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Sydney Strategic Model Re-estimation

Mode-Destination Model

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Preface

RAND Europe were commissioned by the Transport Data Centre (TDC) (now known as Bureau of Transport Statistics, and referred to as BTS) of the New South Wales Ministry of Transport (now known as Transport NSW) to re-estimate the travel demand model components of the Sydney Strategic Transport Model (STM).

The STM was designed by Hague Consulting Group (1997). In Stage 1 of model development (1999–2000), Hague Consulting Group developed mode-destination and frequency models for commuting travel, as well as models of licence ownership and car ownership. In addition, a forecasting system was developed incorporating these components. In Stage 2 of model development (2001–2002), RAND Europe, incorporating Hague Consulting Group, developed mode and destination and frequency models for the remaining home-based purposes, as well as for non-home-based business travel. Then, during 2003–2004, RAND Europe undertook a detailed validation of the performance of the Stage 1 and 2 models. Finally, Halcrow undertook Stage 3 of model development (2007), in which they re-estimated the home–work mode-destination models, and at the same time developed models of access mode choice to train for home–work travel.

By 2009, some model parameters dated back to 1999, raising concerns that the model may no longer reflect with sufficient accuracy the current behaviour of residents of Sydney. Furthermore, changes to the zone structure of the model have occurred with the number of zones approximately trebling in number and the area of coverage increased to include Newcastle and Wollongong. Therefore, TDC decided to commission this study to re-estimate the STM models.

In this stage of model development, the models estimated during Stages 1 to 3 have been re-estimated using more recent Household Travel Survey data in order to reflect travel conditions for a new 2006 base year. Furthermore, the scope of the mode-destination models has been extended in two ways. First, they now model the choice between tolled and non-tolled alternatives for car driver travel. Second, the access mode-choice models have been estimated across all travel purposes, and have been extended so that the choice of station zone is now explicitly represented for park-and-ride and kiss-and-ride travel.

Two reports have been produced by RAND Europe during the course of this study:

a) This mode-destination modelling report

b) A separate frequency, licence, car ownership modelling report.

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CHAPTER 1 Introduction

This report documents the re-estimation of the mode-destination model components of the Sydney Strategic Transport Model (STM) model. The re-estimation of the travel frequency, licence holding and car ownership models is reported separately.

The re-estimation work presented in this report follows on from three earlier phases on model development. In Stage 1 (1999–2000), Hague Consulting Group developed mode-destination and frequency models for commuting travel, as well as models of licence ownership and car ownership, and a forecasting system was developed incorporating these components. In Stage 2 (2001–2002), RAND Europe, incorporating Hague Consulting Group, developed mode and destination and frequency models for the remaining home-based purposes, as well as for non-home-based business travel. Then, during 2003–2004, RAND Europe undertook a detailed validation of the performance of the Stage 1 and 2 models. Finally, Halcrow undertook the third stage of model development (2007), in which they re-estimated the home–work mode-destination models, and at the same time developed models of access mode choice to train for home–work travel. Models from these earlier phases of STM model development are referenced throughout the report, with full references for the relevant reports provided in the references section.

Chapter 2 of this report sets out the key modelling assumptions used in the models, with a discussion of the use of tours and trips, a summary of the travel purposes that are represented, a description of the travel modes, and a definition of the modelled time periods. The chapter concludes with a summary of the sample sizes of tours for model estimation.

Chapter 3 summarises the level-of-service data used for model estimation for both highway modes and public transport modes. It also discusses the cost data used in the models for car, public transport and taxi.

Chapter 4 discusses how the models have been extended so that they predict the choice between toll road and non-toll road alternatives. The chapter starts with an explanation of how the level-of-service data have been created for these two alternatives, before going on to explain how the choice between these two options is defined on the basis of the information collected in the household interview data.

Chapter 5 details the second major extension to the scope of the models, the explicit representation of choice of access mode, and for car access the choice of station, for train. The chapter discusses the level-of-service data used to support this extension, how the access modes have been defined, and how the most attractive stations for park-and-ride and kiss-and-ride access are identified.

Chapter 6 describes the specification of the mode and destination model, including a discussion of the mode and destination alternatives, a summary of the variables used in the utility functions, an overview of the data excluded from the models and an explanation of the structural tests that have been run.

Chapter 7 presents the model results. The chapter begins with a discussion of the cost formulations identified, the level-of-service terms, socio-economic effects and destination constants. The findings with respect to the extensions to the model scope to include choice of toll roads and train access mode and station choice are then described. The chapter concludes with a discussion of the findings from the structural tests, and presents the resulting tree structures.

Chapter 8 presents validation of the models, with analysis of the model elasticities, implied values of time and a comparison of observed and predicted trip length distributions.

Finally, Chapter 9 provides a summary of the findings from the re-estimation task.

Some detailed information is placed in Appendices rather than the main body of the report. In particular, the detailed model parameter results by purpose are given in Appendix B.

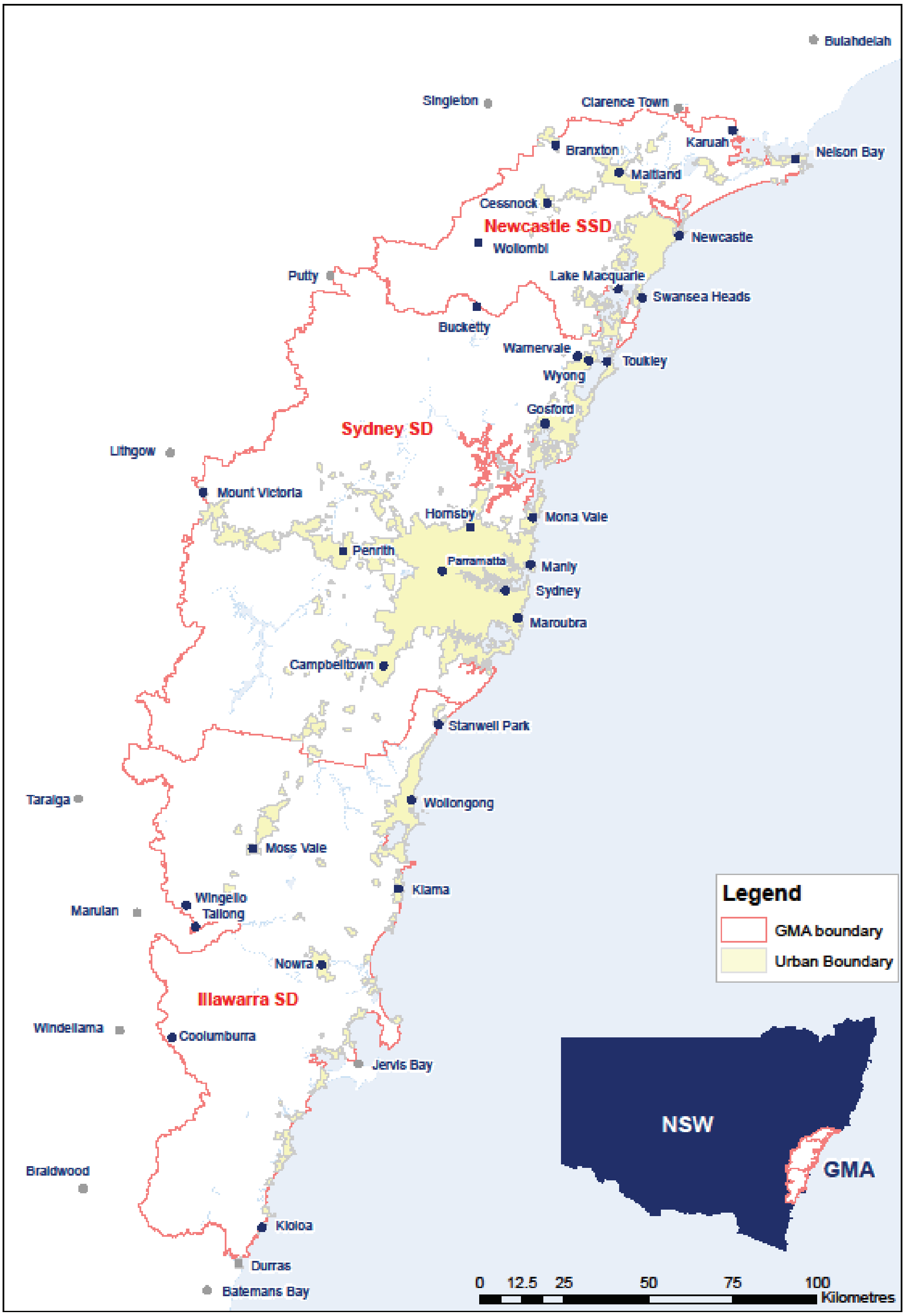
CHAPTER 2 Modelling Assumptions

This chapter sets out the assumptions made to develop mode and destination choice models. Section 2.1 defines the model study area, Section 2.2 defines the units of travel used in the models, Section 2.3 lists the travel purposes for which models have been estimated, Section 2.4 describes the modes that have represented and describes analysis of the symmetry between outward and return modes, and Section 2.5 describes the time periods that are distinguished in the highway networks used in the models. Finally, Section 2.6 describes some analysis to determine the appropriate sample of tours to use for model estimation.

2.1 Study Area

The study area used in the Stage 1 and 2 models covered the Sydney Statistical Division (SD). In this work, the study area has been extended to include Newcastle and Wollongong. Specifically, all of Newcastle SSD, and all of Illawarra SD, are now included as well as Sydney SD. The study area is illustrated in Figure 1.

Figure 1: Model Study Area



2.2 Trips and Tours

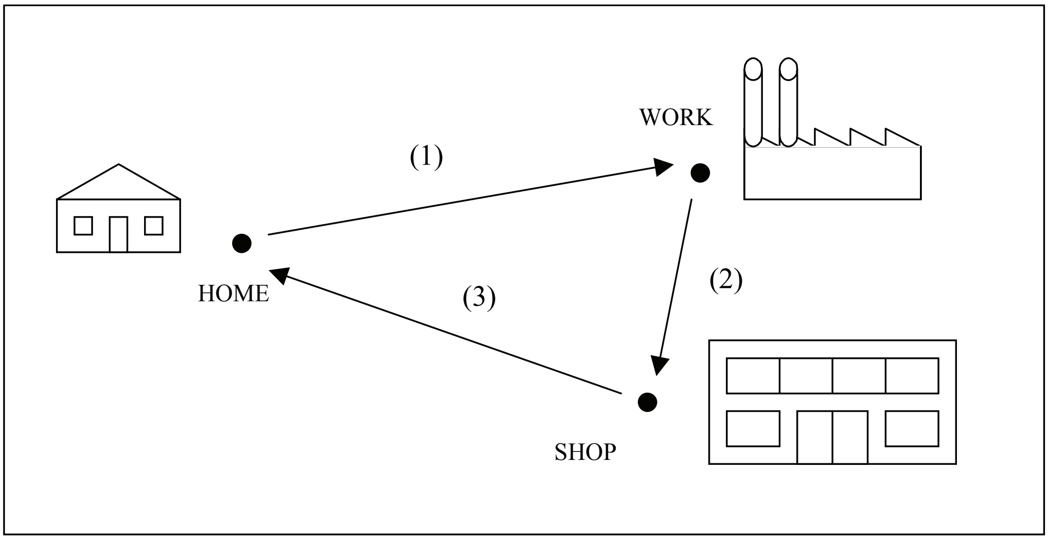
Consistent with the Stage 1 to 3 models, home-based travel has been modelled using tours. A home-based tour is a series of linked trips starting and finishing at the individual's home.

Some half-tours are observed in the Home Travel Survey (HTS) data, i.e. chains of trips that start outside the home and return to home, or chains of trips that leave home but do not return in the 24 hour period in which the survey is undertaken. However, half-tours form a low percentage of the data[1] and are not modelled in the mode-destination models, on the basis that a higher level of error is associated with the purpose, mode and other information for half tours, which in some cases are incompletely recorded full tours. To ensure that the total volume of travel predicted is consistent with that observed in the HTS data, outward half tours *are* included in the frequency models that are documented separately in the report documenting the travel frequency, car ownership and licence-holding models (Tsang et al. 2010).

As noted above, a tour is a series of linked trips starting and finishing at the traveller's home. If a traveller makes a simple return journey then it is straightforward to determine the 'primary destination' of the tour, e.g. a home–work–home sequence of trips has its primary destination (PD) as work, and hence is a work tour. However, for more complex sets of trips, it is necessary to define rules to identify the PD of the tour.

This problem is illustrated in Figure 2.

Figure 2: Tour Example



In this example a worker travels directly to work in the morning, but on the way home they divert to the shops. Rules are necessary to define the PD of the tour.

To determine the PD in this example, the following purpose hierarchy is employed:

- Work

[1] Half tours represent 3.7 per cent of all tours observed in the Household Travel Survey.

- Business
- Other purposes (which includes shopping).

If there are ties, i.e. more than one destination is visited that lies at the same level in the purpose hierarchy, then the destination at which the most time was spent is taken as the PD. In the example given in Figure 2, work is higher in the hierarchy than shopping and so forms the PD. Therefore work is specified as the purpose of the tour, and the return tour between the home and work (the PD) is modelled. Trip (2) between the workplace and the shopping location could be modelled separately as a non-home-based trip.

In fact, non-home-based trips are only modelled for business travel in the STM. In model application, the predictions of travel for purposes that are directly modelled are factored up to account for other non-home-based trips, as well as other components of travel that are not directly modelled, such as tours that leave the study area. Analysis undertaken during the STM validation project in 2003–2004 revealed that 26 per cent of all trips are non-home-based trips for non-business purposes.[2] Therefore, the accuracy of future versions of the STM could be improved by directly modelling non-home-based trips for non-business purposes.

2.3 Purposes

Consistent with the Stage 1 to 3 estimations, travel for seven home-based purposes has been modelled:

- Home-based work, i.e. commuting
- Home-based (employer's) business
- Home-based primary education
- Home-based secondary education
- Home-based tertiary education
- Home-based shopping
- Home-based other travel.

The primary education purpose excludes pre-school education tours. A full explanation of how education travel is segmented into primary, secondary and tertiary travel is given in Section 4.1 of report 0032-2.

Consistent with the Stage 2 estimation approach, travel for two non-home-based (NHB) purposes has also been modelled:

- Work-based business tours
- NHB business detours made in the course of home-based work and home-based business tours.

[2] Please refer to Report RED-03136-1 for details.

It should be noted that NHB travel by other purposes is not modelled. It is understood that BTS correct for this by expanding to total travel during the model application procedure.

2.4 Modes

Eight main modes have been represented in the models:

- Car driver
- Car passenger
- Train, which includes heavy rail, light rail and ferry
- Bus
- Cycle
- Walk
- Taxi
- School bus, for primary and secondary education travel only.

Demand for the car driver mode is predicted separately for toll and non-toll alternatives. A discussion of the definition of toll and non-toll alternatives is given in Chapter 4.

For train, three separate access modes are represented in the model: park-and-ride, kiss-and-ride and bus, walk & bike. A discussion of the access mode alternatives is given in Chapter 5.

Analysis cross tabulating the outward and return modes was undertaken to review the validity of the assumption that the mode observed on the outward tour leg can be used to model the entire tour. If the outward and return tour legs are the same, the modes are said to be symmetric and the assumption is valid. In cases where they are not the same, cross-tabulations of the outward and return tour legs were reviewed to examine the asymmetric cases, and in particular the extent to which off-diagonal elements balance so that no systematic bias is introduced by assuming the outward leg mode for the whole tour.

Overall, the levels of symmetry between the mode used on the outward and return journey were high:

- Commute: 93 per cent
- Business: 97 per cent
- Primary education: 83 per cent
- Secondary education: 72 per cent
- Tertiary education: 92 per cent
- Shopping: 98 per cent
- Other travel: 96 per cent

When considering car driver, the levels of symmetry are higher still, i.e. if a car is taken from home it is usually driven back again as part of the same tour. Lower levels of symmetry are observed for car passenger, public transport modes and in particular taxi, which reflects the fact that it used as an occasional mode in certain circumstances, such as returning home later at night. For education tours, higher levels of asymmetry reflect a pattern whereby a child is driven to school in the morning, often as a detour on a parent's home–work tour, and then the child returns home by bus, walk or school bus in the afternoon.

In general, the off-diagonal elements are fairly balanced and therefore the impact of representing the wrong mode for some tour return legs is reduced. Taxi tours tend to be used more for return tour legs than outward tour legs, but as taxi tours only form a low percentage of the total the impact of this effect on modelled trips is expected to be slight.

Overall, the assumption that the outward and return legs use the same mode was judged to be reasonable, and was retained in this modelling work.

2.5 Times of Day

The highway assignment model represents four periods of the day: morning peak, evening peak, daytime (between the peaks) and evening / night.

For model estimation purposes, each tour must be assigned to highway level-of-service (LOS) data that best fits with the times of day at which the tour was made. This follows from the basic assumption in the modelling that time-of-day is fixed by decisions exogenous to the transport sector, such as the times at which work and study take place. A possible future improvement to the STM would be to model time of day choice directly.

For car travel modes, the mid-point timings of the outbound and return tour legs are used to determine the time period in which each tour leg falls. The time period definitions used in the modelling are summarised below:

- AM peak shoulder: 06:00 to 06:59
- AM peak: 07:00 to 08:59
- AM peak shoulder: 09:00 to 09:59
- Interpeak: 10:00 to 13:59
- PM peak shoulder: 14:00 to 14:59
- PM peak: 15:00 to 17:59
- PM peak shoulder: 18:00 to 18:59
- Off-peak: 00:00 to 06:00 and 19:00 to 24:00

Average LOS for the relevant peak and the interpeak period were used for the shoulder periods, which means that the four time periods identified in the highway assignment modelling are extended to six time periods for the mode-destination model.

