# Appendix A Model Development and Assumptions

TUSTM was originally developed in early 2005 by Transurban's Traffic Services Group (TSG) building from research, models and data files created by consultants commissioned by Transurban prior to this time. Since then, progressive updates and enhancements by TSG have ensured its currency and accuracy for the purposes of annual reporting, prospective bids, and network changes. As such, it provides the foundation for traffic predictions, and remains a comprehensive tool for estimating the impact of significant network changes in terms of both traffic and revenue implications on Sydney toll roads. The TUSTM utilises the Cube Voyager software platform.

The modelling structure and validation of Version 8 of the TUSTM, particularly relating to the modelling investigation of the M2 Upgrade is summarised below.

## Traffic Forecasting Methodology

TUSTM is used as a forecasting tool, predicting traffic conditions at defined future points in time, namely the forecast years of 2011, 2016 and 2021 having been calibrated and validated to a base year of 2006. The input land use assumptions are based on TDC's published land use information. The capacity of the road network links are based on actual lane configuration and sign posted speed limits. For future links such as F3 to M2 assumptions have been made as to lane capacity, toll rates and sign posted speed limits similar to other motorways in the Sydney network.

## TUSTM General Characteristics

The general characteristics of the TUSTM are:

- Trip tables for base and future years; the base year trip tables used in TUSTM have recently been developed and validated by consultant Sinclair Knight Merz (SKM) using data supplied by the Transport and Population Data Centre (TDC). Future year trip tables apply growth factors derived from future year land use projections. The tables are segmented into five categories and assigned to the transport network as separate vehicle classes:
  - Car Commute;
  - Car Business;
  - Car Other;
  - Rigid Trucks; and
  - Articulated Trucks.
- The model is segmented to 4 time period (AM peak, inter peak, PM peak and overnight) an average workday model and calibrated to a "base year" of 2006 using strategic screen-line counts and travel time data;
- Primarily a road based model with public transport travel addressed through direct cross elasticity;
- Model includes 919 travel zones covering the Sydney metropolitan area;
- The travel times on a road link vary depending on the traffic volume, the number of mid-block lanes and the road type, according to "speed-flow" relationships. Strategic intersection delay, acknowledging the volume into a junction and its capacity are incorporated in the speed-flow relationships as are the impact of varying availability of lanes by time of day;
- The input networks include network upgrades and demand management measures that can affect the traffic behaviour including assumptions regarding future projects and timing of works. The future projects are based on the approved list of projects, major network changes and upgrades; as discussed and agreed with RTA;
- The perceived out-of-pocket toll cost is incorporated into a generalised cost function which is used as the measure of impedance in the trip assignment process;

- The equivalent time penalty is calculated from the toll price using relevant Value of Travel Time (VOT). This time penalty is then included in the generalised cost of the tolled route and the assignment algorithm is free to allocate trips between tolled and untolled routes;
- Toll caps are fully captured in the process (specifically that of Westlink M7);

The assignment process works iteratively until such point that balance is achieved between travel demands and network delays for each zone-to-zone paths.

## Assignment within TUSTM

Figure 38 describes the process of assignment in TUSTM.

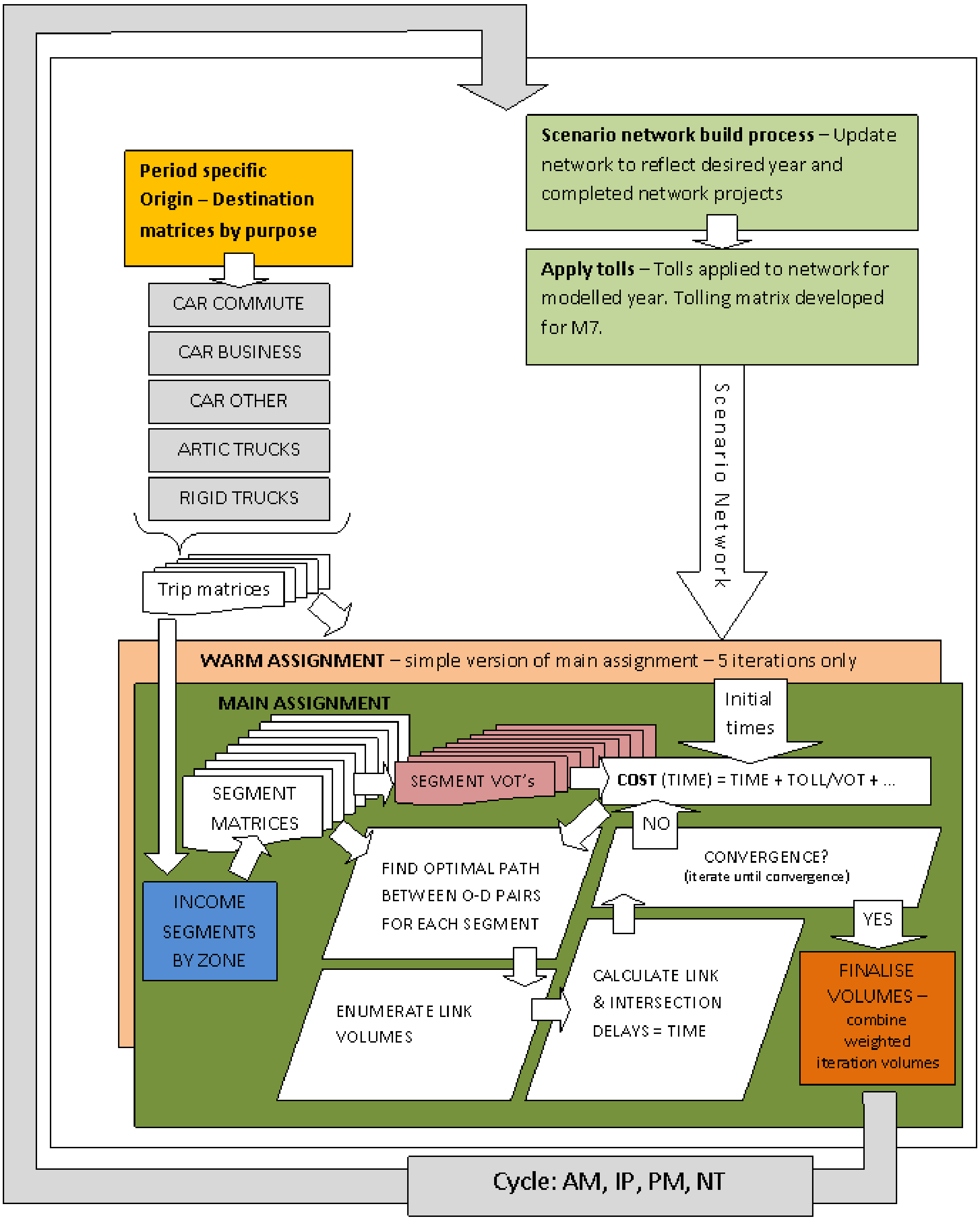


Figure 38 - Overview of TUSTM Assignment

The trip matrices are split by vehicle type and purpose. The private car purposes (commute, business and other) are further segmented by 3 household income groups being high, middle and low. This further segmentation allows for further divisions of value of travel time (VOT), and by increasing the number of segments allows a more detailed assessment of tolled versus non-tolled choice across the network. The segmentation occurs at a zonal level and is based on household income data from the 2006 census. The sensitivity to geography is important as it acknowledges that there are lower income and higher income suburbs across the Metropolitan area.

