the second has capacities of 250 and 500. In both cases, delay is plotted against volume to capacity ratio. Three green to cycle time ratios are plotted – 75% in a solid line, 50% in a dash-dot line, and 25% using a dotted line.

December 2022 │ Status: Final │ Project No.: 310203597 │ Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx
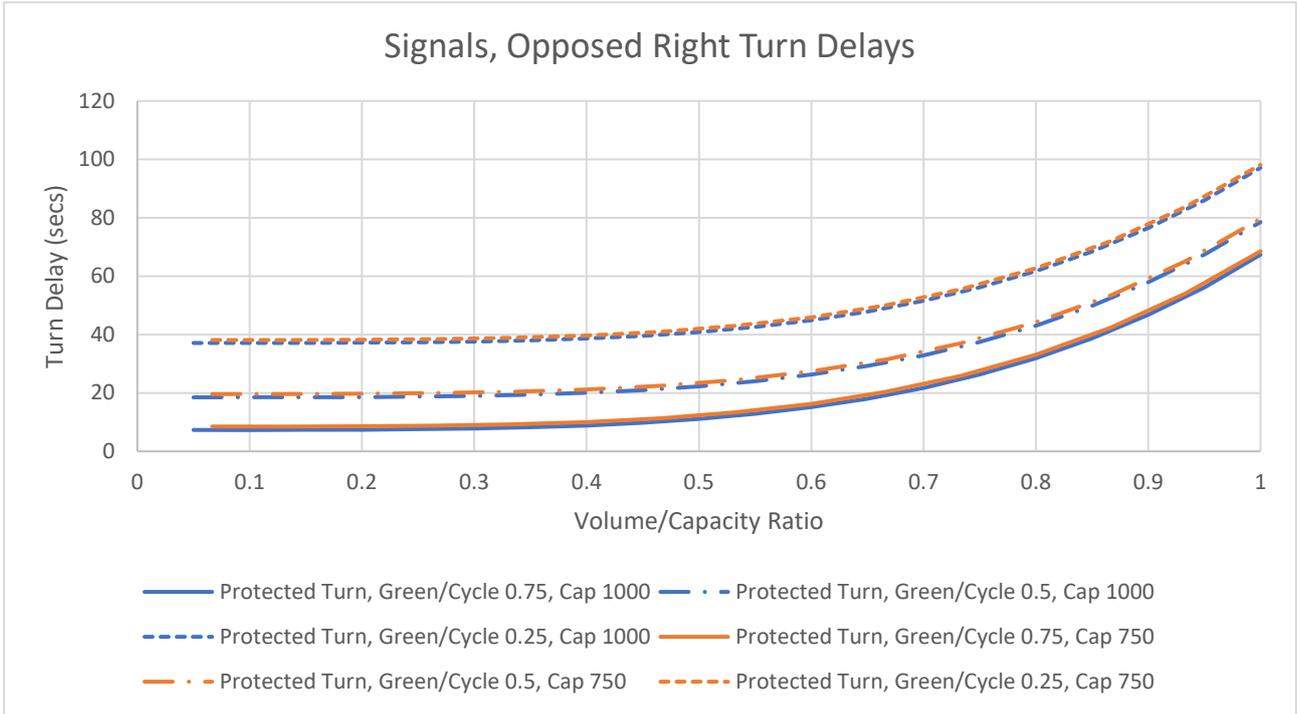
Page 17