For public transport, only AM peak hour LOS were available (based on a 2-hour peak period, from 7 to 9 a.m.). It was assumed that the LOS from this network is applicable for all time periods. While it is recognised that there are differences in LOS between time periods, the impact of these differences is minimised by making the same assumption in both estimation and application.

2.6 Sample Sizes

As discussed in the Introduction, an important factor in BTS's decision to commission this work was the wish to update the model parameters to reflect the behaviour of the current residents of the Greater Sydney area. The updated model will work with a 2006 base year. The current model works with a 2001 base year, although *when the models were estimated* a 1996 base year was used. Household travel data were available from nine waves of the HTS data, from 1999/2000 to 2007/2008 (the earlier waves of HTS data were judged to be too old). Each wave of the HTS data runs from the start of July to the end of June the following year, i.e. following the Australian financial year.

The decision as to how many waves of data to include in the model estimation represented a balance between maximising sample sizes, particularly when considering less frequently chosen alternatives such as park-and-ride, and ensuring the estimation sample was representative of the 2006 base year, for which level-of-service data were available.

The four waves of data from 2004/2005 through to 2007/2008 would provide an estimation sample that had an equal number of waves of data either side of 2006, and would therefore best meet the 2006 base year requirement, but the sample size may be too small for less frequently chosen alternatives. Using earlier waves of data increases the sample size, but may make the sample less representative of 2006 conditions. Following initial analysis of sample sizes and trip frequency rates, it was decided to drop the 1997/1998 and 1998/1999 waves from the sample of data supplied by BTS, given the concerns about the representativeness for current behaviour of these first two waves of data, and also because BTS expressed some concerns about the frequency of trip making observed in the 1997/1998 wave relative to subsequent waves. The earliest 1999/2000 wave is then six to seven years from the 2006 base year for the networks.

In terms of level-of-service, experience from the Stage 1 and Stage 2 estimation work demonstrated that 1996–1998 level-of-service data could be used to model choices observed in 1991–1992 household interview data[3] (HIS data). This approach gave acceptable results, with scale factors for the HIS data that ranged from 0.79 for primary education to 0.96 for home–work. A scale factor less than one indicates a higher level of error in the earlier HIS data, relative to the HTS data. Values substantially less than one would have indicated that using the 1996–1998 networks to model 1991–1992 choices introduced substantial errors. On the basis of these results, using 2006 level-of-service to model 1999/2000 choices was judged to be reasonable.

[3] With some adjustments to the zoning system.

To determine how many waves of data should be included, the tour sample sizes were tabulated by wave, and in particular the volumes of toll road choices, and train access mode choices, were analysed. Sufficient samples were necessary to extend the models to represent these choices explicitly as these choices are relatively infrequent, particularly for certain journey purposes. Table 1 summarises the waves selected, and the associated sample sizes, with a comparison with the sample sizes used in the original Stage 1 and 2 estimations. Note that the 'full tours' column gives the total sample size for each purpose.

Table 1: Selected Sample Sizes of HTS Data

Purpose	Stages 1 and 2	Selected Samples						
		Waves	Full Tours	Toll Rd Choices	Train P&R	Train K&R	Train Bus	Train Wk/bike
Work	7,947	2004/05 -2007/08	6,238	354	221	157	83	411
Business	2,503	1999/00 – 2007/08	4,001	464	64	21	20	95
Primary	2,608	1999/00 – 2007/08	3,705	n/a	0	4	4	14
Secondary	1,774	1999/00 – 2007/08	2,537	1	1	113	47	151
Tertiary	6,73	1999/00 – 2007/08	1,050	24	30	53	39	138
Shopping	6,611	1999/00 – 2007/08	8,918	49	17	19	25	100
Other	8,400	1999/00 – 2007/08	30,173	280	76	111	110	337
Total	30,516	n/a	56,622	1,172	409	478	328	1,246

The samples of toll road and train access mode choices for commute travel are proportionately higher, and therefore it was possible to use a four-wave estimation sample from 2004/2005 to 2007/2008 that evenly straddles the 2006 base year. The estimation sample is smaller than the samples in Stage 1 and 2, but still substantial with over 6,200 tours.

For the remaining home-based purposes, toll road and train access mode choices are more infrequent than for commuting, and therefore it was necessary to use the nine waves of data from 1999/2000 to 2007/2008 to ensure sufficient sample sizes. As can be seen from Table 1, the need to ensure sufficient samples for the toll road and train access mode choices means that the total numbers of tours in the estimation samples are larger than in the previous estimation work.

For primary education, there is little access mode information, and so train access mode and station choice was not modelled. Finally for secondary education, there is only a single P&R observation, so only K&R, bus, walk and bike access to train were modelled.

CHAPTER 3 Level of Service Data

3.1 Car Level of Service

Consistent with the earlier estimation work, BTS supplied highway level of service (LOS) for four time periods: a.m. peak, inter-peak, p.m. peak and nighttime. These time periods are defined in Section 2.5.

Separate road skims were provided with and without toll road links available to allow the modelling of toll road choice. These are discussed in more detail in Section 4.1.

To calculate total car costs, the following formula is used:

car cost = car operating cost * distance
+ parking cost
+ toll cost (if applicable)

Section 3.1.1 explains how car operating costs are calculated, and section 3.1.2 details how the parking cost calculations are made. The determination of toll costs is discussed in Chapter 4.

3.1.1 Car Operating Costs

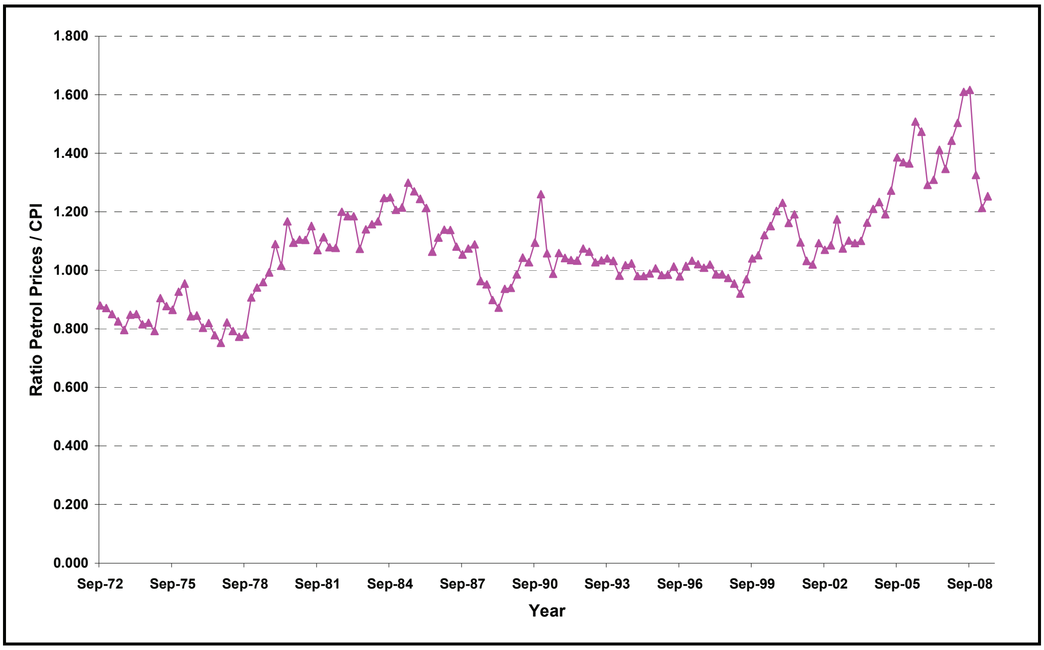
Non-Business Travel

Car operating costs for non-business travel (note that 'non-business' includes commuting) comprises fuel cost and non-fuel cost components, which are calculated separately, as detailed in the rest of this sub-section.

Following discussion with BTS, 95 per cent of the fleet in Sydney use petrol (RTA, 2008), therefore it is reasonable to use petrol prices for the whole fleet of cars.

To determine the appropriate petrol cost values to use in model estimation, analysis was undertaken looking at the variation in petrol prices over time. Figure 3 presents the ratio of the petrol price consumer price index (CPI) to the total CPI in the Sydney region between 1972 and 2008.

Figure 3: Variation in Fuel Prices Relative to Prices as a Whole[4]



While petrol prices were fairly stable during the 1990s, there has been considerable volatility and a significant increase in petrol costs over that period in real terms between 1999 and 2008, the period of HTS data analysed for this study. Therefore, it was decided to use wave specific values for the petrol price in preference to an overall average value. Wave averages were chosen in preference to using quarterly figures for each year to account for the substantial volatility in the petrol prices over the period. The values used in model estimation are summarised in Table 2. The values in the table relate to the wave in question and are in 2006 prices.

Table 2: Fuel Prices by Wave (2006 prices)

Wave	Fuel Price (c/km)
July 1999 – June 2000	70.67
July 2000 – June 2001	87.27
July 2001 – June 2002	86.94
July 2002 – June 2003	85.27
July 2003 – June 2004	90.94
July 2004 – June 2005	98.65
July 2005 – June 2006	112.15
July 2006 – June 2007	125.2
July 2007 – June 2008	124.7

Fuel consumption can be calculated as a fixed cost per kilometre, and this was the approach used in the Stage 1 and 2 estimations. However, in reality fuel consumption varies as a function of speed, so that fuel costs per kilometre are higher in congested conditions. An important consideration in this study was the desire to best represent the relative attractiveness of tolled and non-tolled alternatives, and in this context the higher

[4] Table 13, 6401 Consumer Price Index, Australian Bureau of Statistics.

speeds and less congested conditions on toll roads should be taken into account in the car cost calculations, if possible.

Given these considerations, the approach was revised to calculate consumption using a speed based formulation taken from Austroads (Austroads, 2008). A quadratic relationship is used:

$$L = A + B/V + C.V + D.V^2 \qquad (3.1)$$

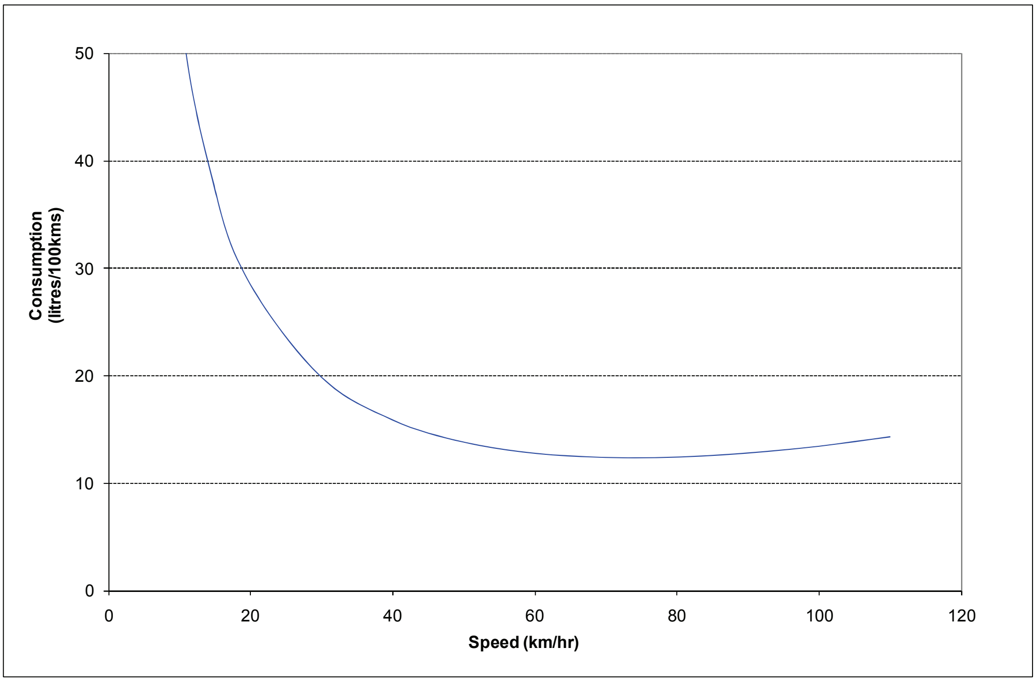
In equation (3.1), the full stop denotes multiplication, and the parameter values A, B, C and D are given in Table 3. Speed is measured in km/hr, and consumption L is measured in litres per km.

Table 3: Fuel Consumption Parameters

A	0.863
B	542.92
C	0.01333
D	0.0005847

The variation in consumption with speed is plotted in Figure 4.

Figure 4: Variation in Fuel Consumption with Speed



It can be seen that the consumption is predicted to rise rapidly at low speeds, and this rise was much more rapid than comparable curves recommended by the UK Department for Transport.[5] To avoid high costs biasing the estimation, the relationship was truncated so that any speed less than 20 km/hr was capped to the consumption value at 20 km/hr of 28.5 l/100 km.

[5] As of 6 May 2015: http://www.dft.gov.uk/webtag/documents/expert/unit3.5.6.php

The fuel consumption per kilometre is calculated for each origin-destination pair using the average speed for that origin-destination pair, using the distances and times from the highway assignments. The consumption per kilometre is then multiplied by the network distance and the fuel cost per litre (from Table 2) to get the total fuel cost for that origin destination pair.

Non-fuel costs are calculated using a fixed cost per kilometre of 13.45 c/km (RTA, 2008). Building on tests undertaken during the Stage 1 and 2 estimations, it is assumed that drivers only perceive a percentage of the full non-fuel cost per kilometre. The percentages that are assumed to be perceived vary with travel purpose, as detailed in Table 4.

Table 4: Marginal Vehicle Operating Cost Percentages

Purpose	Proportion
Work	25 %
Education	25 %
Shopping	10 %
Other	10 %

Business Travel

For business purposes, car costs are modelled using a fixed per-kilometre cost, which individuals can reclaim. The rates that have been used are for New South Wales public services and are summarised in Table 5. These are expressed in nominal costs, i.e. for the wave in question, and therefore in model estimation there is an adjustment to 2006 cost levels.

Table 5: Business Kilometrage Costs by Wave (Nominal Costs)

Wave	Cost (c/km)
July 1999 – June 2000	55.8
July 2000 – June 2001	57.4
July 2001 – June 2002	58.9
July 2002 – June 2003	60.5
July 2003 – June 2004	62.0
July 2004 – June 2005	63.0
July 2005 – June 2006	67.0
July 2006 – June 2007	70.0
July 2007 – June 2008	70.0

Source: http://www.australianbiz.com.au/small-business-tax-rates.aspx

These are the full rates that apply if the individual travels for official business and there is no other mode of transport available. Casual rates also apply, which are 40 per cent of the values above. These values apply when an individual makes occasional travel to work where other transport (e.g. public transport) is available.

Specification tests were made during the development of the home–business model to investigate whether to model the full rates or the casual rates, i.e. 40 per cent of the values presented in Table 5, were found to give a better fit to the observed data. Therefore the casual rates have been used to model both home-based and non-home-based business travel.

3.1.2 Parking Costs

Car costs were supplied by BTS for ten centres in the study area in 2006 prices. For zones not in these centres parking costs were assumed to be zero. Parking costs for these centres were supplied for both full day and half-day parking durations, as detailed in Table 6.

Table 6: Parking Costs (2006 prices)

Centre	Full day cost ($)	Half day cost ($)
CBD	50.00	32.50
North Sydney	50.00	32.50
Ultimo/Pyrmont	25.00	16.25
Central to Sydney Uni	25.00	16.25
Redfern/Strawberry Hills	25.00	16.25
Surry Hills/Kings Cross	25.00	16.25
St Leonards/Crows Nest	25.00	16.25
Chatswood	25.00	16.25
Parramatta	25.00	16.25
Bondi Junction	25.00	16.25

Source: BTS simple parking cost estimates.

Building on the analysis of observed activity durations at the primary destination undertaken during the Stage 2 estimations, full and half-day costs were used according to the following rules:

- For commute, full day costs are used for full-time workers; for other groups the half day costs are converted to an hourly rate and multiplied by the observed activity duration.
- For business, all-day parking costs were assumed (78 per cent of business tours were made by full-time workers).
- Similarly, for education, all-day parking costs were assumed.
- For shopping and other, half day costs converted to an hourly rate were multiplied by the observed activity duration.

A further consideration is that not all individuals have to pay for parking. For commuting, employers may provide free parking, and for shopping and other travel there may be free parking provided at the primary destination. Therefore, the parking costs are multiplied by an assumed percentage of persons paying for parking, using the proportions derived in the Stage 1 and 2 estimation work.[6] These proportions are summarised in Table 7.

Table 7: Assumed Percentages Paying for Parking

Purpose	Percentage
Commute	30 %
Business	100 %
Education	30 %
Shopping	50 %
Other Travel	50 %

[6] This analysis was documented in full in Section 3.2.2 of Report 0032-2.

For shopping and other travel, parking costs are only included for Central Business District (CBD) zones, because BTS have advised that free parking is typically available for shopping and other travel tours in the other centres, where parking durations are relatively short, and therefore it is more reasonable not to represent any parking costs.

3.2 Train Level of Service

'Train' in the STM modelling context more accurately means an all-modes public transport network that includes a number of sub-modes:

- Heavy rail, often termed simply 'rail'
- Light rail
- Ferry
- Bus, as an access/egress mode.

In the modelling, train is considered to be available for a given origin-destination pair if at least one of heavy rail, light rail and ferry is used on the shortest path for that origin-destination (OD).