Figure 39 shows the family income bands by statistical sub-division and indicates a reasonably wide range of family incomes across Sydney. Observations are:

- Lowest family incomes are in the South West of Sydney (Fairfield, Liverpool, Canterbury and Bankstown) where some 40% to 50% of families have a weekly family income of $1,000 or less;
- Highest family incomes are in the Lower North Sydney suburbs of Kirribilli and Mosman and the Eastern Suburbs where 60% to 65% of families have a weekly income of $2,500 or meaning 35% to 40% of families have a weekly income of over $2,500.

This pattern will lead to differential values of times across the region and explains the presence of cashback[17] on the M4 and M5 motorways where the former Labour Government was looking to offer some relief to the less well-off families of the South and West.

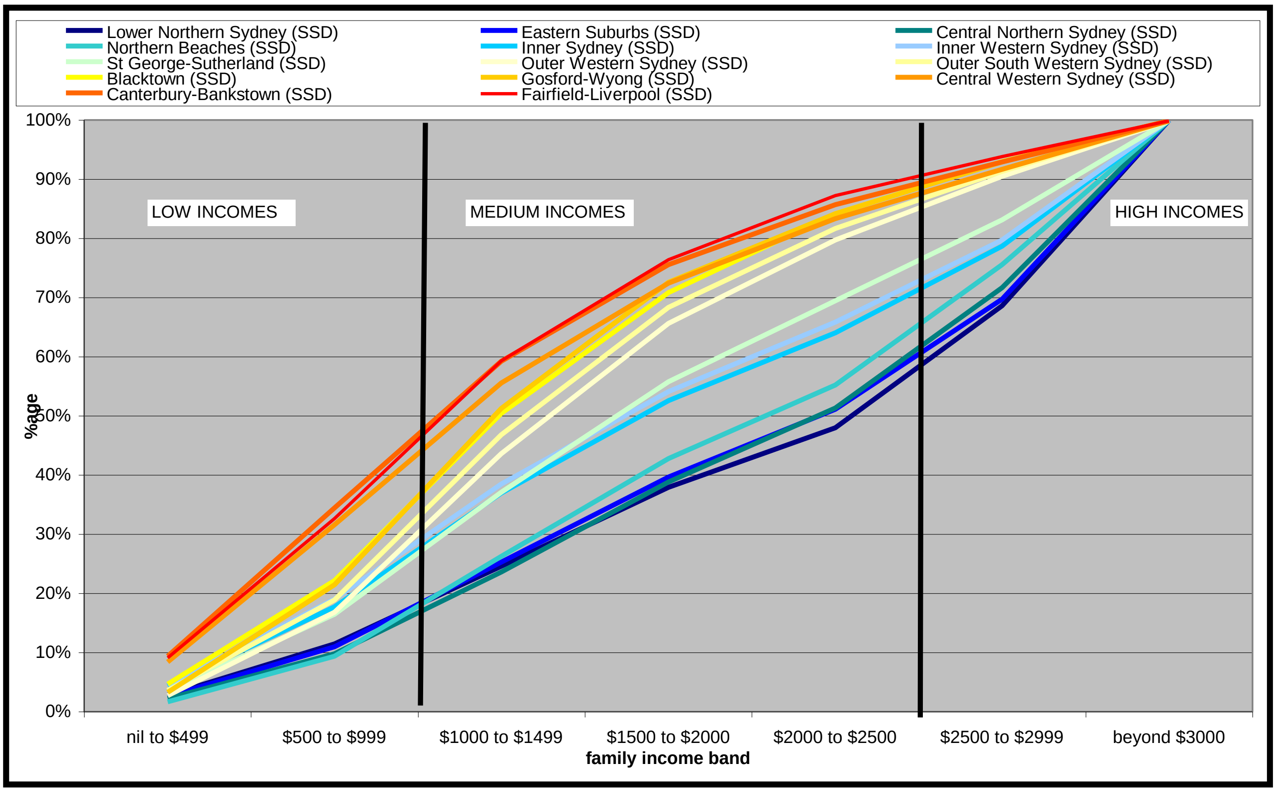


**Figure 39 - Sydney Income Distribution**

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[17] *The NSW Government introduced the M4/M5 Cashback Scheme on 1 January 1997. Cashback allows NSW residents to claim back the value of tolls (excluding GST) paid while using privately registered vehicles on the M4 and M5 motorways.*

## Road Network Representation

The roads that are generally represented within the traffic model network are Secondary Main Roads, Primary Main Roads, Motorways and Tollways, according to SYDWAYS classification. Road characteristics such as the number of lanes, road type, posted speed, trams, parking bans, divided road, distance and intersection flaring have been included in the model and have been used to determine road capacity.

The model network comprises a series of nodes and links. Nodes represent transport zone centroids and intersections between roads and connectors. A connector is a link that connects a transport zone centroid with the road network. Links generally represent both road sections between two intersections (nodes) and centroid connectors. Links also store the road characteristic information that the model requires for modelling.

The model contains 919 transport zones, of this 906 are internal zone and 13 are external zones. A transport zone represents a small area of metropolitan Sydney. The external zones represent connections between major highways and Motorways beyond the boundaries of metropolitan area, i.e. Hume Highway to Melbourne.

All links in the network have been adjusted to reflect:

- Time period and the directionality of lanes (i.e. tidal flow arrangements);
- Presence of Transit lanes (high occupancy vehicle lanes) which restrict access to those cars with 2 or more occupants (T2 lanes) or 3 or more occupants (T3 lanes) and in so doing restrict the capacity available for single occupancy vehicles; Transit lanes can be time of day specific;
- Bus lanes - restrict all cars from the lanes and are only for buses; and
- Parking restrictions also vary by time of day with AM or PM peak clearways increasing lane availability in the peak periods above that available in the inter-peak and off peak periods.