Figure 5-6: Signalised Intersection – Turn Delays, Opposed Right Turns – Capacities 750-1000
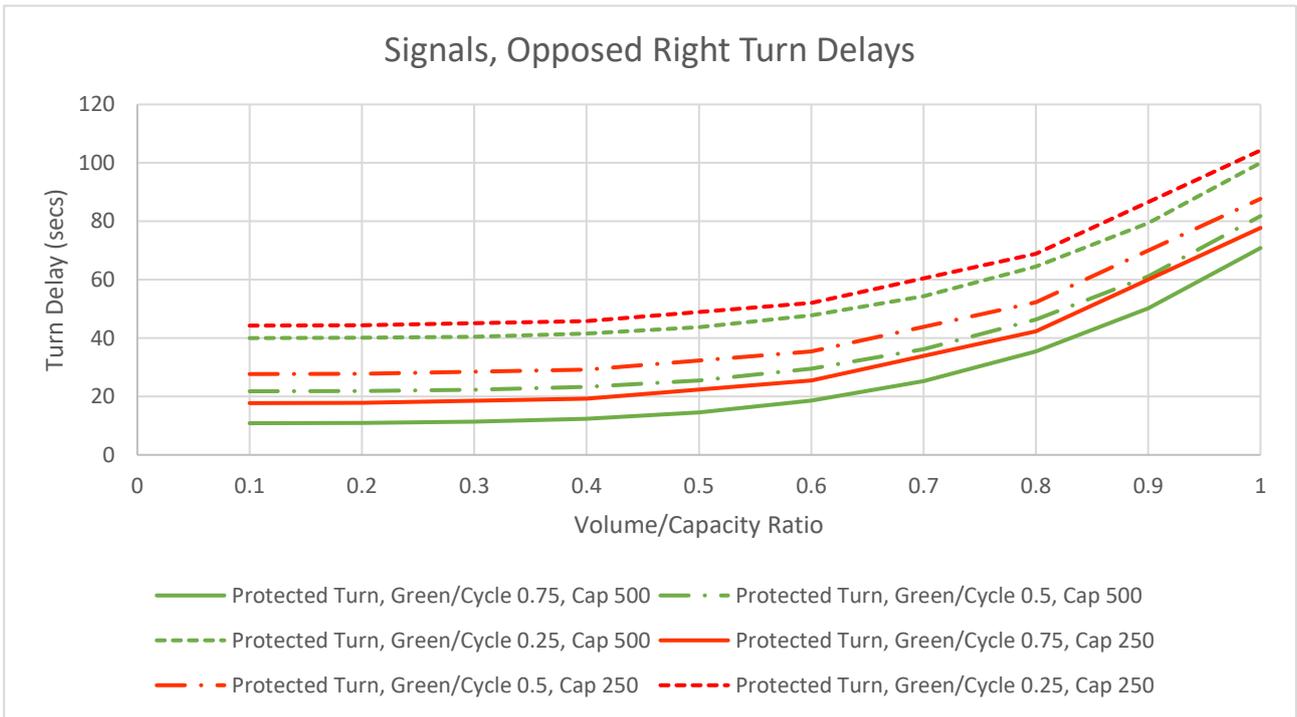
Figure 5-7: Signalised Intersection – Turn Delays, Opposed Right Turns – Capacities 250-500

These graphs show:

- More variation in delay at higher capacities, with an almost flat horizontal line for the lower capacities.

- Delays increase when green time as a proportion of cycle time reduces.

- At lower volumes, the delay experienced is a direct result of the green time.

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 18

For protected movements at traffic signals, the following turn penalty function has been used:

$$tp_{82} = \frac{(ep1 - ep2)^2}{120 * ep1} + \left(\frac{pvolau + up3}{ep3}\right)^4$$

Where:

    tp_{82} =   turn delay, in minutes, calculated by TPF 82

The resulting turn delay for protected movements is illustrated below for a range of green to cycle time ratios. Again, the delays are plotted against volume to capacity ratio.
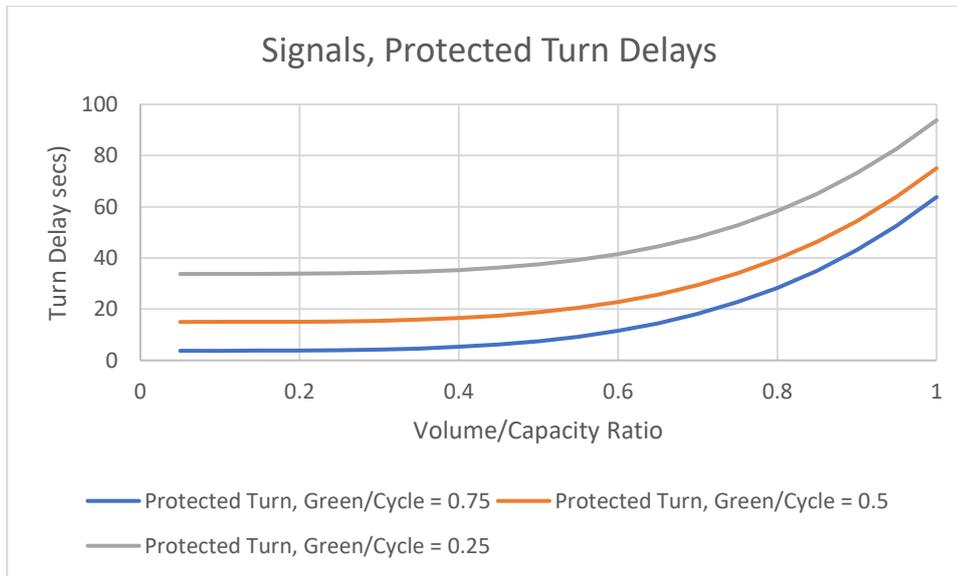

Figure 5-8: Signalised Intersection – Turn Delays, Protected Turn

This shows that turn times decrease as the movement gets a smaller share of the cycle time, and that delays increase with flow.