To build the train paths in the Emme software the following generalised time function was applied and minimised by BTS:

- Waiting time calculated as half the headway with a maximum headway of 40 minutes, weighted by a factor of 2, both for initial and subsequent waits.
- Penalty of five minutes for each boarding.
- Access/egress and connection time weighted by a factor of 2.

Fares are not used in the path building. Walk times are modelled with a speed of 4 km/hr.

Train level of service skims were provided both at the zone-to-zone level, used for initial model development, and at the station-to-zone level used to facilitate the development of models of station choice. The final models use the station to zone level of service, and include the following information:

- Train in-vehicle time, broken down into heavy rail, light rail and ferry components.
- Any bus in-vehicle time as an access/egress time.
- Walk access/egress time.
- First wait time.
- Other wait time.
- Number of boardings.
- Total distance on the PT network.

Fare matrices were also supplied by BTS. These matrices were based on single path traffic assignments. These assignments distinguish between single and weekly fares converted to a per-trip cost. Weekly fares were converted to per-trip costs using a factor of 9.2 trips per week, based on analysis by the Institute of Transport Studies undertaken in 1995 and used in the Stage 1 and 2 estimation work[7].

To model commute travel, the per-trip weekly fares were used for full-time workers, i.e. assuming they would purchase weekly tickets if they travelled by train. For other workers, the single ticket cost was used.

For other purposes, some travel is made by non-workers, and some of these are eligible for concessionary fares. Specifically, full-time students, unemployed persons and retired persons pay half the single fare, and so the full fare is divided by two for these persons in the models. For persons not eligible for concessionary fares, single costs are modelled if they depart after 09:00, as this allows a 50 per cent discount on the full single fare, whereas for those who leave during the peak a weighted average of weekly and single ticket costs is used, with the weekly tickets expressed as a per-trip cost.

3.3 Bus Level of Service

The 'bus' mode in the model is used to represent trips made by bus only, including both government and private bus services. To generate the bus level of service, a network is generated with all heavy rail, light rail and ferry services removed, i.e. containing only bus services with walk/bike access and egress.

In the modelling, bus is modelled as available if the bus-in vehicle time exceeds zero for a given origin-destination pair.

To model bus as a main mode, zone to zone level of service is used. To model bus as an access mode to train, zone to (train) station level of service is used. In both cases, the level of service contains the following components:

- Bus in-vehicle time
- Walk access/egress time
- First wait time
- Other wait time
- Number of boardings
- Total distance on the bus network.

Fare matrices were also supplied for the modelling. These were created by making a single path assignment in Emme. As with train, these are converted into per trip costs.

[7] See Section 3.2.1 of Report 9009-3A.

Concessionary fare holders pay half fare, and for others a weighted average of the weekly and single fare is used.[8]

It is noted that a school bus model is included in the home–primary education and home–secondary education models. No specific level-of-service exists for school bus services; instead they are modelled using time and distance information taken from the highway assignments.

No costs are represented for school bus travel. Primary education students who live more than 1.6 km radial distance from their school and secondary education students who live more than 2 km radial distance from their school receive free school bus travel. Students who live closer have to pay. The mean observed distances using the highway network are significantly higher than these threshold values, with 6.2 km one-way for primary education, and 9.4 km for secondary education. Therefore, the assumption of free school bus costs for all is reasonable.

3.4 Taxi Level of Service

Levels of service for taxi are described by time and cost variables only. Taxi times are taken to be equal to car times in the toll assignment (see Section 4.1). The decision to use times and costs from the toll assignment was made following advice from BTS that taxis typically use toll routes where they are available, and that they pass on the toll costs to the passenger.

To calculate taxi costs, the taxi fare schedule used in Sydney is applied, which calculates taxi costs as follows:

taxi cost = flagfall
+ distance cost * distance
+ waiting cost * waiting time
+ booking fee
+ toll cost

The taxi fare schedule is updated on 1 July each year, which conveniently matches with the start of each new wave of data, and therefore the taxi fare schedule for each wave is defined. The values are summarised in the following table.

[8] Note that the after 09:30 discount does not apply to bus.

Table 8: Taxi Fare Schedules by Wave (Nominal Costs in $)

Wave	Flagfall ($)	Distance Cost ($/km)	Waiting Cost ($/min)	Booking Fee ($)
1999/00	2.20	1.22	0.58	1.00
2000/01	2.35	1.32	0.61	1.10
2001/02	2.45	1.38	0.62	1.15
2002/03	2.55	1.45	0.62	1.25
2003/04	2.65	1.53	0.67	1.40
2004/05	2.75	1.56	0.68	1.45
2005/06	2.80	1.62	0.68	1.40
2006/07	2.90	1.67	0.72	1.50
2007/08	3.00	1.77	0.76	1.60

Waiting times are not available from the highway assignment, and so an assumption of 5 minutes waiting time per 7 kms is used, as per the Stage 2 estimation work.

Only a proportion of taxis are pre-booked, and so the booking fee is multiplied by the mean proportion of pre-booked taxis, as observed in the 1997–2000 HTS data during the Stage 2 work. These values vary by purpose and are summarised in Table 9.

The final stage in the calculation of the taxi costs is to divide by the mean occupancy. Analysis in the Stage 2 work demonstrated that the mean occupancies vary with purpose; these values have been used again for the re-estimation work and are presented in Table 9. Observed occupancies are not used because it is not known what the occupancy would have been for those individuals who do not choose taxi.

Table 9: Mean Taxi Booked Proportions and Occupancies[9]

Purpose	Booked Percentage	Mean Occupancy
Work	35 %	1.18
Business	29 %	1.07
Education	79 %	2.50
Shopping	36 %	1.47
Other Travel	33 %	1.90

[9] Analysis documented in Appendix F of Report 0032-2.

CHAPTER 4 Modelling Toll Roads

This chapter discusses how the model structure has been extended to represent the choice between toll and non-toll alternatives for car drivers. Section 4.1 discusses how highway assignments were generated to represent toll road alternatives, and then Section 4.2 discusses how the toll road alternatives were specified in the choice structure.

4.1 Representation in Assignment

For model estimation it is necessary to obtain level of service for the tolled and non-tolled highway routes in order to predict whether an individual will or will not use a toll road. This is in contrast to some road-based assignment models where a single value of time is used to predict traffic volumes on a toll link.

BTS have indicated that the New South Wales Roads and Traffic Authority (RTA) use a value of time (VOT) for highway assignment of $30/hr when using the STM road network. This value is high compared with the values in the RTA Economic Analysis Manual (2008), specifically the values reported in Appendix B Economic Parameters (2008), in which the value of time for a private car is $11.55 per person per hour, or $12.94 per vehicle per hour.[10]

This high VOT is used because BTS's experience is that values of time substantially higher than the RTA values are required to get appropriate levels of demand to be assigned to toll road links. The need for a higher VOT is likely to reflect both higher values of time for an average toll road user, and a 'toll road bonus' associated with higher levels of reliability, and potentially other factors such as quality of road surface. It could also be a reflection of modelled travel times on the different routes.

The challenge is in setting the appropriate value of time for toll users to generate the level-of-service values. If the value is too low, for some origin-destination pairs the assignment will not use paths along toll roads and so toll roads will not be available in the choice modelling. If the value is too high, toll roads will be used to save a small amount of time for a relatively high cost. It should be emphasised that it is the choice model that will then predict whether an individual will use a toll road.

[10] Using peak hour car occupancy of 1.12 for private cars (Table 8, Appendix RTA Manual).

Test runs were made with toll road user VOTs of $15/hr, $30/hr, $60/hr, $90/hr, $120/hr, $180/hr, $240/hr and $1,000,000/hr. To assess the impact of these different assumptions, the percentage loss of demand on toll roads, relative to a single class assignment with no sensitivity to cost, was calculated. The latter would be problematic for the choice model estimation, as it would introduce toll road alternatives into the modelling for OD pairs where in practice toll roads are never chosen, and this could lead to bias to the parameters associated with toll roads. A further consideration is that for longer routes, the most likely toll road alternative might be to use a toll road for part of the route, but towards the end of the route not pay an additional toll for a marginal additional time saving on a second toll road. Therefore, using an excessively high VOT would lead to less realistic toll skims in these cases.

The tests reported in Table 10 were undertaken on the a.m.-peak network. This time period was chosen as it has the highest levels of congestion. The single class assignment is made by minimising time only, i.e. there is no sensitivity to toll. Table 10 presents analysis segmented by the Sydney Harbour Bridge/Tunnel crossings and other toll roads. The reason for this segmentation is discussed in more detail later.

Table 10: Toll Road Usage, Unweighted Demand (all OD Pairs)

VOT ($/hr)	Toll Road Usage		Loss of Demand on Toll Roads Relative to Single Class	
	Toll ODs	Harbour ODs	Toll ODs	Harbour ODs
15	30.4 %	8.8 %	45.3 %	0.9 %
30	40.8 %	7.7 %	26.5 %	13.6 %
60	45.7 %	8.4 %	17.7 %	5.3 %
90	49.1 %	8.5 %	11.6 %	3.9 %
120	50.3 %	8.6 %	9.5 %	2.5 %
180	51.7 %	8.7 %	6.9 %	1.4 %
240	52.4 %	8.8 %	5.6 %	1.1 %
1,000,000	55.5 %	8.9 %	0.0 %	0.1 %
Single Class	55.5 %	8.9 %	0.0 %	0.0 %

Table 11: Toll Road Usage, Weighted Demand

VOT ($/hr)	Toll Road Usage		Loss of Demand on Toll Roads Relative to Single Class	
	Toll ODs	Harbour ODs	Toll ODs	Harbour ODs
15	5.2 %	1.7 %	53.4 %	-3.9 %
30	7.1 %	1.5 %	35.7 %	4.6 %
60	7.8 %	1.6 %	29.6 %	2.3 %
90	8.6 %	1.6 %	22.6 %	1.7 %
120	9.0 %	1.6 %	18.7 %	1.2 %
180	9.5 %	1.6 %	14.0 %	0.6 %
240	9.9 %	1.6 %	10.6 %	0.8 %
1,000,000	11.1 %	1.6 %	-0.1 %	0.0 %
Single Class	11.1 %	1.6 %	0.0 %	0.0 %

It should be noted that these are equilibrium assignments and therefore, for a given origin and destination (OD in the toll road assignments), some vehicles may use a toll road while others do not.

Table 10 and Table 11 demonstrate that at VOTs of $15/hr and $30/hr, a substantial percentage of demand is lost from toll roads. Therefore, much higher VOTs were tested, but even at $120/hr, 19 per cent of demand is lost relative to the assignment with no sensitivity to toll charges (the single class assignment in Table 11). The VOT that was finally used was $180/hr, which gives a balance between losing demand relative to the single class assignment, and a VOT that is so high that in some instances individuals will pay a toll for a marginal time saving.

Given the decision to use a VOT of $180/hr for the toll road alternatives, Table 12 summarises the average skim components for the a.m.-peak. Similar analysis was run by BTS for the inter-peak, the p.m.-peak and the off-peak highway networks. It is emphasised that the results in Table 12 are obtained as a simple average over all non-zero cells in the matrix, and are not weighted by observed toll demand for each OD pair; the means are far too high to be demand based results.

Table 12: Mean Skim Components for A.M. Peak (Unweighted)

Skim Matrix	Toll Skims	Non-Toll Skims
Generalised time (mins)	97.3	98.3
Distance (kms)	89.3	88.4
Toll ($)	2.70	n/a
Bridge Cost ($)	2.39	2.46
In-vehicle time	96.8	98.3

It can be seen that the non-toll skims have shorter mean distances, but higher mean in-vehicle time, as would be expected, although the mean differences are small (which is reasonable because toll roads form only a small percentage of the total network kilometrage).

For the non-toll assignment, BTS use a network with toll roads removed, but the Harbour Tunnel and Harbour Bridge included as there is no feasible 'non toll' alternative for the majority of routes (ODs) that use these crossings. This issue is discussed further in the following section. The same high VOT of $180/hr is used for the non-toll assignment.

4.2 Toll Road Alternatives

The Household Travel Survey (HTS) records whether a toll road was used for each car driver trip. The toll roads recorded have changed over time as new toll roads have opened. Table 13 summarises the possible toll roads by survey wave, with greyed-out cells illustrating routes not yet available.

Table 13: Toll Roads by HTS Wave

Wave	Harbour Bridge	Harbour Tunnel	M2	M4	M5	Eastern Distributor	Cross City Tunnel	Lane Cove Tunnel
99/00								
00/01								
01/02								
02/03								
03/04								
04/05								
05/06								
06/07								
07/08								

Note that the Eastern Distributor (ED) is only tolled for northbound journeys. For many origin-destination movements this complements the Sydney Harbour Bridge and Tunnel (SHB/T) with motorists paying a toll southbound on the SHB/T and northbound on the ED.

As noted, the Sydney Harbour Bridge and Tunnel (SHB/T) only charge a toll in the southbound direction. However, for routes that use these crossings in a southbound direction there are no feasible non-tolled alternatives for many users, and therefore it was agreed with BTS that they will be represented as part of the 'non-toll' alternative, and that the costs associated with southbound crossings are included in the car costs for these routes. It should be noted that the non-toll assignment is able to output estimates of revenues for the southbound Harbour crossings.

The reason for classifying these southbound Harbour crossings as 'non-toll' is that the decision to use the crossings is a destination choice issue, rather than a route choice issue – the Harbour crossings do not give insight into reduced journey times or improved reliability, whereas these are important factors for other toll routes where there are alternative non-tolled routes.

A potential issue in the modelling is that early waves of the HTS will include some trips where paying a toll for the Cross City Tunnel and/or Lane Cove Tunnel will appear as a feasible alternative in the model skims, despite the fact that the tunnels did not exist at the point at which the individuals were interviewed. However, tests were unable to determine any significant difference in parameters representing the preference for toll roads by survey wave for a model of commute travel estimated using waves from 2004/2005 to 2007/2008, the period over which these two tunnels opened.

The HTS records both whether an individual has used one of the routes named in Table 13, and if so whether they paid a toll. From the 2004/2005 Wave onwards, payments are split into cash and e-tag. It is noted that it is possible to use some toll routes, but pay no toll, for a number of reasons:

- It is possible to travel on parts of the M4 without paying a toll.
- There is a cash-back scheme in operation for the M4 and M5 and individuals (but not businesses) may be reporting that they do not pay on that basis.
- For toll routes that only collect payment on-site via an e-tag, it is possible to make a payment over the phone or internet up to 48 hours after travel.[11]

Given these points, tabulations were run to examine toll road usage by wave and toll route. Following this analysis, two approaches were proposed by BTS for identifying toll and non-toll alternatives:

1. Minimise toll road usage
    - The SHB/T are modelled as 'non-toll' as there is no feasible alternative to paying the toll when travelling southbound for most origin-destination pairs.
    - For other routes, toll road users are only those who reported they paid cash or used an e-tag.

[11] As of 6 May 2015: http://sydneymotorways.com/about.html.

   - This approach would capture the small number of individuals who respond that they are cash payers on the e-tag for only the M7, Cross City Tunnel and Lane Cove Tunnel tolled facilities.

2. Best estimate of toll road usage

   - Definition 1, except:
      - All users of routes where you must pay[12] are considered to be toll users, even if they claim they did not pay a toll.
      - For routes where it is possible not to pay[13] the response recorded in the HTS data is used to classify trips into toll and non-toll alternatives.

Following discussions between BTS and RAND Europe, the 'best estimate of toll road usage' option was selected on the basis that it is believed to be a better representation of actual behaviour.

An important issue that also has to be considered is that for a given trip, an individual could use a number of toll routes. Furthermore, if an individual makes a detour during a tour leg, they could use toll roads on any one of the different car trips that make up the tour leg. To handle these issues, it was decided that the toll alternative would be modelled as chosen if a toll road was used at any stage during the outward and/or return tour leg.

In terms of travel purposes, there is no car driver data in the primary education model, and only a low fraction in the secondary education model, so toll road choice was not modelled for these purposes. For tertiary education travel, there are only 18 observed toll road observations and therefore it was decided there was not sufficient data to develop a reliable toll road choice model. Finally, for work-based business tours the sample size was again relatively low (26 observations) and there was not much data overall. For this purpose it was decided to assume that business travellers would always use a toll road if one was available, on the basis that values of time are high for business travel, and therefore the toll road skims were used to model all car driver tours.

Following these decisions, toll road choice is explicitly modelled in the home-based work, business, shopping and other travel models and in the non-home-based business detour model, and implicitly modelled by the toll road assignment for work-based business. For secondary and tertiary education, it is assumed drivers do not use toll roads (with the exception of the two Harbour crossings). This information is summarised in Table 14,

[12] M2, M7, Cross City Tunnel and Lane Cove Tunnel.

[13] M4, M5, Eastern Distributor.

Table 14: Treatment of Toll Roads by STM Purpose

Purpose	Treatment
Commute	Modelled
Business	Modelled
Primary Education	Not applicable
Secondary Education	Not modelled
Tertiary Education	Not modelled
Shopping	Modelled
Other travel	Modelled
Work-based business	Modelled implicitly using toll assignment
Non-home-based business detours	Modelled

CHAPTER 5 Access Mode and Station Choice

This chapter discusses how the models have been extended to represent access mode and station choice for train. Section 5.1 discusses how the access mode alternatives have been specified, Section 5.2 discusses the level of service that has been used to enable the explicit modelling of access mode and station choice, and Section 5.3 discusses how the station alternatives have been defined.

The location of the key rail lines across the study area is illustrated in Figure 5.