Networks for each forecast year are built from a base year network and a set of network changes to represent future projects and/or changes in operating conditions along routes.

### *Vehicle Type and Passenger Car Unit*

In describing the capacities of links, the term “passenger car unit” (PCU) has been introduced. The PCU is the means of reflecting the impact of trucks on the network whereby they take up more road space, are generally slower to accelerate and hence take up more capacity than the car. PCU values adopted within TUSTM are:

- Cars have a PCU value of 1;
- Rigid Trucks have a PCU value of 2; and
- Articulated Trucks have a PCU value of 2.5.

A capacity of a motorway lane is often taken as 2,000 vehicles per hour per lane, however it will be dependent on the vehicle type mix and implies a higher PCU capacity. As noted in section 3.1 TUSTM adopts a PCU capacity of 2,200 PCUs per lane per hour for motorways which comprises of vehicle type mix of order:

- 1850 Cars yielding 1850 PCUs;
- 90 Rigid Trucks yielding 180 PCUs; and
- 60 Articulated Trucks yielding 150 PCUs.

Hence in total some 2,000 vehicles equate to 2,180 PCUs

### *Link Types within TUSTM*

The TUSTM allocates each and every real road link to one of nine categories, whilst symbolic links between zones and the real road network (centroid connectors) are a tenth category.

The link type is the key to describing the "base" hourly capacity per traffic lane available. The link types and the nominated base capacity are shown in Table 66.

**Table 66 - TUSTM Hourly Lane Capacities**

| DESCRIPTION | LINK TYPE | HOURLY LANE CAPACITY (VEHICLES) | HOURLY LANE CAPACITY (PCU) |
|---|---|---|---|
| Freeways/Motorways | 1 | 2000 | 2200 |
| Ramps | 2 | 1650 | 1300 |
| Motorway-to-Motorway Ramps | 2.5 | 1650 | 1815 |
| Major Arterials | 3 | 1800 | 1980 |
| Arterials | 4 | 1650 | 1815 |
| Sub-arterial | 5 | 1500 | 1650 |
| Collectors | 6 | 1000 | 1100 |
| CBD Streets | 7 | 900 | 1000 |
| Residential Streets | 8 | 550 | 600 |
| Centroid | 9 | N/A | N/A |

Table 66 above details theoretical hourly lane capacity based on the number physical lanes in the network. However, in practice the number of available lanes can vary by:

- Time period and the directionality of lanes (i.e. tidal flow arrangements to maximise peak direction flows);
- Presence of Transit lanes (high occupancy vehicle lanes) which restrict access to those cars with 2 or more occupants (T2 lanes) or 3 or more occupants (T3 lanes) and in so doing restrict the capacity available for single occupancy vehicles; Transit lanes can be time of day specific;
- Bus lanes - restrict all cars from the lanes and are only for buses;
- Parking restrictions also vary by time of day with AM or PM peak clearways increasing lane availability in the peak periods above that available in the inter-peak and off peak periods.

These factors are individually catered for within TUSTM and lanes are adjusted accordingly to match conditions of the 2006 Base Network. Within TUSTM the following capacity adjustments are made for Transit Lanes:

- T2: 20% of link type theoretical capacity; and
- T3: 5% of link type theoretical capacity.

The above assumptions apply equally across all time periods.

For the purposes of modelling the proposed M2 Upgrade T2 lane, a car occupancy survey was undertaken by AusTraffic during the AM and PM peaks at varies locations along the M2 motorway. The following capacity adjustment has been made to the proposed M2 upgrade T2 lane based on the survey results:

- AM EB T2 Lane between Terry's Creek and Lane Cove Road assumed 13% of motorists T2 or above.
    - Therefore total AM capacity equivalent to 2.13 lanes
- PM, OP and NT EB T2 Lane between Terry's Creek and Lane Cove Road assumed 21% of motorists T2 or above.

- Therefore total PM and Off Peak capacity equivalent to 2.21 lanes

## Modelling of Network Times and Delays

Travel times along each link comprise of:

Time / delay incurred whilst traversing the mid-block section of a road between intersections – these are a function of mid-block distance, free-flow speed and the prevailing volume-to-capacity ratio of each iteration;

Additional delays due to intersections – these are a function of approach volume (sum of all link volume), approach capacity (can be different from link capacity i.e. flared lanes at stop lines) and interaction with other traffic (from other links) through the intersection i.e. needs consideration of total flows and capacities of all links into the intersection as well as some regard to intersection capacity.

Figure 40 shows speed-flow curves within TUSTM.