5.2.3   Treatment of Specific Signalised Intersections

There were three five arm signalised intersections where the standard turn penalty function produced significant and inappropriate delays. This may be due to challenges applying HCM equations to five arm intersections and appropriately calculating the conflicting flows and capacities.   To address this, a fixed input turning capacity was used. The equation used is:

$$tp_{84} = \frac{(ep1 - ep2)^2}{120 * ep1} + \left(\frac{pvolau + up3}{up2}\right)^4$$

Where:

    tp_{84} =   turn delay, in minutes, calculated by TPF 84

    up2 =   fixed input turn capacity, in PCUs per hour

Fixed input turn capacities were used at the following intersections:

- Lambton Quay/Bowen Street/Whitmore Street (node 100416)

- Wakefield Street/Taranaki Street/Jervois Quay (node 100667)

- Courtney Place/Taranaki Street/ Manners Street/Dixon Street (node 100473)

It is noted that the five arm intersection at Featherston Street/Bunny Street/Stout Street (node 100108) is modelled with a dynamic turning capacity calculated by JCAT.

December 2022 │ Status: Final │ Project No.: 310203597 │ Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 19

6. Assignment

6.1 Assignment Process

The JCAT process loads demand to the network, calculates delays based on the capacities at that stage, then recalculates turning movement capacities at certain intervals. The assignment process used is referred to as SOLA (Second Order Linear Approximation) in EMME. The process run is illustrated below and described in the bullet points under Figure 6-1.
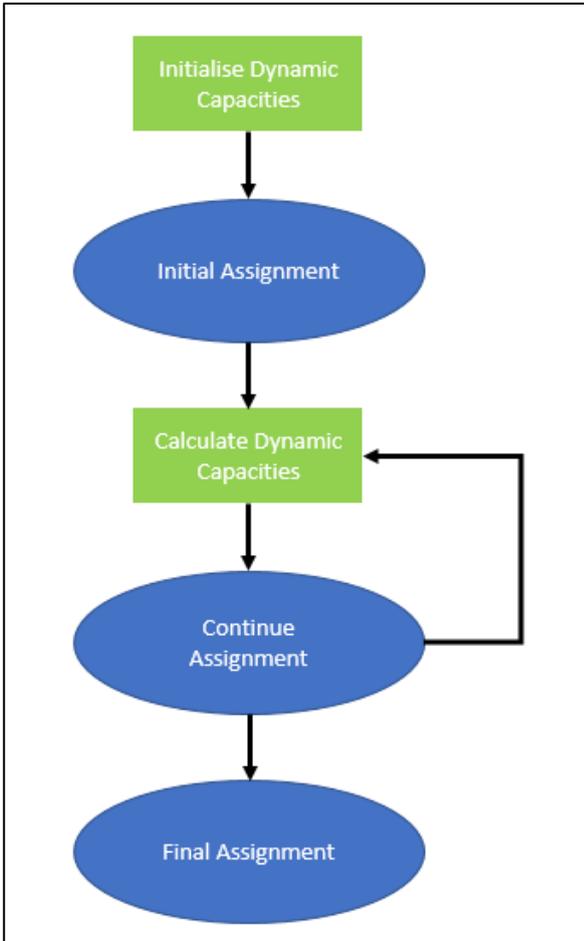

Figure 6-1: Road Assignment Process

The road assignment process is:

- Initialise dynamic capacities to fixed values. See Section 4.2.5.

- Initial assignment in SOLA using input dynamic capacities. These capacities remain fixed during the assignment. The assignment continues until the convergence criteria is reached.

- Dynamic capacities are calculated. These are stored in the EMME variables @lkcap (links) and @tncap (turns). The dynamic link capacity is for intersections with approach delays, such as roundabouts and ramp merges.

- The assignment continues, such that the first iteration number is one higher than the end of the initial assignment. This continues until the specified convergence criteria is reached. Within this assignment, capacities remain fixed as the value calculated in the previous step.