Figure 5: Location of Rail Lines Across Study Area

5.1 Access Mode Alternatives

The specific definitions of P&R and K&R used by Halcrow in the Stage 3 work were:

- P&R was defined as car access where the car is parked at the access station, and therefore can include both drivers and passengers.
- K&R was then defined as car passengers dropped by a car that is driven away.

Consideration was given to representing P&R drivers and P&R passengers separately in the model structure. The arguments for this approach are first that different car availability conditions apply to drivers and passengers, and second that such a specification would directly provide estimates of the numbers of cars parking at stations and the associated congestion that these cause on the highway network.

Sample sizes for such as specification were examined. Table 15 presents cross-tabulations of the access mode to train with the number of persons from the household in the vehicle. The '-9' column indicates cases where car is not used, and therefore the vehicle occupancy information is not collected, i.e. bus, walk and bike access.

Table 15: Access Modes by People in Vehicle (2004–2008 Waves of HTS, all purposes)

	OUT_HH_PEOPLE_VEHICLE							Total
	-9	1	2	3	4	5	6	
Bus	86	0	0	0	0	0	0	86
Taxi	0	4	0	0	0	0	0	4
Walking	427	0	0	0	0	0	0	427
Bicycle	7	0	0	0	0	0	0	7
Park nRide	0	198	27	3	0	0	0	228
Kiss nRide	0	9	124	19	6	3	1	162
Total	520	211	151	22	6	3	1	914

Considering the 228 P&R observations, it can be seen that just 30 (13 per cent) involve a passenger, i.e. two or more people in the car. Once these 30 observations had been split by purpose, the samples of P&R passengers would be too small to support a separate P&R passenger access mode. It should also be noted that the driver and passengers may have different journey purposes, e.g. a parent making a commute journey together with a child undertaking an education tour.

Rather than exclude P&R passengers, it was decided to model a P&R alternative that is available to both drivers and passengers. P&R trips made by passengers who travel with a driver from another household are not modelled, as it is not known where the driver starts their tour in such cases. As a result, the availability of the P&R alternative can be specified as a function of household car ownership; specifically it is only available if the household has one or more cars.[14] Further conditions relating to licence holding can be specified as car availability parameters (with a separate P&R driver alternative. Individual licence holding would have been used to specify availability).

A benefit of modelling station choice for P&R trips is that it enables representation of the additional congestion caused by the car access trips in the vicinity of the station. In model

[14] Analyses by BTS showed that the use of non-household cars for any travel, as a driver or as a passenger, was rare.

application, it will be necessary to divide the P&R demand by the mean occupancy to convert from numbers of P&R individuals to numbers of cars. These car trips can then be added to the matrix of car main mode trips to represent the impact of congestion around stations. As the mean occupancies are close to one, it is not unreasonable to assume the distribution across access stations of P&R drivers is equal to that of P&R users as a whole.

It was agreed with BTS that bike access would be grouped together with walk access, in preference to adding an additional access mode for such a small sample, or excluding bike observations altogether. It was also agreed that observations of taxi access to rail will be dropped from the modelling, on the basis that the small volumes of additional data do not justify the complexity of adding an additional access mode.

Therefore, initially the four access modes to rail represented in the models were:

- Park-and-ride, where the car is parked at the station, for both drivers and passengers.
- Kiss-and-ride, where one or more passengers are dropped at the station and the car continues onwards, i.e. is not parked.
- Bus access.
- Walk and bike access.

However, following model tests described in Section 5.3.2, it was decided to merge the bus access and the walk and bike access alternatives. Therefore, the three access modes represented in the final models are:

- Park-and-ride
- Kiss-and-ride
- Bus, walk and bike access.

Section 5.3.2 explains how level of service was obtained for the bus, walk and bike access option.

5.2 Level of Service

During the Stage 3 model developments undertaken by Halcrow, BTS developed level of service (LOS) for park-and-ride (P&R) and kiss-and-ride (K&R) alternatives. To represent station choice for P&R and K&R, the station the individual was observed to choose was included in the set of alternatives, plus another six alternative stations, chosen based on their distance to the home zone.

Building on this experience, discussions took place in Sydney in April 2009 between RAND Europe and BTS on the LOS required to support access mode and station choice modelling in the current study. Following these discussions, it was proposed that the following LOS would be tested to model access to train:

- P&R and K&R choices (i.e. car access): highway LOS from the home (origin) zone to the zone in which the train station lies would be used, together with train LOS from station zone to destination zone.
- Bus access: the access leg skims will be taken from the bus-only assignment for zones to stations; for the train leg skims will be taken from the train assignment from stations to zones.
- Walk/bike access: for the access leg highway LOS for zones to stations will be used, and for the train leg skims will be taken from the train assignment from stations to zones.

LOS data to support these definitions was supplied by BTS.

5.3 Station Alternatives

Modelling the choice of station for P&R and K&R ensures that the modelling represents the impact of congestion caused by these trips in the vicinity of stations, and also allows predictions to be made of the demand for parking at each P&R location.

Station alternatives in the model include heavy rail stations, ferry wharves and light rail stops/stations. Following discussion with BTS, it was agreed that the ferry services included within the station choice models for P&R and K&R alternatives would be restricted to services on Sydney Harbour and therefore exclude other ferry services in the Greater Sydney area. The excluded ferry services are:

- Woy Bay – Empire Bay
- Empire Bay – Ettalong
- Church Point – Scotland Island
- Cronulla – Bundeena
- Brooklyn – Dangar Island
- Palm Beach – Ettalong & Wagstaff
- Palm Beach – Mackerel Beach and the Basin
- Newcastle – Stockton

5.3.1 Park-and-Ride and Kiss-and-Ride Access

Representing the choice of station for P&R and K&R adds another level in the choice structure, with an expectation, based on experience from the development of the PRISM model for the West Midlands region of the UK, that station choice would lie beneath access mode choice.[15] For the station choice set to be exhaustive, every station zone in the model area should be represented. However, this approach would mean looping over approximately 400 station alternatives for each destination zone, and for a given journey

[15] See Fox (2005).

the probability of selecting most of these stations is low. This would lead to substantial run times, both in estimation, and, more importantly, in model application.

The approach that was used in the PRISM models was to estimate the models using the full sample[16] of stations. Then, in application, the number of stations is identified during a pre-processing step, based on analysis that demonstrated that only a few stations are likely to be chosen in reality, as would be expected. In PRISM, the maximum number of stations used in application is three (some applications use only one station to save run time).

However, there are two problems with the PRISM approach is this context. First, including all station zones in the estimation structure will result in substantial impacts in estimation run times, given that the model structure also includes main mode, toll road and destination choices. Second, the difference between the PRISM estimation and application structures introduces unwanted complexity, and the lesson from that work was that achieving full consistency between the estimation and implementation structures is preferable.

The approach that was used for this re-estimation work was to identify, for a given purpose and origin, the most attractive station zones using a pre-processing run, and to output to a file the levels of service for these station zones. The advantage of this approach in the main model estimation is that there is no need for an additional time-consuming loop over station zones. Instead, the model reads in sets of level-of-service for P&R access and for K&R access that represent each of the possible stations.

Drawing on the PRISM approach, the attractiveness of a station can be defined by the utility of a station alternative including:

- Car access time to the station
- Train in-vehicle time to the final destination
- Bus in-vehicle time to the final destination (in some cases)
- Egress time from the station to the final destination
- Waiting time for the first and any subsequent train and bus services
- The number of interchanges for the journey
- Cost of parking, if relevant
- Potentially some measure of the attractiveness of the station for P&R, such as the number of park-and-ride spaces provided.

Discussions with BTS have suggested that providing measures of attractiveness defined by number of spaces would be problematic for two reasons:

- First, because a lot of parking takes place on-street around stations, and this will not be captured in the parking data.

[16] The P&R models were estimated using separate station choice data, and so including all station alternatives was not problematic for run times, as only the chosen origin-destination pair was considered.

- Second, for many stations capacity is not an issue, so using the number of spaces may artificially boost the attractiveness of large stations.

Therefore the following approach was adopted:

- The attractiveness of stations was represented purely based on level-of-service attributes.
- Where parking is not possible, e.g. some stations in the CBD, these stations were set to be unavailable for P&R.

The most attractive stations were identified by ranking the utility of each of the approximately 400 possible station zones, and then selecting the top stations from that ranking. Up to five stations were selected; the numbers vary by travel purpose as detailed in Section 7.6.1.

5.3.2 Bus and Walk/Bike Access

For bus access, and walk/bike access, it would also be possible explicitly to model station choice, assigning trips to multiple paths for a single origin-destination movement. However, to do so would add further complexity to the model structure and would therefore increase run times, both in model estimation and in application. Furthermore, it is less important explicitly to represent station choice for these access modes compared with P&R and K&R, where the impact of the access legs on the highway network needs to be represented and demand for parking is of interest.

Therefore it was decided that station choice would not modelled on the choice model structure for bus and walk/bike access. This meant that it was necessary to combine zone to station information and station to zone estimation prior to model estimation.

A number of approaches for selecting an access station were considered: using the nearest station to the home zone, using the most attractive station based on the utility of both the access and train legs, and using zone to zone level-of-service which means taking account of station choice using Emme rather than the choice model.

Initial tests were undertaken for commute. Analysis of the stations selected on the basis of utility revealed that for bus access, the station identified matched the chosen station in only 28 per cent of cases. For walk and cycle access, the percentage was much higher (78 per cent) as would be expected, as the access station is typically the station closest to home. However, the impact of the poor prediction for bus was that the bus access time parameter in the model was insignificant, and the rail time parameter was weakly estimated.

Therefore, an alternative structure was tested whereby bus and walk/cycle access were merged, and zone to zone Emme level-of-service was used. In this approach, Emme selects the chosen station, and determines whether or not bus is used as an access mode. It is noted that this is the approach that was used successfully in the Stage 1 and 2 estimation work, where car access to train was not explicitly modelled.

More acceptable results were obtained when Emme was used to model bus and walk/cycle access. In particular, the bus time parameter (now shared with bus main mode) was not changed from earlier models where it applied to bus as a main mode only, and the significance of the access and egress time parameter was improved. Thus the terms associated with bus and walk/cycle access were improved. It was therefore concluded that this structure was preferable, and it was used for the other model purposes also.

CHAPTER 6 Model Specification

This chapter describes the model specification. A description of the mode and destination alternatives is given, including representation of the toll road, access mode and station choices introduced as part of this modelling work. The variables represented in the models are described, and a summary is provided of the data that is excluded from the estimations. Finally, the structural tests used to investigate the relative sensitivity of the different choice decisions are described.

6.1 Alternatives

6.1.1 Mode Alternatives

As discussed in Section 2.4, eight different main mode alternatives are included in the choice models. The modes are:

- Car driver, toll and non-toll modelled separately
- Car passenger
- Train, with three separate access possibilities
- Bus only
- Bike
- Walk
- Taxi
- School bus (primary and secondary education only).

The aggregation of the modes recorded in the HTS into these modelled modes is documented in Table 7 of the HCG and ITS (2001a) report. The split of car driver into toll and no-toll alternatives is documented in Section 4.2.

The public transport (PT) alternatives were nested together in order to test whether individuals were more likely to switch between train and bus than between PT and non-PT modes.

Three access modes to train are represented:

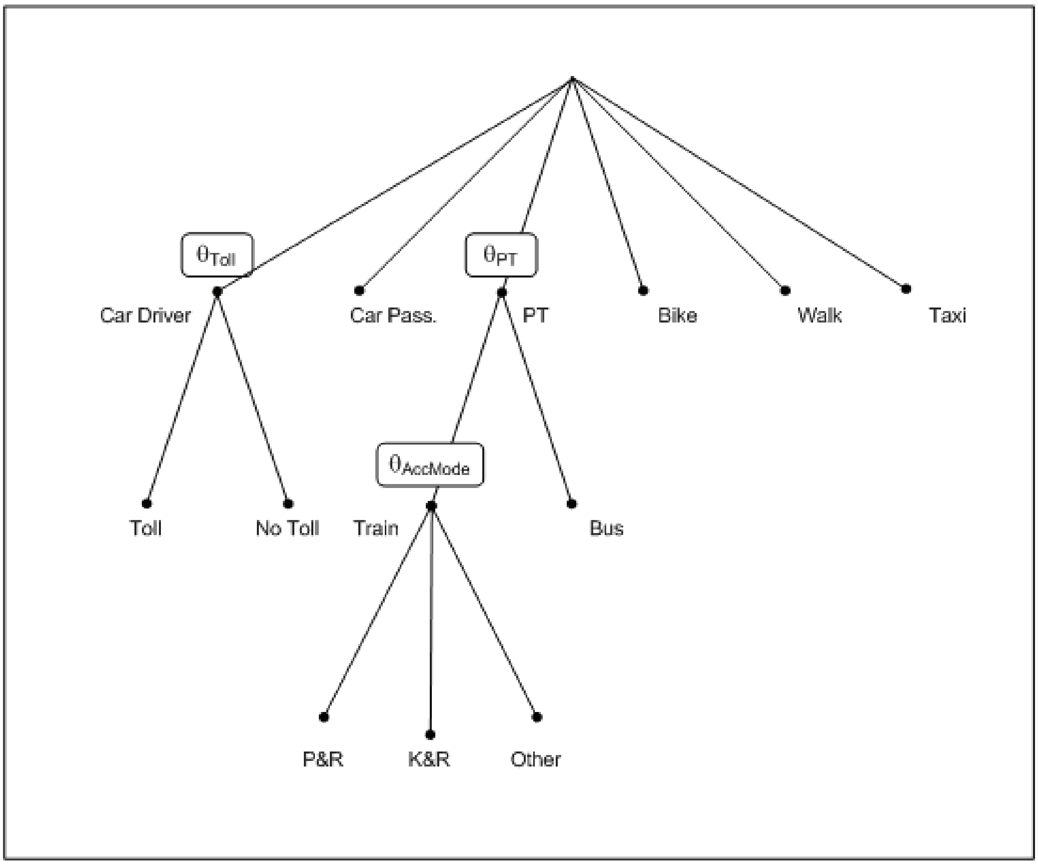
- Park-and-ride

- Kiss-and-ride
- Other: bus, walk and bike.

These access modes are discussed further in Section 5.1.

The structure for the different combinations of mode alternatives that result from the toll road, public transport and train access mode nests is shown in Figure 6. It should be noted that beneath the P&R and K&R alternatives, there are further station alternatives, with up to five stations represented per access mode (the actual number of stations represented depends on the model purpose).

Figure 6: Mode Structure[17]



6.1.2 Destination Alternatives

Since the Stage 1 and 2 estimations, the zoning system has been revised. The new zoning system uses smaller zones. Also, the geographic coverage of the model has been extended to include Newcastle and Wollongong. As a result the number of zones has increased substantially from 884 to 2,690.

Each zone represents a destination alternative in the models.

[17] It is noted that for clarity this structure is presented without normalisation. However, the structure used for the estimations is normalised.

6.1.3 Availability

Each combination of mode and destination represents an alternative in the models. The availability of these alternatives is specified depending on both the mode and destination.

To determine the availability of each alternative, there is first a check that a non-zero attraction variable exists in the destination zone. If total employment is the attraction, this condition is nearly always met, but for some purposes such as primary education (for which the number of education places is used) this reduces the number of zones available considerably.

If the attraction test is passed, then the following checks are applied to the modes represented in the models:

- Car driver toll is available if the individual owns a licence, their household owns at least one car and there is a toll road skim between the origin and destination zones.
- Car driver non-toll is available if the individual owns a licence and their household owns at least one car.
- Car passenger is available to all individuals, as it is possible to get a lift from people from outside the household.
- Train P&R is available if the household owns at least one car, and the tour is not within the same zone (an intrazonal).
- Train K&R is available if the household owns at least one car, and the tour is not within the same zone (an intrazonal).
- Train other is available if there is a rail path in the all-modes public transport network between the origin and destination, there are at least 0.5 rail entries for the path (see paragraph below) and the tour is not intrazonal.
- Bike is always available (but see note below about impact of distance).
- Walk is always available (but see note below about impact of distance).
- Taxi is available if the tour is not intrazonal.
- School bus is available to all school children in the primary and secondary education models.

Note that the train P&R alternative includes both drivers and any passengers, and because passengers are included availability is not conditioned on individual licence holding. For both P&R and K&R, it is always possible to drive to a station to access train services, and the pre-processing step checks whether a rail path exists to the destination. Therefore, there is no need to condition availability on the train skims in the main estimation file (whereas for train other, train is only available where there is a rail path between the origin and destination).

The condition on train other availability on the number of train entries is necessary because Emme may average demand over different PT paths for the same origin-destination pair. It is possible that one path might be bus-only, while a second uses train.

The value of 0.5 rail entries is specified to take account of such multi-pathing, and means that train is set to be available if Emme suggests at least 50 per cent of the demand would travel by train for the origin-destination pair in question.

Bike and walk are available for all destinations, including those some distance from the origin. However, the bike and walk distance terms included in the models mean that the predicted probability of choosing walk bike and walk for more distant destinations is extremely low.

6.2 Model Variables

6.2.1 Level of Service

The level of service information is described in Chapter 3. Table 16 summarises how these level of service variables are represented in the mode utilities in the initial model specification for each purpose.