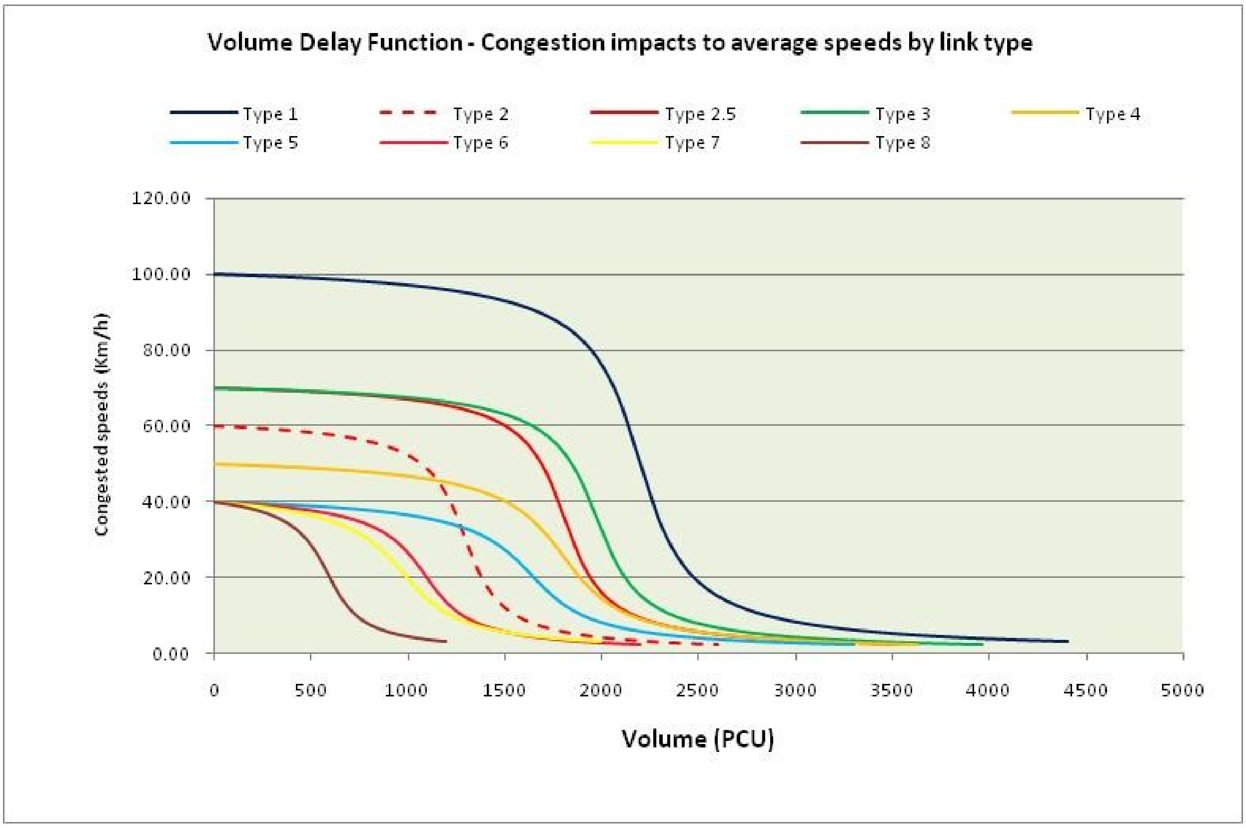



**Figure 40 - TUSTM Volume Delay Functions**

## Base Year Model Calibration/Validation

### *Base Year Trip Tables*

Sinclair Knight Merz (SKM) were commissioned by Transurban in 2006 to estimate and validate base year trip tables (2006) for each of the market segments and time periods of the TUSTM. Trip tables were estimated for the five categories of Car Commute, Car Business, Car Other, Rigid Trucks and Articulated Trucks and for the four time periods of AM Peak. Inter Peak, PM Peak and Night Time.

SKM estimated the 2006 trip tables from data and raw model outputs from the Sydney Traffic Model (STM) of The Transport and Population Data Centre (TDC), and utilised the earliest implementation of the

STM non-home based models; the lack of non-home based models in earlier STM releases has always been acknowledged as a weakness for the estimation of trip tables outside of the peak periods.

### *Network Audit*

As part of the calibration and validation of the base year model, a full independent network audit was undertaken by SKM to ensure the accuracy of all link attributes such as:

- Traffic lanes available;
- Link type; and
- Link distance.

Attributes were confirmed using recent aerial photography and road inventories where appropriate. A detailed report noting all amendments was provided by SKM.

### *Validation Criteria*

A set of model validation criteria has been adopted for assessing the TUSTM performance and its "fitness for purpose". These are based on recognised international best practice for modelling. Specifically the threshold criteria adopted for TUSTM has been drawn from traffic model calibration guidelines published by the UK Highways Agency (Traffic Appraisal Advice, Highways Agency, May 1996) and Land Transport NZ (at the time called Transfund NZ).

### *Screenline Validation*

The RTA has a system of screenlines at which it collects traffic data on a regular and continuous basis. Screenlines are used to ensure that the model accurately represents the movement of vehicles along natural corridors within the network. They are designed to cover all of the logical choices available to drivers moving between the major segments of the city. As such they provide a comprehensive and detailed method of evaluating whether there are geographic distortions in the model that would otherwise not be evident.

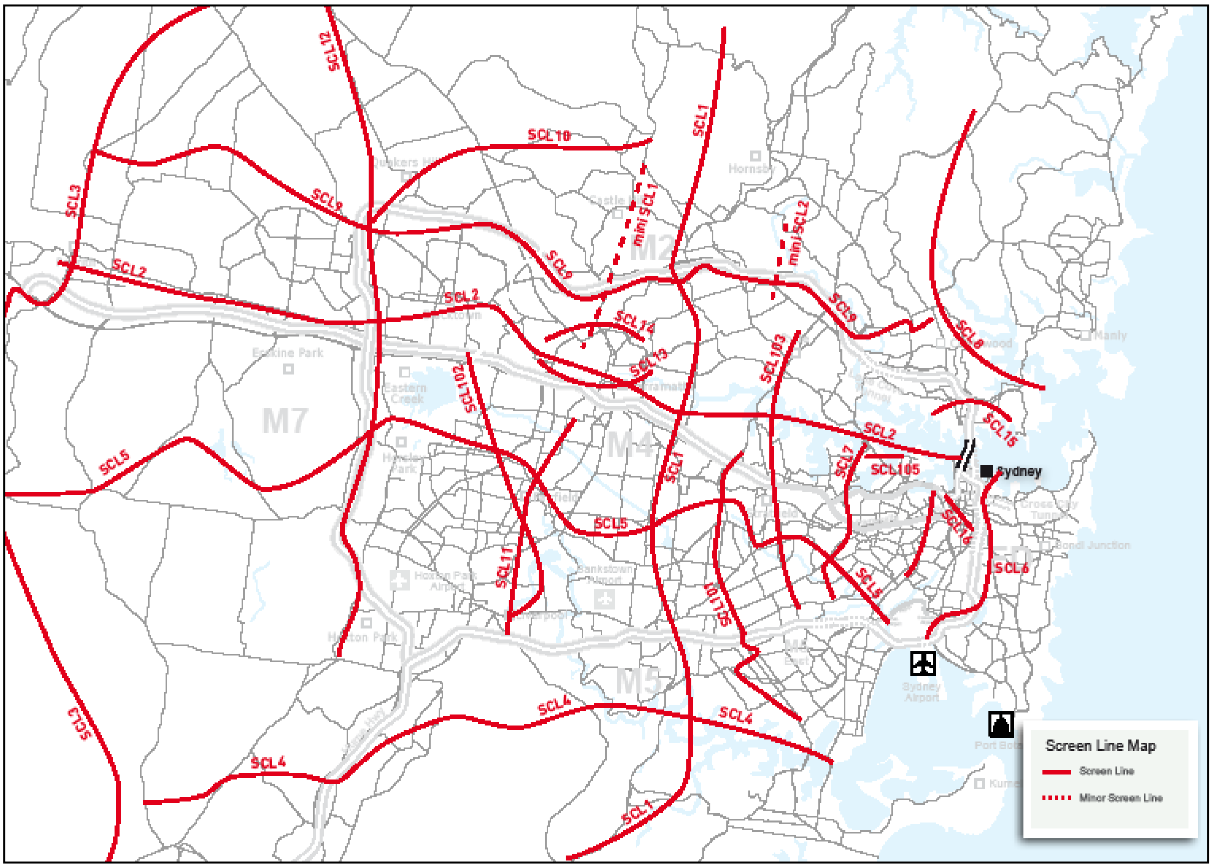



Figure 41 - Screenline Locations

Figure 41 above shows all screenline locations as maintained by RTA. The RTA continuously collects data at specific points along each screenline.