- Dynamic capacities are recalculated.

- Assignment continues. This step is iteratively undertaken with the previous step.

- Final assignment, which is not a continuation with the iteration number reset to one.

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 20

The number of capacity update/assignment loops is controlled by an input integer value. A value of 10 is recommended in the documentation and has been found to produce stable results.

To minimise run times, the JCAT process ("Initial" and "Continue" assignments in Figure 6-1) is a single user class assignment with light vehicles and heavy vehicles added together in units of PCUs. The "Final Assignment" is multi-class, with light and heavy vehicles separated.

6.2   Assignment Convergence Criteria

Each traffic assignment will stop when one of the following criteria is met:

- Maximum number of iterations

- Relative gap, difference between the total travel time on the network and the total travel time on the shortest paths for the current iteration

- Best relative gap (percentage), estimate of the difference between the current assignment and a perfect equilibrium in which all paths used for an OD pair would have exactly the same cost

- Normalised gap (minutes), difference between the mean trip time of the current assignment and the mean minimal trip time. Mean trip time is the average time on the paths used in the previous iteration. Mean minimal time is the average time using shortest paths of current iteration.

The convergence criteria values used are listed in the table below.

Table 6-1: Assignment Convergence Criteria

Criteria	Value
Maximum iterations	100
Relative gap	0.001
Best relative gap	0.01
Normalised gap	0.005

The number of iterations is not considered as a stopping criterion in the final assignment.

6.3   Generalised Cost

Path building in the assignment is based on generalised cost, combining time and distance components. The light and heavy vehicle generalised cost equations for assignment are reported below.

$$Light\ GC = timau + \frac{\frac{voc\_lv}{100} * length + toll}{\frac{vot\_lv}{60}}$$

Where:

timau =	congested travel time, minutes
length =	distance, kilometres
toll =	toll, dollars
voc_lv =	vehicle operating cost, light vehicles, cents per km
vot_lv =	value of time, light vehicles, dollars per hour

$$Heavy\ GC = timau + \frac{\frac{voc\_hv\_fuel\ +\ voc\_hv\_nonfuel}{100} * length + toll}{\frac{vot\_hv}{60}}$$

Where:

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 21

voc_hv_fuel =   vehicle operating cost, fuel, heavy vehicles, cents per km

voc_hv_nonfuel =   vehicle operating cost, non-fuel, heavy vehicles, cents per km

vot_hv =   value of time, heavy vehicles, dollars per hour

In the single class assignment within the JCAT process, the combined light and heavy vehicles use the light vehicle generalised cost equation.

Parameter values are specified in Technical Note 22: Model Input Parameters, Table 2-4 for vehicle operating costs and Table 2-7 for value of time.

7. Summary

This technical note has documented:

- JCAT mandatory requirements and idiosyncrasies

- Calculation of dynamic capacities and congested travel times on links and turns

- The assignment process, convergence criteria, and generalised costs in path building

Key points to note are:

- Priority intersections are modelled using the 2-way stop equation in JCAT.

- Turn delays for roundabouts and merges are calculated as a link variable, hence timau (the EMME attribute for travel time on the link) includes both link and turn time/delay for these two intersection types.

- There are further changes applied to capacities by JCAT to account for lane sharing. These are not documented in this technical note but can be found in the JCAT documentation.

- The assignment is in units of PCUs.

December 2022 | Status: Final | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 22