Table 16: Level of Service Variables, Main Modes Except Train

Variable	Car Driver Toll	Car Driver Non Toll	Car-Pass.	Bus	Bike	Walk	Taxi
Driving cost	Cost						
Harbour crossing tolls	Cost	Cost					Cost
Other Tolls	Cost						Cost
Parking Cost	Cost	Cost					
Taxi Fare							Cost
Bus Fare				Cost			
Car time, toll skims	CarTime		CarTime				TaxiTime
Car time, non toll skims		CarTime					
Bus Time				BusTime			
Access/ Egress Time				AcEgTm			
Initial Wait Time				FWaittime			
Other Wait Time				OWaittime			
Boardings				Boardings			
Distance			CarPDist		BikeDist	WalkDist	

For car passenger, level of service was averaged over toll and non-toll alternatives. For origin-destination pairs where a toll route is available, the averaging used the observed toll/non-toll share for car driver. However, for the majority of origin-destination pairs there is no toll route available and therefore the non-toll skims were used directly.

For taxi, it is assumed that toll routes are used if they are identified in the toll skims, and that the tolls are added to the taxi fare. Therefore, the toll skims are used for taxi.

For home–primary and home–secondary, an additional school bus mode is represented using time and distance from the non-toll highway assignment.

Table 17: Level of Service Variables for Train Access Modes

Variable	P&R	K&R	Other
Train fare	Cost	Cost	Cost
Driving Cost	Cost	Cost	
Car time, non toll skims	CarAcTm	CarAcTm	
Rail time	RlTime	RlTime	RlTime
Ferry time	RlTime	RlTime	RlTime
Light rail time	RlTime	RlTime	RlTime
Bus Time	RlTime	RlTime	BusTime
Access/ Egress Time	AcEgTm	AcEgTm	AcEgTm
Initial Wait Time	FWaittime	FWaittime	FWaittime
Other Wait Time	OWaittime	OWaittime	OWaittime
Boardings	Boardings	Boardings	Boardings

For P&R and K&R access alternatives, it is assumed that the access leg uses the non-toll network described in Section 4.1. Note also that if bus egress is used for P&R and K&R, then this receives the rail time parameter, rather than the bus time parameter, due to how the LOS processing operates.

6.2.2 Treatment of Intrazonals

No level of service data is available for intrazonal trips.

For car, walk and bike, intrazonal level of service was imputed by taking half the level of service to the nearest zone to provide an approximation of the time and distance associated with an intrazonal trip within the zone. In addition, mode specific intrazonal constants were estimated.

Recent RAND Europe experience in developing model systems for the West Midlands and Manchester in the UK, as well as for The Netherlands, has demonstrated that this approach gives a better fit to the data. A further advantage of imputing level of service for intrazonals in this way ensures that demand is responsive to changes in level of service. For example, if congestion is predicted to increase substantially, then some short car trips would be expected to switch to walk or cycle and the imputed level of service would ensure this response, whereas a model with intrazonal constants only would not represent any change in the attractiveness of car for intrazonals relative to other modes. Therefore, this imputation procedure has been adopted for the model estimation work to give an improved treatment of highway intrazonals.

For public transport and taxi, intrazonal trips are rarely observed and so they were set to be unavailable.

6.2.3 Cost Sharing

In the Stage 1 and 2 modelling work, it was assumed that all car costs were borne by the driver. However, recent RAND Europe work in the UK has demonstrated that an improved fit to the data may be obtained by assuming that passengers pay some fraction of the total car cost.

The cost sharing is achieved by specifying cost components for the car driver and car passenger utility functions as specified in equations (6.1) and (6.2):

$$V(Cost)_{CD} = \beta_{Cost} CarCost_{OD} \left[1 - \frac{S(O_{CD} - 1)}{O_{CD}} \right] \quad (6.1)$$

$$V(Cost)_{CP} = \beta_{Cost} CarCost_{OD} \left(\frac{S}{O_{CP}} \right) \quad (6.2)$$

where:

β_{Cost} is the cost parameter, estimated across all modes in the model

$CarCost_{OD}$ is the car cost, including parking costs at the destination

S is the cost sharing factor

O_{CD} is the mean occupancy for car driver observations in the HTS (by purpose)

O_{CP} is the mean occupancy for car passenger observations in the HTS (by purpose)

If S takes a value of 0, there is no cost sharing and the driver pays the full cost. If S takes the value of 1, there is equal sharing, i.e. drivers and passengers pay an equal share.[18] Intermediate values of S imply both drivers and passengers contribute towards the total cost, but the driver pays a greater share. The value of S that gives the best fit to the observed data is determined by testing different values iteratively.

Mean occupancies are used rather than observed values because the occupancy is not known for PT and slow mode observations. The mean occupancy values vary with purpose and are summarised in the following table.

Table 18: Mean Occupancy Values (source: HTS Data)

Purpose	Car Driver	Car Passenger
Commuting	1.20	2.27
Home-Tertiary Education	1.22	3.03
Home-Shopping	1.47	2.41
Home-Other Travel	1.57	2.68

No cost information is used in the final primary education model, and so the issue of cost sharing does not arise. For secondary education, there is a substantial volume of car passenger information, and a few car driver observations. However, in the majority of cases it will be the parent who is paying the costs, not the student, and therefore representing sharing between drivers and passengers is not appropriate. For home tertiary travel, there are substantial numbers of both car driver and car passenger observations and therefore cost sharing has been assumed.

For business travel, it is assumed that it will be the driver (rather than any passengers, if they exist) who reclaims the costs of their travel from their employer, and therefore representing sharing of costs between drivers and passengers was not modelled.

[18] Strictly this is only true if $O_{CD} = O_{CP}$, whereas in reality $O_{CP} > O_{CD}$. If observed occupancies were used, equal sharing would occur. The problem is for non-car observations – it is not known what the occupancy would have been and so mean occupancies have to be used instead.

6.2.4 Socio-Economic Variables

The socio-economic variables in the models were identified using a two-stage process. First, the socio-economic variables identified during the Stage 1 and 2 estimation work were retested, and effects that remained significant were retained. Second, the models were applied to specific segments of the population, and observed and predicted behaviour was compared to identify any further terms that were required.

The following segmentations were investigated:

- Car availability, determined from a combination of household car ownership and personal and household licence holding
- Household income
- Personal income
- Gender
- Age
- Adult status
- Occupation type.

For the income terms, specification tests were used to investigate the variation in the sensitivity to cost with income band.

6.2.5 Attraction Variables

In the home–work model estimated during Stage 1, separate attraction variables were used for manufacturing and non-manufacturing workers, in part to achieve consistency with previous versions of the STM. However, the proportion of jobs in manufacturing has declined substantially since the first STM was developed, and furthermore the validation project revealed that the spatial variation in where manufacturing and non-manufacturing workers live was not predicted well by the population model.

Therefore, alternative specifications for the commute attraction variable were tested in this model. Initial model development used a single total employment attraction variable. A test was made of segmenting the attraction variable by the five income bands that had been identified to segment the cost parameter (these are defined in Section 7.1.2). The income segmented attraction variables reflect the number of jobs in each zone for each personal income band. This specification for the attractions should give a better fit to the data, as the attractions will better reflect where jobs in a given income band are located. Using income segmented attractions did indeed lead to a substantial improvement in the fit of the model to the observed data. Therefore, this specification was retained.

For the remaining purposes, the attraction variables used in the models are the same as those used in the Stage 2 estimations, as summarised in Table 19.

Table 19: Attraction Variables

Purpose	Attraction Variable
Commute	Employment by personal income band
Business	Total employment
Primary education	Primary enrolments
Secondary education	Secondary enrolments
Tertiary education	Tertiary education employment
Shopping	Retail employment
Other	Population, retail employment, service employment

6.3 Model Exclusions

Observations were excluded from the model estimation for the following reasons:

- All half tours
- If there was no attraction zone in the chosen primary destination zone
- Where the chosen destination zone lies outside of the study area
- If the observed mode was air or monorail
- Car driver observations where the household does not own a car, and/or the individual does not own a full or provisional licence
- Car driver toll observations where there is no toll road skim in the assignment
- Car driver toll observations where the toll falls below the $1 threshold (see Section 7.5)
- Train main mode with taxi, school bus or other access
- Train P&R observations where the household does not own a car
- Train K&R observations where the household does not own a car
- Train observations where there is no path for the chosen destination in the rail assignment
- Bus observations where there is no path for the chosen destination in the bus assignment
- Train, bus and taxi intrazonals.

The volumes of data excluded from the final models are detailed in Appendix A.

For commute and employer's business, the largest exclusion is of half tours (4 to 5 per cent of the data). These are excluded from the mode-destination models, but outward half-tours are included in the frequency modelling so that the overall volume of travel predicted by the models is consistent with that observed in the HTS data.

For the three education models, substantial numbers of tours are excluded because there is no attraction variable in the destination zone; in the case of secondary education 14 per cent of the data is excluded for this reason. The attraction data supplied includes non-government (private) schools, as well as government schools, but the relatively high percentage suggests that there may be some special schools that are not captured in the data.

For shopping and other travel, the volumes of data excluded are lower than the other purposes. The major exclusion for other travel is also half tours. As noted above these are included in the frequency modelling and so this will not result in an under-prediction of observed shopping and other travel.

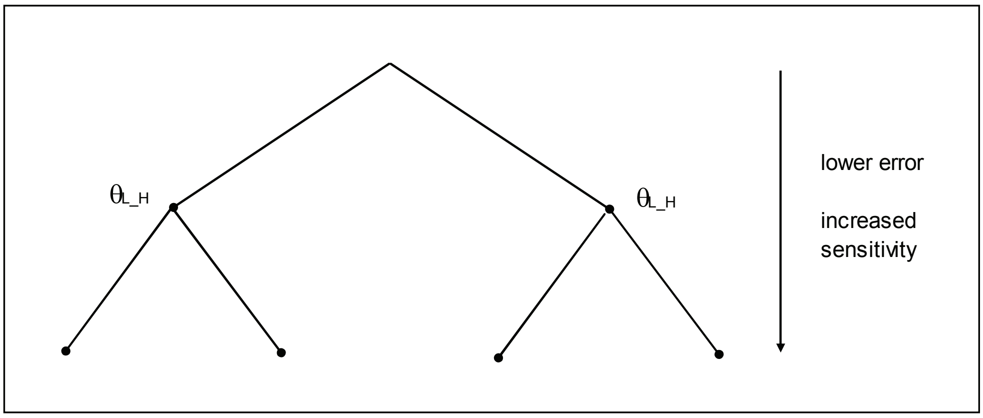
The exclusions associated with the toll road and train access mode alternatives are discussed further in Sections 7.5 and 7.6 respectively.

6.4 Structural Tests

The initial model development was undertaken assuming a multinomial logit model structure, i.e. mode choice, toll road, public transport, access mode, station and destination choices all equally sensitive to changes in utility. Once the final model specification had been identified, structural tests were made that provide insight into the relative sensitivities of the different choice decisions.

To perform the structural tests, nested logit structures were set up with the different choices represented at different levels in the structure, as illustrated in Figure 7.

Figure 7: Nested Structures



Choices represented lower down in the structure have lower levels of error, and are more sensitive to changes in utility. The structural parameter θ_{L_H} defines the relative levels of error in the lower and higher levels of the structure, where L denotes lower level and H denotes higher level:

$$\theta_{L\_H} = \frac{\sigma_L}{\sigma_H} \tag{6.3}$$

where: σ_L is the standard deviation of the error in the utilities at the lower level

σ_H is the standard deviation of the error in the utilities at the higher level

For the structure to be valid the condition $\sigma_H \geq \sigma_L$ should hold, which gives the condition $0 \leq \theta_{L\_H} \leq 1$. If a model is estimated that gives $\theta_{L\_H} > 1$ then the structure is rejected, and a structure would be tested with the higher and lower levels reversed or the parameter would be constrained to a value of one.

In the Sydney estimations, there are up to six choice decisions represented for a given travel purpose. This means that there are up to 720 possible structures. This number is reduced in practice, as certain conditions apply to the ordering, specifically:

- The mode nest must be above, or at the same level as, the public transport nest (though in theory it would be possible to nest other combinations of modes).
- The public transport nest must be above, or at the same level as, the access mode nest as the access modes nest beneath train.
- The access mode nest must lie above, or at the same level as, the station choice nest as the station alternatives nest beneath access modes.

Despite these reductions, the number of possible structures was too high (30) for it to be feasible to test each possible combination. Therefore, the strategy employed was to make a number of tests, and then analyse the information provided from these runs as to the relative sensitivity of each choice to determine the next structure for testing.

CHAPTER 7 Model Results

This chapter discusses the model results. Section 7.1 summarises the specification of the cost terms in the models. Section 7.2 describes the level of service terms represented in the final models. Section 7.3 details the socio-economic terms included in the models. Section 7.4 describes the destination effects included in the models. Section 7.5 describes the results from the inclusion of toll road choice in the models. Section 7.6 highlights the key results from the modelling of train access mode and station choice. The chapter concludes in Section 7.7 with a summary of the structural tests run to investigate the relative sensitivity of the different choices represented in the models. The full parameter results from the models are given in Appendix B.

7.1 Specification of Cost

7.1.1 Linear and Logarithmic Cost

An important consideration during the model development was how the cost variable entered into the utilities. During the Stage 1 and 2 estimation work, log-cost specifications were used for most of the travel purposes. Consistent with other studies, logarithmic cost was found to give a significant improvement in fit relative to linear cost, and the implied values of time were judged reasonable for the mean observed costs.

However, a feature of the log-cost specification is that in elasticity tests, destination choice is inelastic to cost changes, because a uniform increase in costs across all destinations becomes a constant change in utility across all destinations once it has been logged. This means that the only response to cost changes is some mode shifting, and low kilometrage elasticities are observed.

In the UK context, there has recently been increased emphasis on model elasticity and in response to this, RAND Europe have recently developed models with cost entering the utility in both linear and logarithmic cost forms in the same model.[19] In some cases, the combined form has resulted in an improved fit to the data, as well as yielding more plausible cost elasticities and values of time.

Therefore, the default specification for Sydney was to start with both linear and logarithmic cost terms and then test which terms were negative and significant. Table 20 summarises the results from those tests for each travel purpose.

[19] See Fox et al. (2009).

Table 20: Tests of Linear and Logarithmic Cost Terms

Purpose	Terms Identified
Commute	Linear and logarithmic
Home-business	Logarithmic only
Home-primary	No cost term
Home-secondary	Logarithmic only
Home-tertiary	Logarithmic only
Home-shopping	Logarithmic only
Home-other	Logarithmic only
Work-based business tours	Logarithmic only
NHB business detours	Logarithmic only

For commuting, significant linear and logarithmic terms were identified, consistent with model tests in the UK. However, for other journey purposes it was not possible to identify both effects simultaneously. The reasons for this are likely to vary with journey purpose, but it may relate to differences in the distribution of costs between the UK and Sydney contexts.

For home–primary education travel, there is little cost data. For infants in Kindergarten up to year 2 (K-2) travel is free regardless of distance. For primary (years 3 to 6) travel is free for pupils travelling more than 1.6 km from school receive free bus/train travel to school.[20] For home–secondary education travel there is also not much cost data to fit two cost terms to, as individuals travelling more than 2 km do not have to pay for education travel. Finally, for home–tertiary there are fewer than 900 observations in total and so identifying two cost effects is difficult.

For home–business, home–shopping and home–other travel, there are substantial samples of car tours, and in application these purposes will account for a substantial fraction of total kilometrage. Accordingly, investigations were made to assess the fuel cost elasticity obtained with the logarithmic only formulation. As expected, these tests demonstrated relatively low fuel cost elasticities, with values of -0.01 for home–business,[21] -0.10 for home–shopping and -0.14 for home–other.

Building on other RAND Europe experience (Fox et al. 2009), tests were then undertaken where a mixed logarithmic and linear form was imposed in order to increase the cost elasticity by introducing a linear cost effect. This was achieved using a cost term specified as follows:

$$\beta_{\cos t}\left\{\gamma.\text{cost}+(1-\gamma)\log(\text{cost}).\frac{\text{E(cost)}}{\text{E(log(cost))}}\right\} \qquad (7.1)$$

where: γ controls the relative contribution of linear and logarithmic cost

E(cost) is the mean cost

E(log(cost)) is the mean logarithmic cost

the term E(cost)/E(log(cost)) ensures linear and logarithmic cost use the same scale

[20] www.transport.nsw.gov.au/ssts/ssts.html (accessed 26/11/10).

[21] Note that for business, car costs are modelled using the casual kilometrage rate, and not by calculating fuel costs. Therefore, for business a car cost elasticity is computed instead of a fuel cost elasticity.

The parameter γ is varied by trial and error to investigate the impact of different mixtures of logarithmic and linear cost, on model fit, elasticities and implied values of time. A value of γ=0 gives a pure log-cost model, whereas γ=1 gives pure linear cost.

For home–business, a value for γ=0.05 resulted in only a minor loss in fit to the data, measured by the log likelihood, and slight changes to the model parameters, but yielded a substantial improvement in the fuel cost elasticity, as shown in Table 21.

Table 21: Logarithmic Linear Mixture Tests, Home–Business

γ	Fuel Cost Elasticity	Log Likelihood
0	-0.01	-26,291.5
0.05	-0.10	-26,294.8

The car cost elasticity of -0.10 was judged to be plausible, and therefore the value of γ equal to 0.05 was retained in the final model specification.

The tests for home–shopping demonstrated that a small linear cost effect gave more plausible fuel cost elasticities, but that this resulted in a decline of the strength of the rail in-vehicle time parameter, and as a consequence a decline in the values of time for rail.

Table 22 summarises how the fuel cost elasticity, log likelihood and rail values of time (the values of time vary with cost, therefore they have been calculated using the mean rail cost of shopping tours that choose rail) varied with the mixing parameter γ. In a UK context, fuel cost elasticities for these purposes would be expected to be in the region of -0.3 to -0.4. However, fuel costs are substantially lower in Sydney and following discussion with BTS a value of -0.2 to -0.25 was judged reasonable for Sydney. For commuting, the train values of time are $5/hr to $9/hr (depending on income), and in discussion with BTS it was viewed sensible for shopping and other values of time to be around half that value, i.e. around $3.50/hr. A full discussion of values-of-time and elasticity is presented in Chapter 8.