In order to validate the screenline volumes, scatter plot analysis has been undertaken. Modelled and observed volumes are plotted as part of the scatter plot analysis and a linear regression line of goodness-of-fit derived. The target criterion for the scatter plot analysis is given by two measures:

- A coefficient of determination (R2) of 0.85 is generally considered to represent a high level of correlation between the two data sets; and
- the slopes for the best-fit line should be in the range of 0.9 and 1.1 to represent a strong goodness-of-fit.

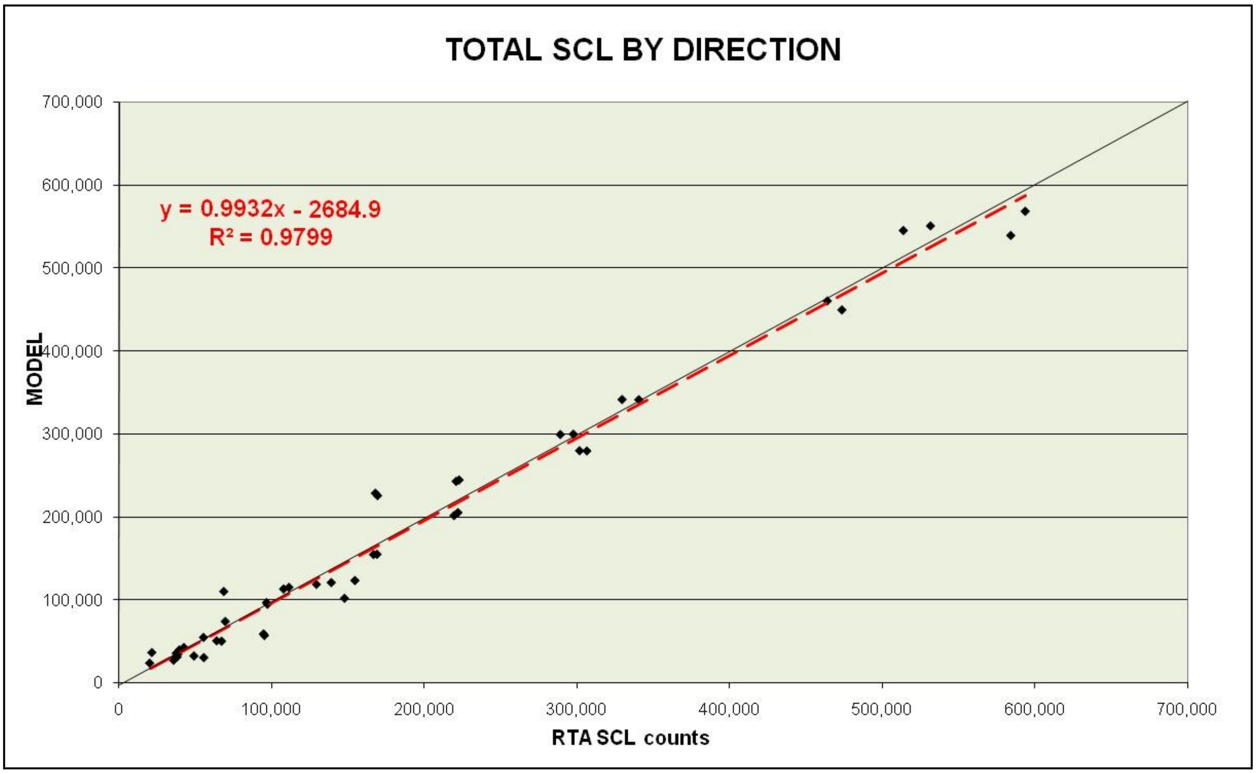



**Figure 42 - Screenline Validation**

Figure 42 represents scatter plot analysis for daily screenline totals by direction. It shows an excellent "goodness of fit" (0.98) and equally good slope (0.99), indicating that the assigned trip matrices are fit for purpose.

### *Toll Point Validation*

The GEH statistic is named after Geoff E. Havers (hence the name GEH) of the Greater London Council and is in the form of the Chi-square measure of fit. It is defined as:

$$GEH = \sqrt{\frac{(V_2 - V_1)^2}{0.5(V_2 + V_1)}}$$

$$V_1 = Modelled\ Flow\ (in\ Vehicles/Hour)$$

$$V_2 = Observed\ Flow\ (in\ Vehicles/Hour)$$

The GEH statistic is considered a useful measure of the performance of a model in a particular area. Examination of absolute or relative differences can provide misleading results over a wide range of volumes. A large percentage difference may relate to a small absolute difference on a lightly trafficked link, and a small percentage difference may relate to a large absolute difference for links with greater volumes. The GEH statistic is less sensitive to these variations and gives roughly the same result for both large and small volumes with the same degree of error.

Generally accepted GEH targets are:

- At least 60% of individual link volumes should have a GEH value of ≤5
- At least 95% of individual link volumes should have a GEH value of ≤10
- All individual link volumes should have a GEH value ≤12