Appendices

Appendix A   Client Comment and Consultant Response

No.	Comment By	Comment	Response
1	Andrew Ford	2.1 - Maybe change the language to along the lines of "following discussions within the client team, the assignment has been changed from vehicle to PCU" and provide a brief rationale for this decision	Done
2	Andrew Ford	3. Road Network – I assume it also includes the Mackays to Peka Peka Expressway……	Correct, this has been included. Updated in notes
3	Andrew Ford	Additional connectors requested by PCC – again implies that we haven't added detail elsewhere, and just did it because PCC asked? I think – but not sure – that the additional connectors in PCC area could change route choice, whereas new connectors elsewhere such as Wellington Northern Suburbs are connecting sub-divisions into an existing access road? Or was it just that they were one of the only TLAs to come back with comments?? Only a minor point as I am confident, we haven't missed out any significant new roads	All TLA's were contacted, PCC provided a detailed response. No other areas have been flagged or highlighted so we don't believe there is anything significant left out.
4	Ian Clark	From Review of TN25 - Should HCVs have a higher PCU value than 2?	Traffic counts are now only classified as "heavy", without the previous 14 categories to enable a more detailed estimate of a PCU factor. In the absence of other data, we consider a value of 2 is appropriate. It indicates heavies take in the order of twice the road space as cars. Happy to adopt a different value if you have access to more data.
5	Ian Clark	From Review of TN25 - The TN should make it clear that TN28 relates to WTSM and WTAM – this is not clear, currently	Paragraph added to introduction.
6	Ian Clark	Section 4.2.1: what is meant by "give way intersections in the NZ context" – when the main difference between NZ and other countries was removed a few years ago (ie the old give way to left turns rule)?	Rephrased. There is no intersection model for a give way in JCAT as its an intersection form used predominantly in NZ and Australia but not in the US. The US reference is that the JCAT equations come from the HCM, which is American.
7	Ian Clark	Section 4.2.2: Presumably the values in Table 4.2 are per lane (based on the calculation in Figure 4.1) – this should be made apparent.	These values are for through movements only turns i.e. Figure 41 shows the through @lanes values. Left and right turns have @lanes values of the total turning lanes regardless of whether it is shared

December 2022 | Status: **Error! Reference source not found.** | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 24

No.	Comment By	Comment	Response
8	Ian Clark	Section 4.2.3: Do the @nema values have any significance, or are they just identifiers?	They identify the inbound direction and turn + protected, permissive turns for signals. The numeric values for signals come from the HCM (Vol 3, Exhibit 18-2). Unsignalised intersections are the signalised value multiplied by 10 with 9 added.
9	Ian Clark	Section 4.3: it appears that many of the calculations are made automatically by JCAT, based on HCM, without user ability to change the values. Is that correct, as it then appears (for example Section 4.3.3) that the user can then make changes?	There are input fields for minimum turn and link capacities that can be set before running JCAT. This is essentially the extent of control the user has (noted in section 4.4). The reference in section 4.3.3 to changing how ramp merges are modelled would mean we would remove the intersection modelling if it is not realistic, and replace with a simple relationship.
10	Ian Clark	Section 4.3.4. I note the comment that the values have been adjusted from right to left hand drive - which then further implies that the user can change the JCAT values.	The JCAT @nema values have been reversed to account for this. The note about reversing for left hand drive is to indicate if you look up the HCM or the JCAT documentation, you need to read "left" as "right". We have changed the directional referencing in this report for the NZ context.
11	Ian Clark	Section 4.4 It may be useful at some time for the number of times the minimum values are invoked to be made apparent – so that we can see the significance of this issue. Also, I'm interested in Figure 4-4 and the paragraph beneath (bottom of page 10) which implies that the capacity of ramp merges is close to 0, when the main line is operating at capacity. This is not how ramp merges operate in reality, with the bottleneck affecting both the ramp and the mainline, roughly on a "merge like a zip" courtesy.	During the validation stage we expect there may be manual interventions with some ramp merges, which may have the minimum capacity when they should have more. We concur with your point about how ramps operate in reality – but this is not possible in JCAT. Hence our note in section 4.3.3 that we may need to remove some JCAT ramp merges.
12	Ian Clark	Section 5 has some interesting (!) formulae. I haven't worked through each and every one in minute detail, but note as with other technical notes, that the proof is in the validation. In addition, there may be a need for sensitivity tests on certain equations, such as that relating to generalised cost (Section 6.3).	We have not planned to sensitivity test the generalised cost for assignment. We will assess the mode choice sensitivity related to changes in generalised cost. If you would like to discuss the merits of sensitivity testing the generalised cost for assignment, please let us know.
13	Ian Clark	Several of the Figures showing modelled delays only go to a V/C of 1. What happens beyond this – do delays continue to increase, or are they capped at the V/C of 1 value?	V/C can increase and delays increase also
14	Ian Clark	It is not clear why delays in Figure 5-6 increase as V/C increases (for capacities of 750-1000) while delays in	You are correct, these graphs had an error and have been updated.

December 2022 | Status: **Error! Reference source not found.** | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 25

No.	Comment By	Comment	Response
		Figure 5-7 (for capacities of 250-500) do not, for opposed right turns at signals.	

December 2022 | Status: **Error! Reference source not found.** | Project No.: 310203597 | Our ref: TN28 - Wellington Analytical Tools 2019-21 Update - Road Assignment V3.docx

Page 26