Table 22: Logarithmic Linear Mixture Tests, Home–Shopping

γ	Fuel Cost Elasticity	Log Likelihood	Rail VOT ($/hr)
0	-0.10	-33,064.3	6.63
0.05	-0.17	-32,876.4	3.33
0.10	-0.23	-32,907.9	1.92

It can be seen that a relatively small linear cost effect results in a substantial improvement in the fuel cost elasticity. A value for γ of 0.1 gives a plausible elasticity, but a low rail value of time, and further loss in model fit. A value for γ of 0.05 was selected to give a trade off between cost sensitivity, fit to the data and value-of-time.

A similar pattern was observed for other travel, although the elasticity of the model with a log-only formulation was higher.

Table 23: Logarithmic Linear Mixture Tests, Home–Other Travel

γ	Fuel Cost Elasticity	Log Likelihood	Rail VOT ($/hr)
0	-0.14	-146,355.9	7.67
0.025	-0.25	-146,396.5	4.65
0.05	-0.35	-146,456.5	3.44
0.10	-0.53	-146,621.8	2.11

A value of γ of 0.025 was selected to give a balance between cost sensitivity, fit to the data and value of time.

It is noted that following validation of the tour lengths predicted by the models, modifications were made that have resulted in higher train values of time for shopping and other travel. The values of time in the final models are presented in Section 8.2.

For the two non-home-based business purposes, the log-cost formulation was retained on the basis that the relatively low elasticity of the models to cost changes was viewed as reasonable for business travel, and the volumes of travel are relatively low so that they will have only a small impact on the total elasticity of the model system in application.

7.1.2 Income Segmentation

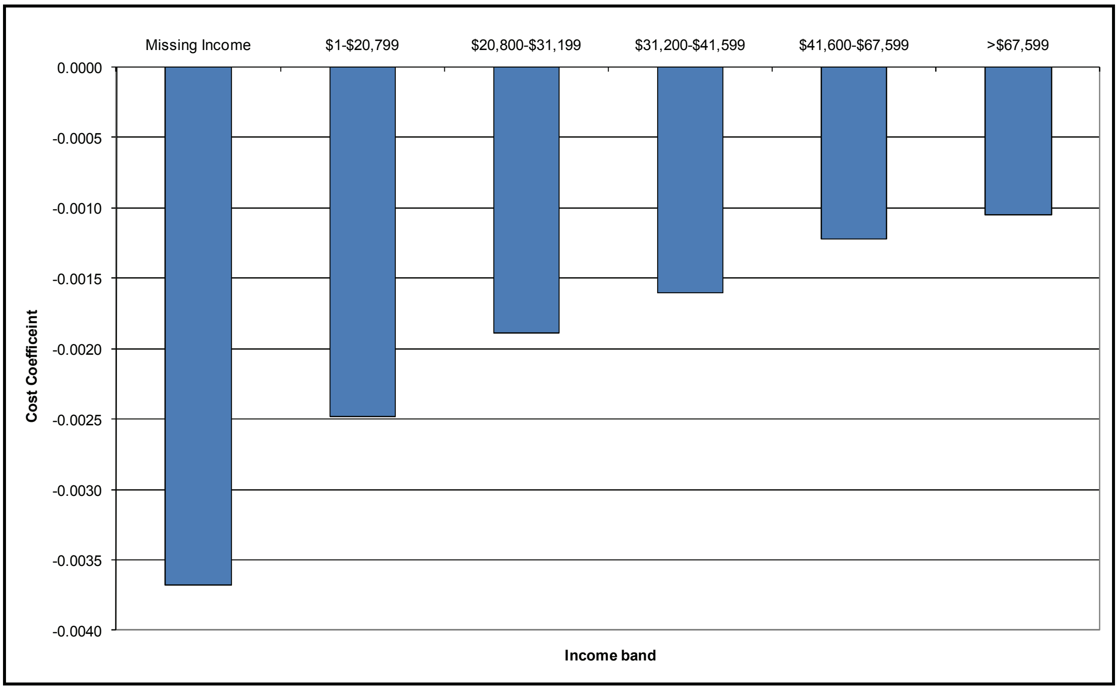
In the Stage 1 and 2 specifications, significant variation in cost sensitivity with income was identified for commute, home–business, home–other travel, work-based business and non-home-based business detour purposes. Income segmentations were retested in the new models, using income bandings used in the HTS that are defined in 2006 prices.

For commuting, which has both linear and logarithmic cost terms, significant variation in cost sensitivity with income was identified for the linear cost effect, but no significant variation in sensitivity to logarithmic cost with income was identified. Six personal income bands were identified from the data, with a steady pattern of decreasing sensitivity to cost with increasing income:

1. Missing income
2. $1–$20,799
3. $20,800–$31,199
4. $31,200–$41,599
5. $41,599–$67,599
6. > $67,599

Figure 8 illustrates the variation in the linear cost term with personal income band. It can be seen that cost sensitivity decreases as income increase. The high sensitivity to cost that is observed for those with missing incomes suggests that these individuals may have low incomes. It should be noted that a logarithmic cost term is applied to all income bands in addition to the relevant linear cost term.

Figure 8: Variation in Linear Cost Sensitivity with Income, Commuters

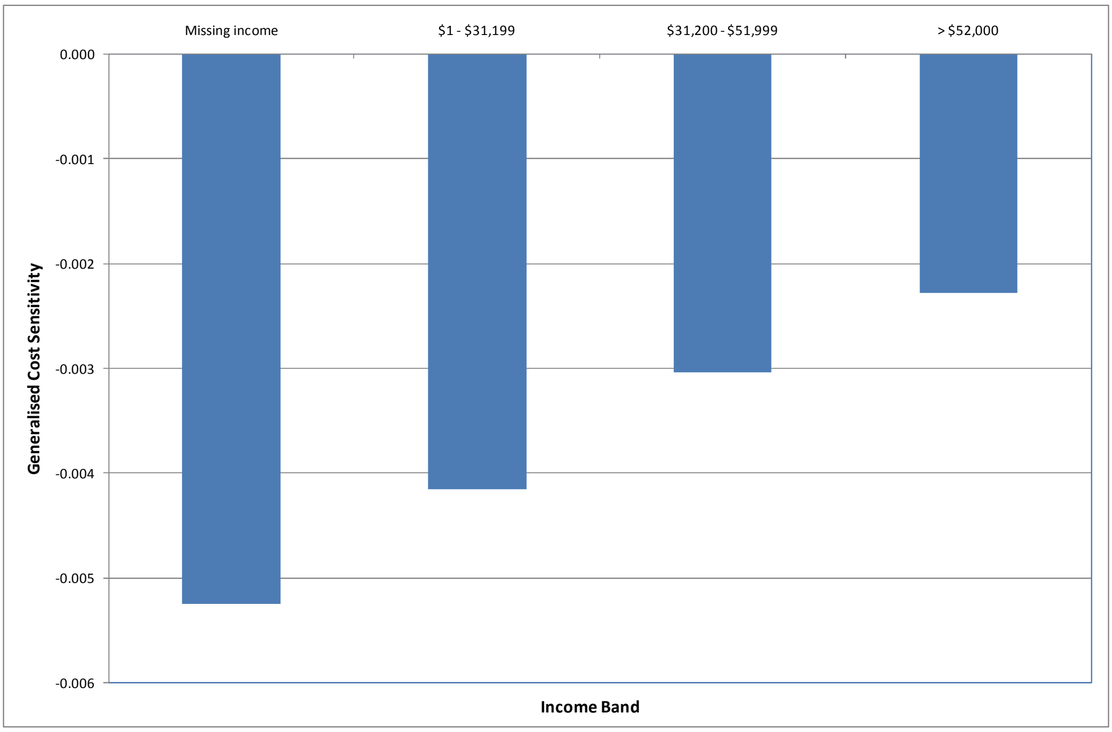


For home–business, cost enters the utility function in a combined linear and logarithmic form (as discussed in Section 7.1.1), and the sensitivity to this combined linear and logarithmic form varies between four personal income bands. Again, sensitivity to cost declines with increasing income:

1. Missing income
2. $1–$31,199
3. $31,200¥$51,999
4. > $52,000

The variation in sensitivity to the combination of linear and logarithmic cost is summarised in Figure 9.

Figure 9: Variation in Sensitivity to Linear-Logarithmic Cost Mixture with Income, Business



As per the commute model, cost sensitivity decreases with income, and those with missing incomes have the highest cost sensitivity.

For secondary and tertiary education purposes, the sample sizes are relatively small, and in the case of secondary there is little cost information. Therefore, variation in cost sensitivity with income was not investigated.

For shopping and other travel, variation in the sensitivity of logarithmic cost with income was investigated but no pattern of variation was identified. For shopping, the results indicated remarkably uniform cost sensitivity with income. For home–other, a marginal effect of reducing log-cost sensitivity with increasing income was identified, but the log-cost parameters were not significantly different from one another, and therefore a single cost parameter estimated across all incomes was used in the final model specification.

For work-based business and NHB business detours there is little data and therefore variation in cost sensitivity with income was not investigated.

7.1.3 Cost Sharing

The results of the cost sharing tests, described in Section 6.2.3, are summarised in Table 24. For business travel, it is assumed that drivers can reclaim the cost of travel from their employers, and so cost sharing is not represented in the three business models.

Table 24: Cost Sharing Factor S

Purpose	Sharing Factor S
Commuting	0.5
Home-Tertiary Education	0.5
Home-Shopping	1.0
Home-Other Travel	1.0

For commuting, the best fit is obtained assuming passengers pay a share of car costs, but that the share paid by the driver is higher. The same assumption gave the best results for tertiary education.

For shopping and other travel, the best fit is obtained assuming drivers and passengers pay an equal share of the total car costs.

These results indicate that cost sharing is higher for discretionary travel purposes than for mandatory travel purposes.

7.2 Level of Service Terms

For home–tertiary education, substantial volumes of travel are observed to the University of New South Wales zone. A high-frequency shuttle bus service is used to connect the university to Central rail station, and as many of the services are not timetabled the attractiveness of these services is not fully described by the public transport skims. To account for this in the tertiary education model, a public transport constant is applied to this zone, and in addition the number of train boardings was reduced by one in each direction for trips to the university zone to account for the easy transfer at Central rail station. Both adjustments improved the fit of the model to the data.

For each purpose, the initial model specification for the level-of-service terms was shown earlier in Table 16 and Table 17. However, it was not always possible to estimate separate parameters for each of the public transport level-of-service components. Table 25 summarises the final specifications for each home-based model purpose.

Table 25: Final Public Transport Level of Service Specifications, Home-Based Models

<table>
<tr><th>Variable</th><th>Commute</th><th>Business</th><th>Primary</th><th>Second.</th><th>Tertiary</th><th>Shop</th><th>Other</th></tr>
<tr><td>Rail time</td><td rowspan="3">RlFrTime</td><td rowspan="3">RlFrTime</td><td rowspan="3">RlFrTime</td><td rowspan="3">RlFrTime</td><td rowspan="3">RlFrTime</td><td rowspan="3">RlFrTime</td><td rowspan="3">RlFrTime</td></tr>
<tr><td>Ferry time</td></tr>
<tr><td>Light rail time</td></tr>
<tr><td>Bus Time</td><td>BusTime</td><td>BusTime</td><td>BusTime</td><td>BusTime</td><td>BusTime</td><td>BusTime</td><td>BusTime</td></tr>
<tr><td>Access/egress time</td><td>AcEgTm</td><td>AcEgTm</td><td>AcEgTm</td><td>AcEgTm</td><td>AcEgTm</td><td>AcEgTm</td><td>AcEgTm</td></tr>
<tr><td>Initial wait time</td><td>FWaitTm</td><td rowspan="3">WaitTm</td><td rowspan="3">WaitTm</td><td rowspan="3">WaitTm</td><td rowspan="3">WaitTm</td><td>FWaitTm</td><td rowspan="2">WaitTm</td></tr>
<tr><td>Other wait time</td><td rowspan="2">OWaitTm</td><td>OWaitTm</td></tr>
<tr><td>Boardings</td><td>Boardings</td><td>Boardings</td></tr>
</table>

It was only possible to identify separate valuations of first and other wait time for commute and shopping travel. For commute, business and the three education models, the boardings term was not significant, and therefore was merged with wait time (other wait time for commuting) assuming five minutes of wait time per boarding.

In the work-based business and NHB business detour models, there is little public transport data, and therefore it was not possible to identify separate parameters for each level of service component. Instead, generalised public transport time parameters have been estimated, assuming that wait and access/egress times receive twice the weight of in-vehicle time, and each boarding is equivalent to ten minutes of in-vehicle time.

The following tables summarise, for the home-based models, the relative valuations of the out-of-vehicle terms relative to rail/ferry time and to bus time.

Table 26: PT Out-of-Vehicle Time Valuations Relative to Rail & Ferry Time, Home-Based Models

<table>
<tr><th>Variable</th><th>Commute</th><th>Business</th><th>Primary</th><th>Second.</th><th>Tertiary</th><th>Shop</th><th>Other</th></tr>
<tr><td>Access/egress time</td><td>2.73</td><td>4.18</td><td>0.23</td><td>0.23</td><td>0.27</td><td>0.91</td><td>0.19</td></tr>
<tr><td>Initial wait time</td><td>4.42</td><td rowspan="3">4.03</td><td rowspan="3">0.34</td><td rowspan="3">0.34</td><td rowspan="3">1.71</td><td>1.79</td><td rowspan="2">0.86</td></tr>
<tr><td>Other wait time</td><td rowspan="2">3.30</td><td>0.92</td></tr>
<tr><td>Boardings</td><td>16.1</td><td>12.4</td></tr>
</table>

Table 27: PT Out-of-Vehicle Time Valuations Relative to Bus Time, Home-Based Models

<table>
<tr><th>Variable</th><th>Commute</th><th>Business</th><th>Primary</th><th>Second.</th><th>Tertiary</th><th>Shop</th><th>Other</th></tr>
<tr><td>Access/egress time</td><td>1.51</td><td>2.51</td><td>0.29</td><td>0.22</td><td>0.27</td><td>1.33</td><td>0.47</td></tr>
<tr><td>Initial wait time</td><td>2.46</td><td rowspan="3">2.42</td><td rowspan="3">0.42</td><td rowspan="3">0.32</td><td rowspan="3">1.73</td><td>2.63</td><td rowspan="2">2.04</td></tr>
<tr><td>Other wait time</td><td rowspan="2">1.83</td><td>1.35</td></tr>
<tr><td>Boardings</td><td>23.6</td><td>29.7</td></tr>
</table>

For commute and business tours, the valuations of the out-of-vehicle time components are relatively high.

For education tours, the relative valuations of the out-of-vehicle components are low, in most cases weighted less than in-vehicle time. For wait time for primary and secondary education, it may be that the relatively infrequent services that pass schools are timed to coincide with the school day, and as such the wait times from the skims overestimate what pupils actually experience. However, it is not clear why the valuations of access and egress time are so low. The relatively small sample sizes for the three education purposes may be a factor.

For shopping and other where sample sizes are large, the valuations are generally plausible, although the weighting of access and egress time is low for other travel.

7.3 Socio-Economic Terms

7.3.1 Car Availability Terms

As per the Stage 1 and 2 modelling work, substantial improvements in model fit were achieved by specifying terms relating to levels of car availability. These terms were specified as a function of:

- Individual licence holding
- Household licence holding
- Household car ownership.

On the car driver alternative, 'car competition' terms are defined if there are more licence holders than cars in the household. In such cases, there is competition for the cars in the household and consequently the likelihood of a given individual having a car available is lower. Constants are added to the models to reflect the lower probability of choosing car driver when there is car competition. Constants are also added to reflect the higher probability of travelling as a car driver if there are one or more company cars in the household.

For the car passenger alternative, the probability of travelling as a passenger is substantially higher if another household member is able to provide a lift. This is possible if at least one *other* household member has a licence, and there are one or more cars in the household. This condition is used to specify 'passenger opportunity' terms.

Table 28 summarises the car availability terms identified in the home-based models. It is noted that car driver is not available for primary education, and that for secondary education there are only a few car drivers.

Table 28: Car Availability Terms, Home-Based Models

Term	Comm.	Bus.	Primary	Second.	Tertiary	Shop	Other
Car competition (car driver)	✓	✓			✓	✓	✓
Company car (car driver)	✓	✓			✓	✓	✓
Passenger opportunity (car passenger)	✓	✓	✓	✓	✓	✓	✓
Company car (car passenger)			✓				

In addition to the terms placed on car driver and car passenger main modes, car availability terms have been placed on the P&R and K&R access mode alternatives for train for commute and employer's business, where the P&R and K&R samples are large enough to allow such terms to be identified. These terms are summarised in Table 29.

Table 29: Car Availability Terms on Train Access Modes, Home-Based Models

Term	Comm.	Bus.
Licence holding, P&R	✓	
Car competition, P&R	✓	✓
2 plus cars, P&R	✓	
Passenger opportunity, K&R	✓	

It is noted that the P&R alternative includes passengers who travel with someone who parks, and therefore the availability of the alternative is not conditioned on licence holding. However, the majority of individuals who travel by P&R are drivers, and therefore the PRlicence term proxies for the availability effect for drivers. For business, it was not possible to estimate this term as all P&R persons held a licence.

For the work-based business model, the car availability variables have not been tested because they are household-level conditions that do not apply to tours starting from the workplace.