Table 67 - Toll Point Validation

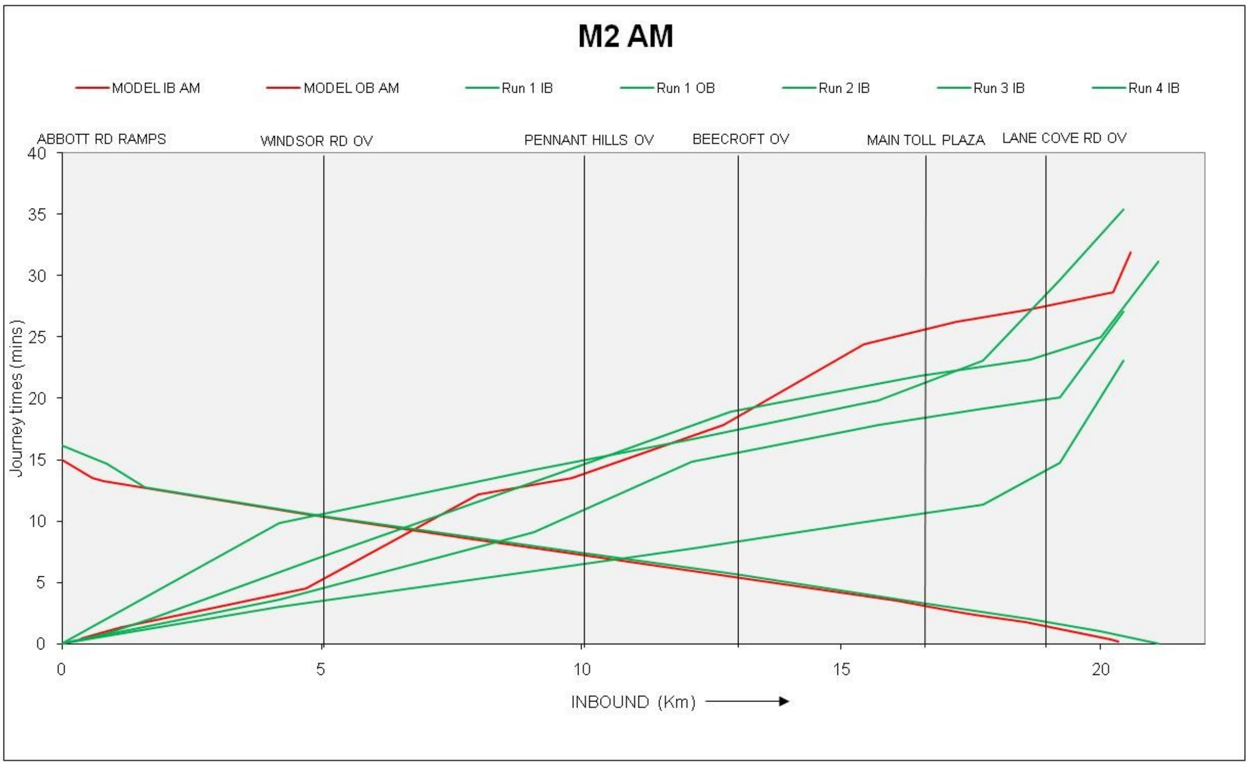
| TOLL POINT | OBSERVED DAILY | MODEL DAILY | GEH |
|---|---|---|---|
| M2 Main | 71,660 | 71,296 | 0.27 |
| M2 Pennant Hills | 24,567 | 19,896 | 6.40 |
| M4 | 113,391 | 116,586 | 1.92 |
| M5 | 114,404 | 115,836 | 0.86 |
| ED | 52,068 | 41,592 | 9.88 |
| M7 | 119,858[18] | 136,306 | 9.38 |

Table 67 is a comparison of modelled and observed daily toll point volumes. As seen, all locations are within the prescribed criteria.

## *Journey Times*

Journey time surveys have been collected for a wide range of routes throughout Sydney and include number of the key routes relevant to the study area. Validation of modelled travel times against the observed travel times involves plotting the two sources on an accumulating distance axis – thereby providing an understanding of any variation between travel times and where on the network the variation may occur.

The results presented in Figure 43, Figure 44, Figure 45 and Figure 46 show comparison of modelled and observed AM and PM peak travel times along the M2 and the alternative free route. As shown the modelled results is compares extremely well to observed travel times along both M2 and alternative in both periods and directions.