For the NHB business detour model, the terms used reflect the strong correlation between the mode chosen for the home-based tour, which will be influenced by the car availability terms in the home-based models, and the mode used for the detour. Therefore, the impact of car availability is presented through the link to the home-based models. In addition, a company car dummy has been added to car driver to reflect the higher probability of individuals from households with one or more company cars making a business detour.

7.3.2 Other Socio-Economic Terms

In addition to the car availability terms, a number of socio-economic terms have been identified in the models to account for variations in preferences according to the characteristics of the individual or their household. In most cases, these terms account for differences in mode preferences, but in one case a term is interacted with level-of-service and so influences destination choice as well.

The starting point in the models was to retest the socio-economic terms identified during the Stage 1 and 2 model development work. Once these terms had been retested, and insignificant effects dropped, model predictions were compared to observed data across a range of socio-economic segmentations, and where there were differences new socio-economic terms were tested and retained if they yielded a significant parameter.

The following tables summarise, for each journey purpose, the socio-economic parameters that have been estimated, and detail whether the effect was identified in Stage 1 or 2, or was identified during this estimation work.

Table 30: Commute Socio-Economic Effects

Parameter	Mode	Definition	Stage 1?
MaleCrD	Car driver	Males more likely to choose car driver than females	Yes
MaleBike	Bike	Males more likely to choose bike than females	Yes
FTwkrDist	All modes	Full-time workers travel further to work than other workers	No[22]

A number of terms were dropped from the commute model that were present in the final Stage 1 specification, namely an under 25 term on car driver, a full-time worker term for travel on train, and a high personal income term on train.

Table 31: Home–Business Socio-Economic Effects

Parameter	Mode	Definition	Stage 2?
CarPu25	Car passenger	Car passenger more likely to be used by those aged under 25	No
TrnManProf	Train	Train more likely to be used by manager and professional occupations than other occupation types	No

Two terms that were present in the final Stage 2 model specification were dropped from the model, a male term on car passenger, and an age 10–19 term for travelling by bike.

[22] In Stage 1, a term was specified on part-time workers, which has a similar effect, as most workers are either full-time or part-time, and only a small fraction of other worker types are observed.

Table 32: Home–Primary Education Socio-Economic Effects

Parameter	Mode	Definition	Stage 2?
CarP<8	Car passenger	Car passenger more likely to be used by those aged under 8	Yes
Bike_Male	Bike	Males more likely to choose bike than females	Yes

No significant socio-economic effects were identified for home–secondary education. In the Stage 2 specification for home–secondary, terms were identified for bike use by males, and a tendency for pupils from higher income households to travel further, although it is noted that the significance of these effects was not strong. However, these effects were not significant when the model was re-estimated.

No socio-economic effects were identified in the home–tertiary model, this is consistent with the findings from the Stage 2 estimations.

The socio-economic terms included in the home-based shopping model are shown below.

Table 33: Home–Shopping Socio-Economic Effects

Parameter	Mode	Definition	Stage 2?
CarD<20	Car driver	Car driver less likely to be used by those aged under 20	Yes
CarP_Male	Car passenger	Males less likely to choose car driver than females	Yes
CarP<10	Car passenger	Car passenger more likely to be used by those aged under 10	Yes
Ret_CarP	Car passenger	Retired persons more likely to be car passengers than other adult status groups	No
Bus_Male	Bus	Males less likely to choose bus than females	Yes
Bus_Pens	Bus	Retired persons aged 60 or more are more likely to choose bus than others	Yes
Bike_Male	Bike	Males more likely to choose bike than females	Yes
Bike_10_19	Bike	Persons aged 10-19 more likely to choose bike than other age groups	Yes

None of the Stage 2 socio-economic terms were dropped from the home–shopping model.

The socio-economic terms included in the home-based other travel model are shown below.

Table 34: Home–Other Travel Socio-Economic Effects

Parameter	Mode	Definition	Stage 2?
CarD_DrPu	Car driver	Car driver more likely to be used for drop/pick up tours than other tour types	Yes
CarP_Male	Car passenger	Males less likely to choose car driver than females	Yes
CarP<10	Car passenger	Car passenger more likely to be used by those aged under 10	Yes
CarP_enter	Car passenger	Car passenger more likely to be used for entertainment tours than other tour types	Yes
CarPFTPTW	Car passenger	Car passenger less likely to be used by workers compared to other adult status groups	No
PT_enter	Train, bus	Public transport more likely to be used for entertainment tours than other tour types	Yes
Bike_Male	Bike	Males more likely to choose bike than females	Yes
Bike_10_19	Bike	Persons aged 10-19 more likely to choose bike than other age groups	Yes
Walk_Male	Walk	Males more likely to walk than females	Yes
Walk_Recr	Walk	Walk more likely to be used for recreation tours than for other tour types	Yes

The negative 'public transport serve passenger' term identified in the Stage 2 other travel model was not retained.

Only one socio-economic term is identified in the work-based business model, which indicates that males are less likely to walk than females.

Table 35: Work-Based Business Socio-Economic Effects

Parameter	Mode	Definition	Stage 2?
WalkMale	Walk	Males less likely to walk than females	Yes

As per the Stage 2 models, no socio-economic effects were identified in the NHB business detour model other than the car availability terms.

In summary, the majority of the terms identified in the Stage 1 and 2 estimations have been retained, and relatively few additional effects have been identified. This demonstrates that the socio-economic effects impacting on mode choice have not changed much between the two estimation datasets.

7.4 Destination Effects

Destination effects have been added to some of the models to account either for particularly popular destinations, where the attractiveness is not sufficiently represented by the attraction variable alone, or for cases where a particular mode is more attractive for a certain destination than is predicted by the model.

For commute, CBD destination effects have been added for bus and rail to account for the fact that CDB destinations are more attractive for bus and rail than is predicted on the basis of the level-of-service alone. It was argued in the Stage 1 estimation report that these terms may reflect the additional flexibility of public transport for making short diversions to other CBD destinations, relative to CBD destinations. A related factor may be that car travel to the CBD is perceived as difficult, for example due to difficulties in finding a parking space, and this makes bus and train more attractive compared with non-CBD destinations.

For commute, income segmented attraction variables were used in the models following validation of the Stage 1 models, which demonstrated that the Stage 1 model under-predicted commuting from high-income residential areas to the CBD. The attraction variables use the same definition of income bands as the linear cost terms that are defined in Section 7.1.2. Moving to income-segmented attractions significantly improved the fit to the observed data, but nonetheless commute trips to certain central areas remained under-predicted, and furthermore there was a general tendency to under-predict travel from the west to the east. To correct for these two effects, the following destination terms were added to the model:

- North Sydney centre
- St Leonards Crows Nest centre
- Chatswood centre
- Parramatta centre
- Inner Sydney area
- Eastern Sydney area
- Northern Beaches area.

The destination effects for the first four centres are stronger than those for the last three areas.

For primary education, a term has been added to account for higher school bus usage in Newcastle relative to Wollongong and Sydney. In the Stage 2 model, terms were added to account for higher school bus usage in outer and middle rings of Sydney, relative to the central area, but these were not significant in the new estimations.

For secondary education, terms for higher school bus usage were added for the following areas, with the terms listed from largest, i.e. the strongest effect, to smallest:

- Wollongong
- Newcastle
- Outer Sydney ring.

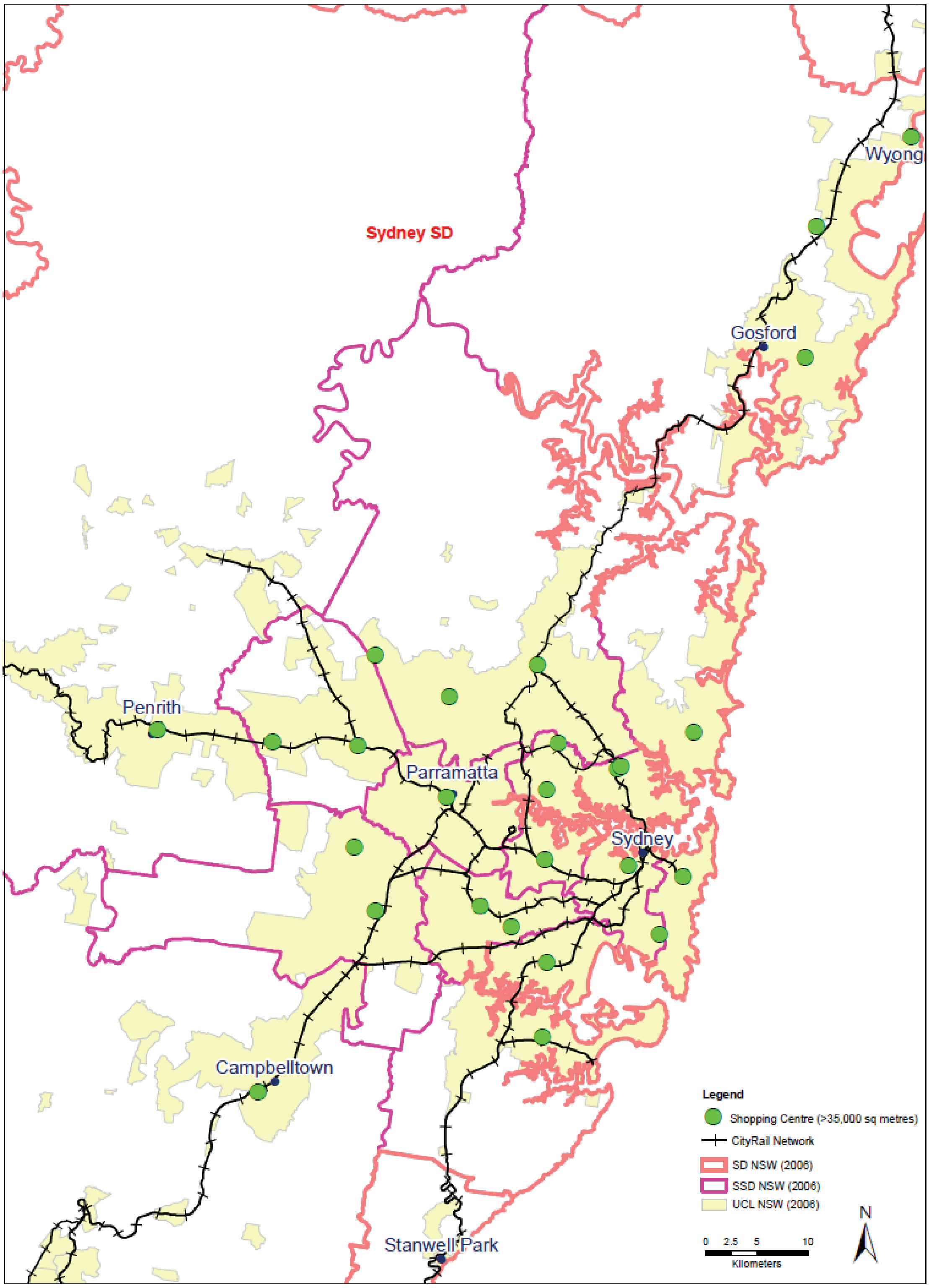
The three terms are estimated relative to the middle and inner Sydney rings.

For tertiary education, a term was added for public transport use to the University of New South Wales zone. High frequency shuttle bus services operate to this destination, and the attractiveness of these may not be fully represented by the level-of-service. Restrictions on parking may also increase the attractiveness of public transport for travel to this destination.

The shopping model retains the destination population density term identified during the Stage 2 estimations, although the effect is noticeably smaller in the new model. The middle and outer ring terms for car use (driver and passenger) identified during the Stage 1 estimations have also been retained. These reflect greater car use in the middle and particularly outer rings relative to the inner ring.

Destination terms have also been included for shopping to account for the high attractiveness of large shopping centres. Two terms have been identified, one for regional shopping centres, defined as these centres having floor space greater than 35,000 m^2 (plotted in Figure 10), and one for other centres. A full list of these large shopping centres is provided in Appendix C. As would be expected, the term for regional centres is stronger than that for other centres. In additional to the large shopping centres terms, a *negative* CBD destination dummy has been estimated in the model. It is believed that this term is required because the majority of retail employment located in the CBD is associated with shops that serve office workers, i.e. shops that attract non-home-based shopping trips, rather than home-based shopping trips.

Figure 10: Large Shopping Centres



For other travel, a positive destination term has been identified to reflect higher car usage (both as a driver and as a passenger) in the outer Sydney ring, relative to the rest of Sydney, Newcastle and Wollongong. This term was also identified during the Stage 2 estimations. Destination population density terms were identified during the Stage 2 estimations but these terms were not significant in the new models. The increase in the number of zones may have had an impact on the population density terms.

No destination effects were included in the work-based business tour and NHB business detour models. In the Stage 2 estimations, CBD destination dummies were identified for these purposes, but the CBD effects were not significant in the new models.

7.5 Toll Roads

The choice between toll and non-toll alternatives for car drivers is modelled by using separate skims for the two alternatives, allowing the time and distance associated with each skim to be defined, representing the toll as part of the car costs for the toll alternative, and adding a toll road constant to the toll route alternative.

The expectation at the outset of this work was that the toll road constant would be positive, i.e. that the time savings provided by toll routes would not fully justify the additional toll cost, and that an additional positive toll road constant would be required to explain observed levels of toll road usage. This positive constant would account for factors such as increased reliability, which are in addition to the journey time savings associated with toll routes.

However, when tests were run for the commute model, substantially negative toll road constants were estimated, and therefore a number of investigations were undertaken to try to understand this result.

Analysis revealed that for some origin-destination pairs, toll roads were available but the toll road cost was close to zero. These cases result from the multi-pathing in the assignment, and cause a bias to the constant as they are rarely chosen. For example, if the toll is $1.00 and the tolled route in the assignment is used by 5 per cent of the traffic (i.e. 95 per cent of the traffic uses the free route) for an OD, the skim derived toll value will be $0.05. Therefore, a minimum toll threshold was introduced. The following table summarises the impact on the commute model of different minimum threshold values on the volume of data excluded, and the toll constant expressed in minutes of car time.

Table 36: Commute Toll Road Constant Runs

Threshold	Exclusions	Sample		Toll Constant (car time mins)
None	0	334	100.0%	n/a
$ 0.00	63	271	81.1%	-38
$ 0.50	44	227	68.0%	-17
$ 1.00	2	225	67.4%	-16
$ 2.00	11	214	64.1%	-11
$ 2.50	91	123	36.8%	-9
$ 3.00	1	122	36.5%	-5

It can be seen that a zero threshold maximises the sample size, but results in a negative toll constant equivalent to 38 minutes of car time, which is a large amount of disutility per return journey. Increasing the threshold to $1 results in a substantial improvement in the toll bonus term. Higher thresholds lead to further improvements in the toll constant, but result in a substantial loss of data. Therefore, a value of $1 was selected as a balance making sure unlikely origin-destination pairs are unavailable with minimal loss of observed data.

Detours are problematic for the toll choice modelling, because in tour-based modelling a direct tour between the home and primary destination is modelled. However, if detours are made during the tour, it is possible that toll roads can be used during the tour but that they would not have been used for a direct journey between the home and the primary destination. Thus, of the 63 commute tours in Table 36 that are excluded because they choose toll road but there is no toll road skim, 50 (80 per cent) are tours where one or more detours were made. Tests were made to investigate whether different toll constants should be estimated for tours with and without detours, but no significant difference was identified between the two groups.

Tests were also undertaken to investigate for differences in the toll constant between waves of data, but no plausible pattern of difference was identified and therefore a single toll bonus term was retained.

One possible cause of the negative toll constant was that toll skims were being identified for origin-destination pairs that are rarely chosen, and therefore a negative toll constant is needed to get the overall toll road share correct. To investigate this hypothesis, the mean distances associated with observed toll road choices were compared with the mean distances for cases where a toll road is available according to the skims, but was not chosen, and with the mean distances for other cases car driver observations where no toll road route is available. The results are summarised in Table 37.

Table 37: Toll Road Mean Tour Distance Analysis (km)

Purpose	Toll road available and chosen	Toll road available but not chosen	No toll road available
Commute	66.1	51.4	26.6
Business	90.2	70.0	32.4
Shopping	74.0	47.0	10.0
Other Travel	71.1	50.1	13.4

It is clear from Table 37 that mean distances when toll roads are chosen are significantly longer than those when toll roads are not available. The skims reflect this to an extent, but not fully, so that the mean distances associated with cases where toll roads are available but not chosen up to 27 km shorter than cases where toll roads are available and chosen. Therefore, the negative toll constant will in part be correcting for shorter toll road alternatives that are less likely to be chosen.

Given the strong relationship between toll road usage and journey distance, a model formulation was tested whereby a distance term was added to the toll constant, so that the effect varied with distance. The toll distance effect was significant for all purposes, and by taking the ratio of the negative constant and the positive distance term, it is possible to identify the distance at which the net effect of the term turns positive. Table 38 presents this analysis, and also calculates the 'toll bonus' that the constant and distance term provide at the mean observed distance, expressed in minutes of car time.

Table 38: Impact of Toll Road Distance Specification

Purpose	Tour distance at which toll constant and toll distance term balance	Mean distance of toll road tours	Toll bonus at mean tour distance, minutes of car time
Commute	53.9 km	66.1 km	2.8
Business	94.2 km	90.0 km	-1.0
Shopping	51.3 km	74.0 km	14.3
Other Travel	93.0 km	70.0 km	-12.1
NHB Business Detour	30.7 km	38.2 km	1.4

For commute, shopping and NHB business detours, the results are plausible, with the net impact of the constant and distance terms turning positive before the mean toll distance, and the toll bonus values at the mean distance reasonable. For business and other travel, the net impact of the terms is negative at the mean toll road distance. For business the effect is small, equivalent to just one minute of car time, but for other travel there remains a substantial negative effect at the mean distance. This result is caused in part by the low toll road share for this purpose, where just 1 per cent of car drivers choose the toll alternative.