[18] *Observed data effected by ramp up*

Figure 43 - Modelled M2 AM Peak Travel Time

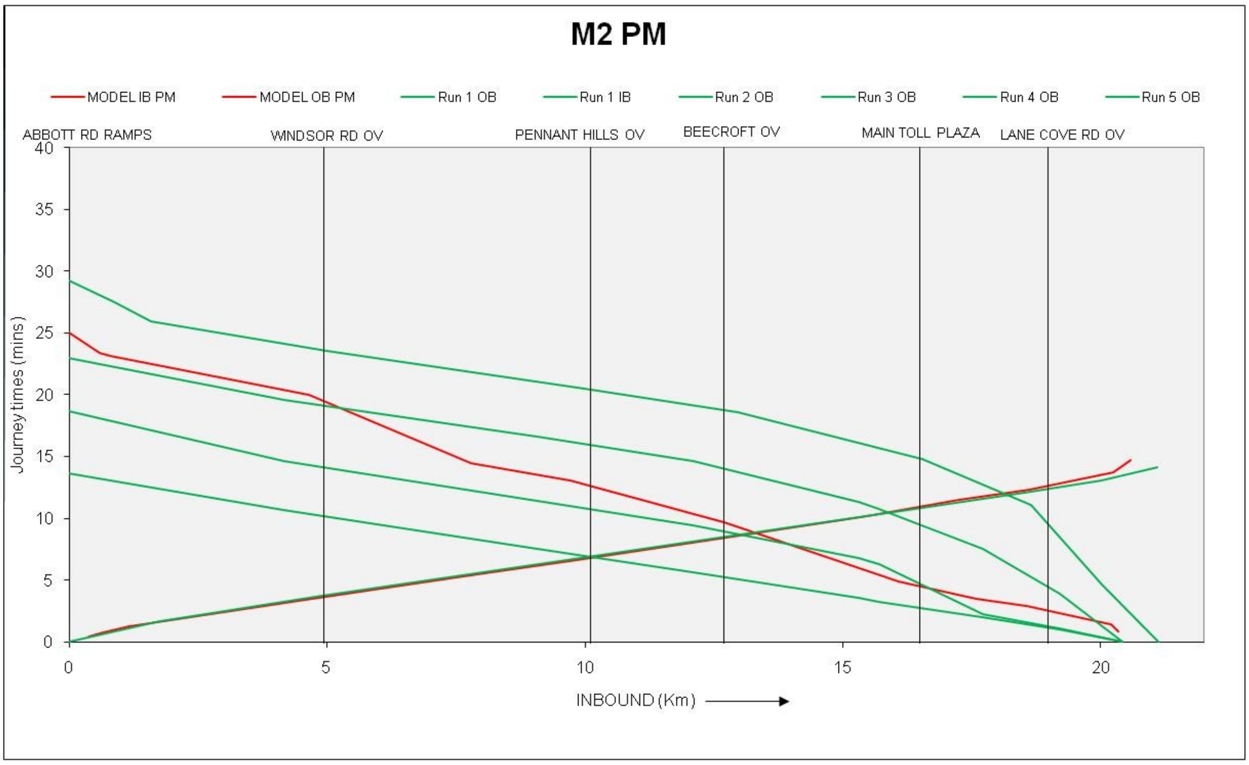



Figure 44 - Modelled M2 PM Peak Travel Time

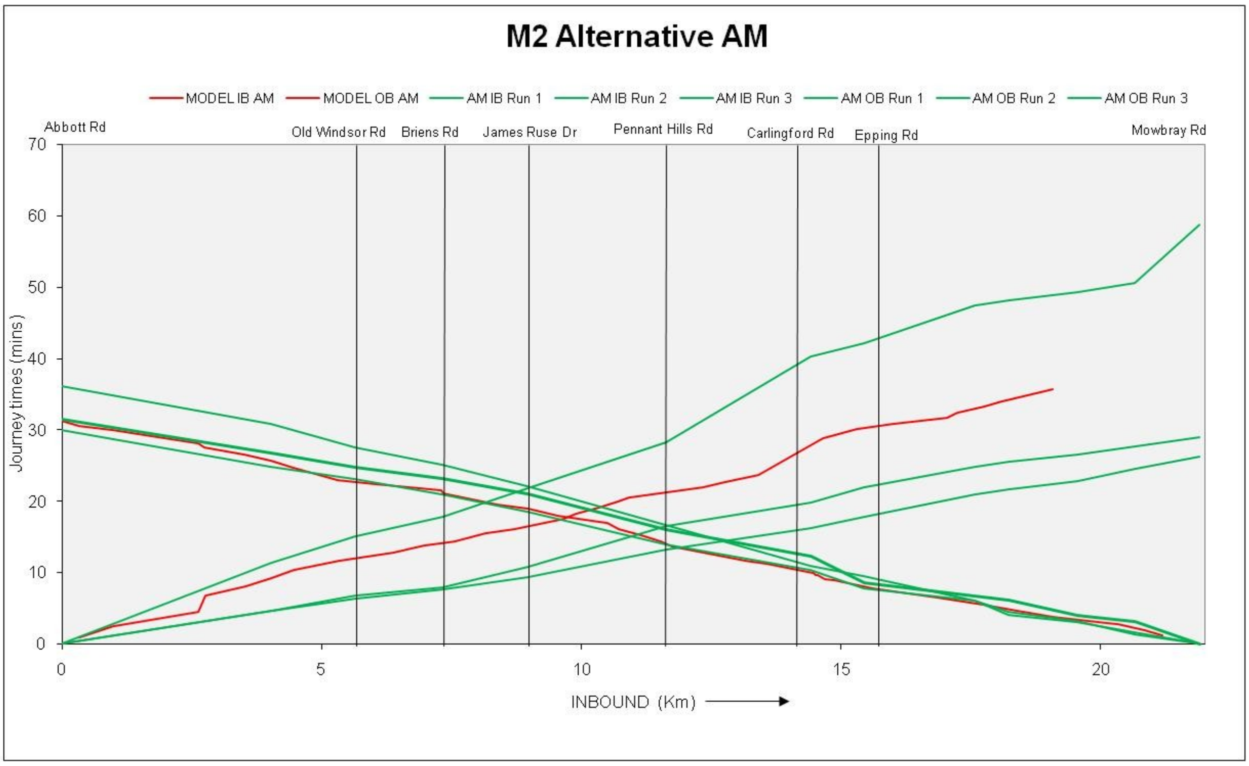



Figure 45 - Modelled M2 Alternative Travel Time

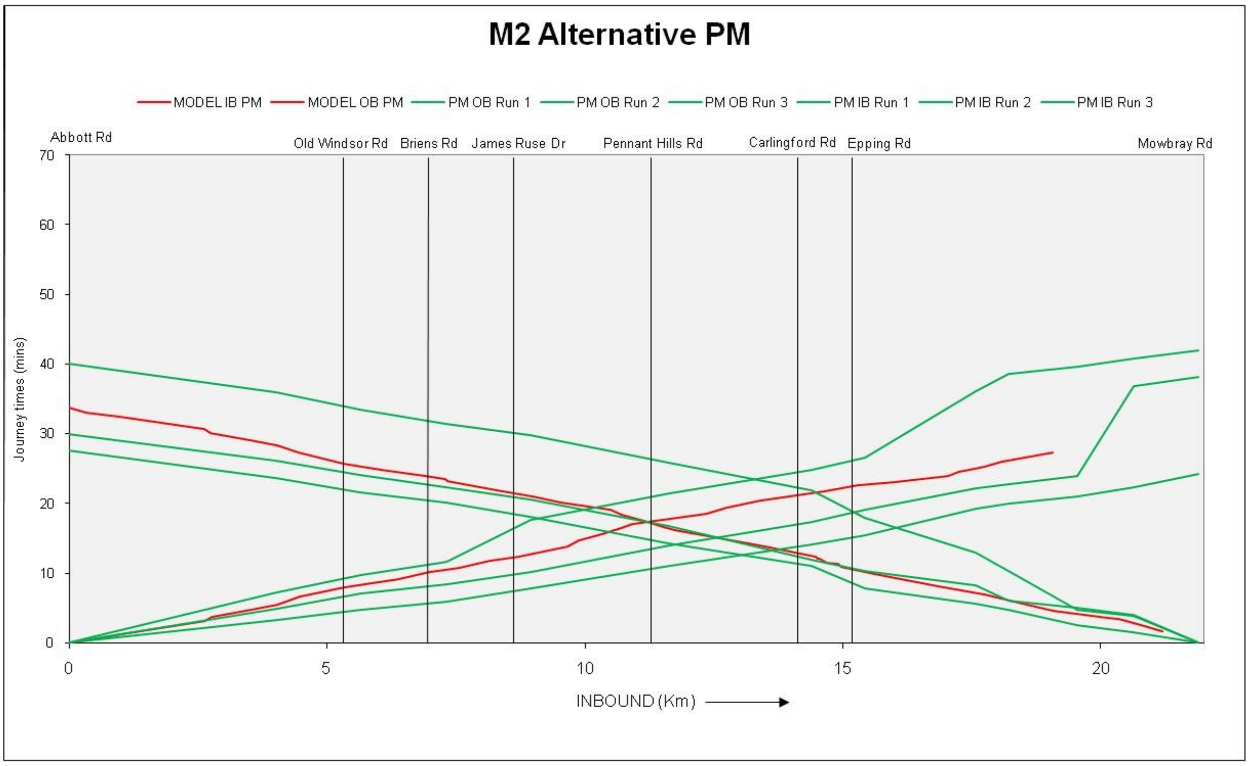



Figure 46 - Modelled M2 Alternative PM Peak Travel Time

## *Demographic Assumptions*

Table 68 - TDC Forecast Population

| Sector Description | 2006 | 2011 | 2016 | 2021 | 2026 | Average p.a. Growth |
|---|---|---|---|---|---|---|
| Inner Sydney | 294,088 | 328,500 | 360,178 | 385,240 | 398,834 | 1.5% |
| Eastern Suburbs | 238,635 | 241,684 | 248,699 | 252,734 | 253,954 | 0.3% |
| Inner Western Sydney | 162,856 | 174,445 | 187,092 | 196,194 | 201,912 | 1.1% |
| Lower Northern Sydney | 292,978 | 301,453 | 309,780 | 315,767 | 323,859 | 0.5% |
| Canterbury-Bankstown | 309,486 | 312,694 | 320,237 | 327,535 | 333,418 | 0.4% |
| Fairfield-Liverpool | 348,080 | 361,191 | 380,752 | 401,756 | 417,218 | 0.9% |
| Central Western Sydney | 295,796 | 311,905 | 334,990 | 354,471 | 374,654 | 1.2% |
| Blacktown | 264,799 | 282,003 | 297,062 | 315,770 | 339,562 | 1.3% |
| Central Northern Sydney | 406,900 | 431,833 | 449,987 | 471,048 | 491,252 | 0.9% |
| Northern Beaches | 231,230 | 236,562 | 240,889 | 244,202 | 252,844 | 0.4% |
| St George-Sutherland | 433,055 | 443,692 | 456,123 | 462,705 | 460,961 | 0.3% |
| Outer South Western Sydney | 234,032 | 246,927 | 269,476 | 296,946 | 339,248 | 1.9% |
| Outer Western Sydney | 303,381 | 306,539 | 316,974 | 330,381 | 345,780 | 0.7% |
| Gosford-Wyong | 299,089 | 316,589 | 334,493 | 354,252 | 372,354 | 1.1% |
| TOTAL | 4,114,405 | 4,296,017 | 4,506,734 | 4,709,001 | 4,905,851 | 0.9% |

Source: Based on the NSW Transport Planning Data Centre (TDC)

Table 69 - TDC Forecast Employment

| Sector Description | 2006 | 2011 | 2016 | 2021 | 2026 | Average p.a. Growth |
|---|---|---|---|---|---|---|
| Inner Sydney | 503,951 | 533,420 | 544,697 | 560,196 | 571,631 | 0.6% |
| Eastern Suburbs | 75,328 | 79,561 | 81,864 | 82,295 | 81,920 | 0.4% |
| Inner Western Sydney | 69,505 | 76,402 | 79,421 | 80,825 | 81,906 | 0.8% |
| Lower Northern Sydney | 228,503 | 244,929 | 258,940 | 268,502 | 277,739 | 1.0% |
| Canterbury-Bankstown | 102,288 | 108,700 | 111,722 | 111,839 | 110,686 | 0.4% |
| Fairfield-Liverpool | 111,229 | 119,501 | 128,733 | 136,327 | 143,846 | 1.3% |
| Central Western Sydney | 179,849 | 192,555 | 204,529 | 207,544 | 211,756 | 0.8% |
| Blacktown | 83,087 | 91,372 | 101,004 | 112,904 | 119,771 | 1.8% |
| Central Northern Sydney | 131,636 | 156,652 | 178,118 | 193,405 | 200,442 | 2.1% |
| Northern Beaches | 82,841 | 89,603 | 94,540 | 97,690 | 99,650 | 0.9% |
| St George-Sutherland | 127,309 | 137,435 | 144,793 | 149,915 | 154,479 | 1.0% |
| Outer South Western Sydney | 64,993 | 74,045 | 81,781 | 89,012 | 96,575 | 2.0% |
| Outer Western Sydney | 94,823 | 104,590 | 111,255 | 119,672 | 126,976 | 1.5% |
| Gosford-Wyong | 95,603 | 109,457 | 119,915 | 128,270 | 134,493 | 1.7% |
| TOTAL | 1,950,945 | 2,118,222 | 2,241,313 | 2,338,397 | 2,411,871 | 1.1% |

Source: Based on the NSW Transport Planning Data Centre (TDC)

## *Values of Time*

The values of time applied to tolls for conversion to equivalent travel minutes are given in Table 70. These values comprise a wide ranging review of survey and values applied in toll road forecasts around Australia and are hence of the right order.

Table 70 - Base Year 2006 Value of Time ($2006)

| Purpose | Income Segment | | |
|---|---|---|---|
| | Low | Medium | High |
| Car Commute | $15 | $17 | $20 |
| Car Business | $20 | $30 | $40 |
| Car Other | $8 | $10 | $15 |
| HCV Rigids | (skewed) distribution with a mean VOT of $30 | | |
| HCV Artics | | | |

In future years it can reasonably be expected that the relative difference between users' willingness-to-pay and the toll rates will become more apparent due to differential changes in disposable incomes and tolling rates.

Users' willingness-to-pay can be expected to increase over time as disposable incomes increase (as indicated by the higher AWE growth above CPI growth). The relative difference between these factors has been reflected in the model by de-escalating the willingness-to-pay parameter by a rate that is the expected difference between AWE and CPI. Table 71 documents the AWE inflators and the resultant values of time applied in each year of the model.

**Table 71 - Future Year VOT**

| Purpose | 2011 AWE Inflator 1.07 | | | 2016 AWE Inflator 1.13 | | | 2021 AWE Inflator 1.22 | | | 2026 AWE Inflator 1.31 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Med | High | Low | Med | High | Low | Med | High | Low | Med | High |
| Car Commute | $16 | $18 | $21 | $17 | $19 | $23 | $18 | $21 | $24 | $20 | $22 | $26 |
| Car Business | $22 | $32 | $43 | $23 | $34 | $45 | $24 | $37 | $49 | $26 | $39 | $52 |
| Car Other | $9 | $11 | $16 | $9 | $11 | $17 | $10 | $12 | $18 | $10 | $13 | $20 |
| HCV Rigids | (skewed) distribution with a mean VOT of $32 | | | (skewed) distribution with a mean VOT of $34 | | | (skewed) distribution with a mean VOT of $37 | | | (skewed) distribution with a mean VOT of $39 | | |
| HCV Artics | | | | | | | | | | | | |