It is noted that for work-based business, it was assumed that travellers will use toll roads where they are identified from the toll skims, rather than explicitly modelling toll road usage. This assumption was made as the sample sizes were judged too small to support modelling toll road choice explicitly, and assuming travellers would use toll roads where available was judged reasonable for work-based business travel where values of time are high.

Overall, adding the distance specification gives substantially more plausible results compared with a single toll constant. These results suggest that individuals are substantially less willing to pay for time savings on short journeys than long journeys, even if the cost per minute of time saved is comparable.

7.6 Access Mode and Station Choice

7.6.1 Analysis of Selected Stations

Following the approach set out in Section 5.3.1, the first stage in the analysis was to identify the most attractive stations for park-and-ride (P&R) and kiss-and-ride (K&R) based on the level-of-service of both the car access legs and the train legs, and to compare these with the stations actually chosen.

For commute, analysis was made with five stations included for each origin-destination pair, with the value of five selected on the basis that in the PRISM model for the West Midlands, three were necessary (Fox, 2005), but that the Sydney public transport network is more complex and so more stations may be needed. Table 39 summarises the number of cases where the chosen station was included in the five stations selected, and the mean probability of each of the selected stations.

Table 39: Analysis of Selected Commute P&R Stations

Station Rank	Percentage of Cases Rank is Chosen	Mean Predicted Probability
1	51.9 %	0.304
2	19.7 %	0.228
3	7.8 %	0.183
4	6.0 %	0.153
5	2.9 %	0.131
6 plus	11.7 %	
Total Predicted	88.3 %	

It can be seen that for 88% of cases, the chosen station lies in one of the five selected stations, and for over half of the cases the chosen station is rank 1.

Table 40: Analysis of Selected Commute K&R Stations

Station Rank	Percentage of Cases Rank is Chosen	Mean Predicted Probability
1	55.9 %	0.321
2	18.6 %	0.231
3	5.6 %	0.178
4	5.6 %	0.147
5	1.9 %	0.123
6 plus	12.4 %	
Total Predicted	87.6 %	

The performance for K&R is similar to P&R. Overall it was concluded that representing five stations captures a high enough proportion of observed cases and so this number was used in the model estimation. The same number of stations will be used in model implementation.

Similar analysis was undertaken for the other travel purposes, taking five stations as a starting point based on the commute results, and then the number of station alternatives that were required for each purpose was determined on the basis of the results obtained. Table 41 summarises the number of stations represented for each purpose, and the percentage of cases where the chosen station lies in the selected stations. Again, the number of stations represented applies both for model estimation and for model implementation.

It should be noted that the runs presented in Table 41 assume that car access time to stations is weighted at 1.5 times the value of car time. Once the top ranked stations have been identified, the models estimate a value for car access time directly, and when this is used the top ranked stations change for some origin-destination pairs, and the percentage of demand captured increases because the car access time parameter is a best estimate, rather than an assumed value.

Table 41: Analysis of Selected P&R and K&R Stations

Purpose	P&R		K&R	
	Stations	Demand Predicted	Stations	Demand Predicted
Business	5	73.5 %	5	54.6 %
Secondary education	n/a	n/a	5	71.1%
Tertiary education	2	81.9 %	2	81.9 %
Shopping	2	76.5%	2	84.2%
Other travel	5	74.7%	5	81.1%

For business and other travel purposes five stations were used, consistent with commuting.

For secondary education, initial analysis revealed that the stations identified by the analysis only captured 48 per cent of the observed station choices. Tests were undertaken, and by doubling the access time and cost substantially improved results were obtained, with 71 per cent of the observed station choices captured. Doubling the impact of the access leg assumes that the majority of parents drop their child at the station, and then return home. However, some parents will drop their children on the way to work, and in these cases the choice of station will be influenced by their work location, which the ranking takes no account of. This explains why the proportion of demand predicted for secondary education tours remains relatively low relative to the other model purposes, and highlights one of the limitations of the tour-based approach, namely that travel for each purpose is modelled independently. In an activity-based approach, it would be possible to establish a linkage between travel for different purposes, and therefore model kiss-and-ride trips more accurately.

For tertiary education, demand was more concentrated at stations ranked 1 and 2, and therefore it was possible to represent just two stations in the structure and still capture a high percentage of chosen stations. Building on the results obtained in secondary, specification tests were undertaken whereby the access costs and times for K&R were doubled. This assumption improved the percentage of demand captured in the top ranked stations, and therefore was retained.

For shopping, the proportions of persons travelling by P&R and K&R is low, with just 17 P&R and 19 K&R records out of a total sample of 8,630, as most people drive directly to large shopping centres. However, the station ranking procedure is able to capture most of these cases using the top two ranked stations, and so only two stations were represented in the final model structure for shopping.

7.6.2 Car Access Time Parameter Results

Once the number of stations that need to be represented had been determined, the next stage was to add access mode and station choice to the overall model structure. At this stage, the model is able to directly estimate the sensitivity associated with car access time to stations. This parameter is informative as it provides an indication of whether P&R and K&R travellers have a similar sensitivity to car access time as to rail-in vehicle time, or whether they are more sensitive to car access time and therefore seek to minimise the duration of the access leg as much as possible. As mentioned above, once an estimate for the car access time parameter has been obtained, it is necessary to rerun the processing procedure to identify the most attractive stations, as the directly estimated car access time parameter will give different sets of stations to those identified with the original estimate of 1.5 times car time. The model was then run with this revised set of stations to finalise the estimate of the car access time parameter. Table 42 summarises the estimates of the car access time parameter for each model purpose, presenting the results scaled relative to car time (for car as main mode), train in-vehicle time, bus time and access and egress time, together with the t-ratio of each relative valuation.

Table 42: Car Access Time Parameter Valuations

Purpose	Car Time	Rail Time	Bus Time	Walk Access & Egress Time
Commute	1.20 (9.8)	3.24 (6.6)	1.80 (8.0)	1.19 (6.9)
Business	1.39 (4.6)	3.98 (2.9)	2.39 (3.3)	0.95 (3.4)
Secondary education	0.36 (4.0)	0.61 (3.8)	0.58 (3.9)	2.62 (3.5)
Tertiary education	1.00 (*)	2.01 (6.8)	2.03 (6.1)	7.51 (1.5)
Shopping	1.00 (*)	3.19 (7.6)	4.68 (7.0)	3.52 (5.9)
Other travel	1.00 (*)	3.58 (12.5)	8.55 (5.6)	18.3 (4.1)

For commute, car access time is valued slightly higher than car time for car being the main mode, and over three times the value of rail time. Thus commuters will aim to reduce their car access leg relative to their train leg, all other things being equal. Car access time is weighted more highly than bus access time, and almost the same as walk access and egress time.

For business, car access time is valued more highly than car time for car as a main mode, and considerably higher than the rail time parameter. This suggests business travellers aim to minimise the car leg as much as possible, although it should be noted that the significance of the rail in-vehicle time parameter is relatively low (t=3.4), and so the magnitude of the term may be understated. Comparing it with the other access modes to train, car access time is weighted more than twice as highly as bus time, and at a similar level to walk access and egress time.

For secondary education, the valuation of the car access time parameter is low, resulting in low valuations, except to access and egress time which itself has a low valuation. A factor in the low valuation will be the doubling of access costs and times, i.e. the assumption that the parent drops their child at the station, then returns home, and repeats this journey at the end of the school day. Some parents will drop their children on their way to work or other locations, and in these instances doubling the access costs and times will over-estimate their actual access cost and times, which would lead to some reduction in the car access time parameter. However, it is emphasised that tests demonstrated that doubling the access costs and times gave a better fit to the data relative to not doubling.

For tertiary education it was not possible to estimate a separate car access time parameter, and therefore the parameter was fixed to be equal to car time, based on the results from commute and business (as noted earlier, for K&R access in the tertiary model, the access times for car are doubled). This gives higher valuations of car access time relative to rail time and bus time, consistent with the commute and business model results. The access and egress time parameter is small in magnitude and weak in significance, and hence the valuation of car access time relative to this parameter is high.

For both shopping and other travel, it was also necessary to constrain the car access time parameter to be equal to the car time parameter. This gives models where the car access leg is minimised strongly relative to the train leg, and is also weighted significantly higher than bus and walk access. It should be noted that P&R and K&R access is rarely chosen for these purposes, where journey lengths are typically shorter than commute and business.

7.6.3 Improvements to Access Mode Shares by Distance

While the station choice models were able to identify the top ranked stations successfully, comparison of observed and predicted tour length distributions by access mode revealed a consistent pattern across purposes of under-predicting tour lengths for P&R and K&R, and over-predicted tour lengths for the other access mode, which has the largest overall share. These differences meant that the pattern in the observed data of P&R and K&R usage increasing as tour distances increase was not being adequately predicted by the models.

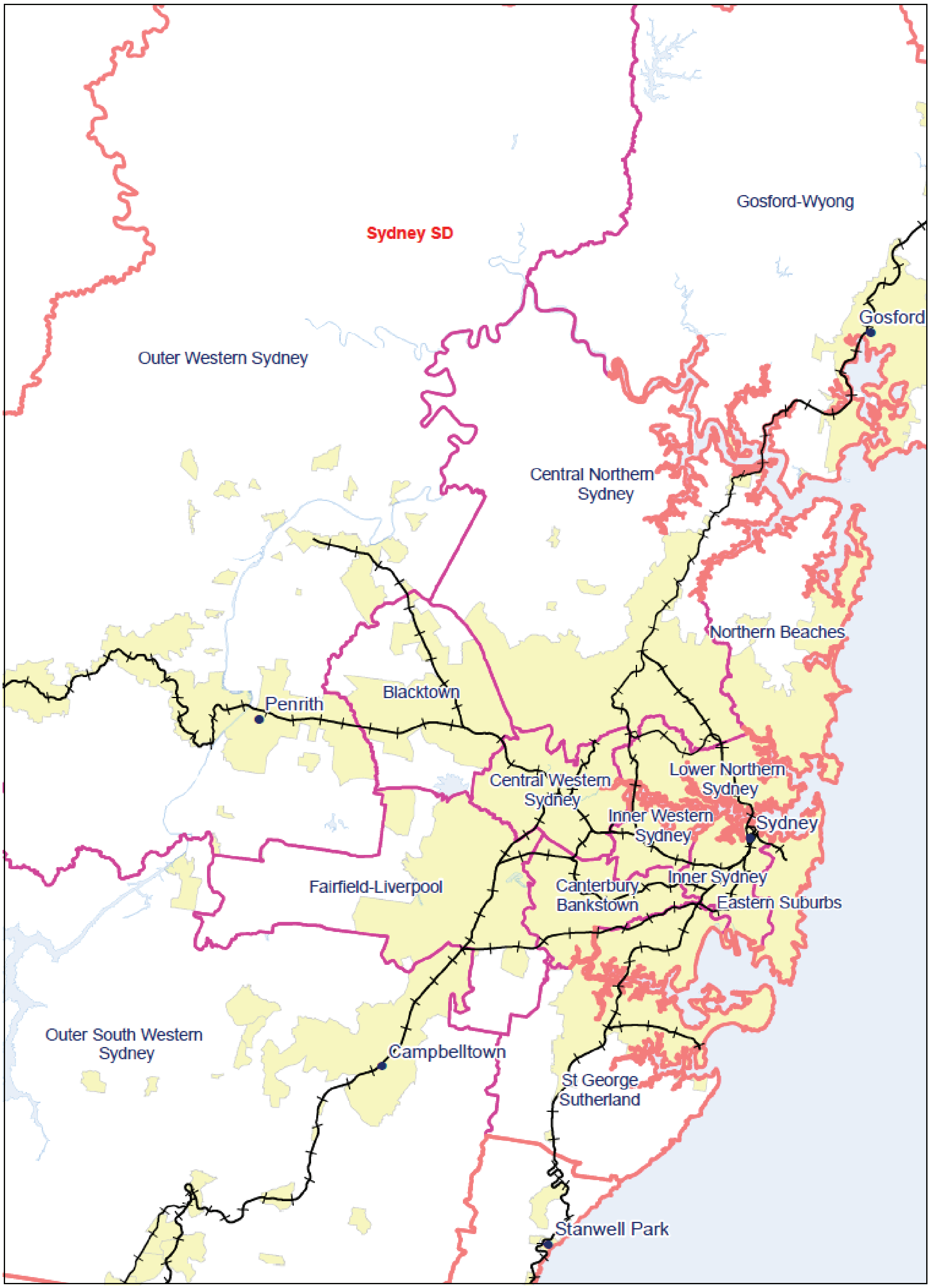
A number of changes were made to the models to provide substantial improvements in the model predictions. First, P&R and K&R were set to be unavailable for tours under 10 km in length on the basis of the observed data. Second, a number of origin-specific access mode share effects were added, in particular a strong preference for car access for tours originating in Gosford-Wyong, an area where the rail line is 10 km inland but some of the population lives along the coast (i.e. accessing rail by car involves a 20 km tour). Third, constants for some purposes were added to reflect a lower likelihood of using other access for the longest train tours. Finally, distance terms were added to car access modes for some purposes to increase the predicted mean tour length for car access tours.

Table 43 summarises the origin region effects that have been added to the models for each journey purpose. The table details whether the effects have been added to the utilities for P&R, K&R, other access or both car access modes. The regions listed in the table are Statistical Sub-Divisions (SSDs) as defined by the Australian Bureau of Statistics, and are plotted in relation to the rail lines in Figure 11.

Table 43: Car Access Mode Origin Region Constants

Region	Commute	Business	Secondary Education	Tertiary Education	Shopping	Other Travel
Gosford-Wyong	P&R	P&R		K&R		P&R and K&R
Outer South Western Sydney	P&R					
Central Western Sydney			Other			
Inner Western Sydney			Other			
Canterbury Bankstown			Other			
Central Northern Sydney						P&R and K&R

Figure 11: Location of Regions and Rail Lines



No terms were identified for shopping, as the sample sizes were too small to allow the effects to be reliably identified.

To improve the fit to the observed tour length distributions for train other access, constants were added to reflect the lower probability of choosing other access for longer train tours. The distance at which the terms were introduced varies according to travel purpose, with the following distances used:

- Commute, 75+ km
- Business, 100+ km
- Secondary, 30+ km
- Tertiary, 50 + km

For shopping and other travel, the rail time parameters are weak in magnitude relative to car time and not strongly significant, and when higher distance terms were tested for other access it was found that while they improved the fit to the other access tour length distributions, the rail time parameter reduced in magnitude and significance. As a result, the values of time for rail were unacceptably low. An alternative formulation was tested, whereby a distance term was added to car access modes to increase the predicted tour lengths for these modes. This formulation successfully improved the fit to the observed tour lengths, and had the further advantage that it boosted the magnitude and significance of the rail time terms.

To demonstrate the improvement to the model predictions that result from adding these terms, the variation in observed and predicted access mode shares with distance have been plotted before and after improving the model fit.

Figure 12: Commute Train Access Mode Shares with Distance Band (km), Prior to Improvement

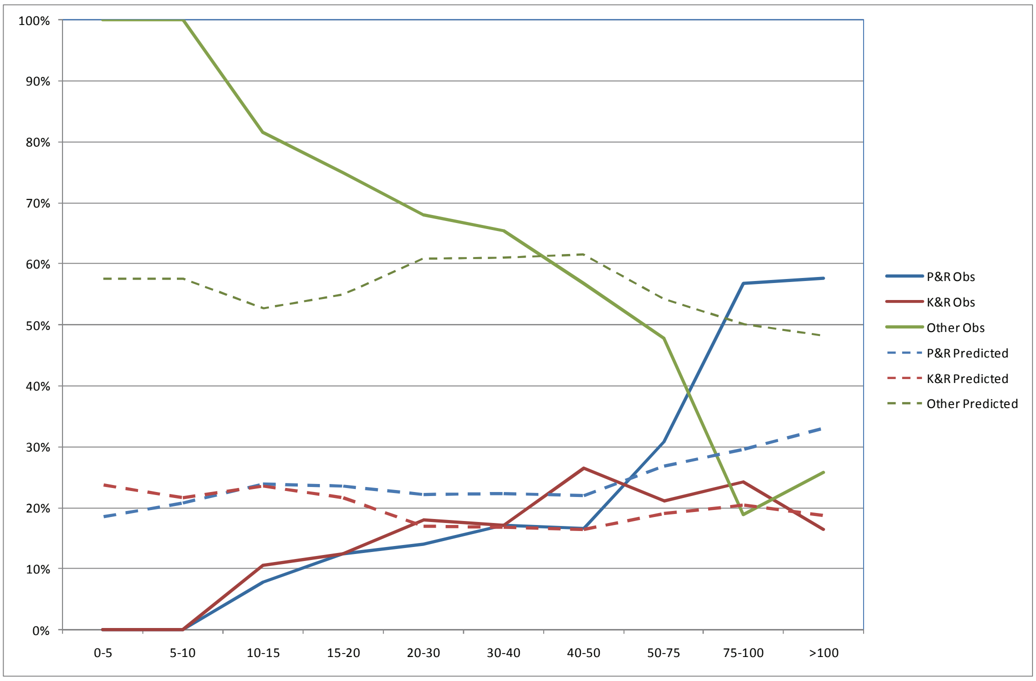
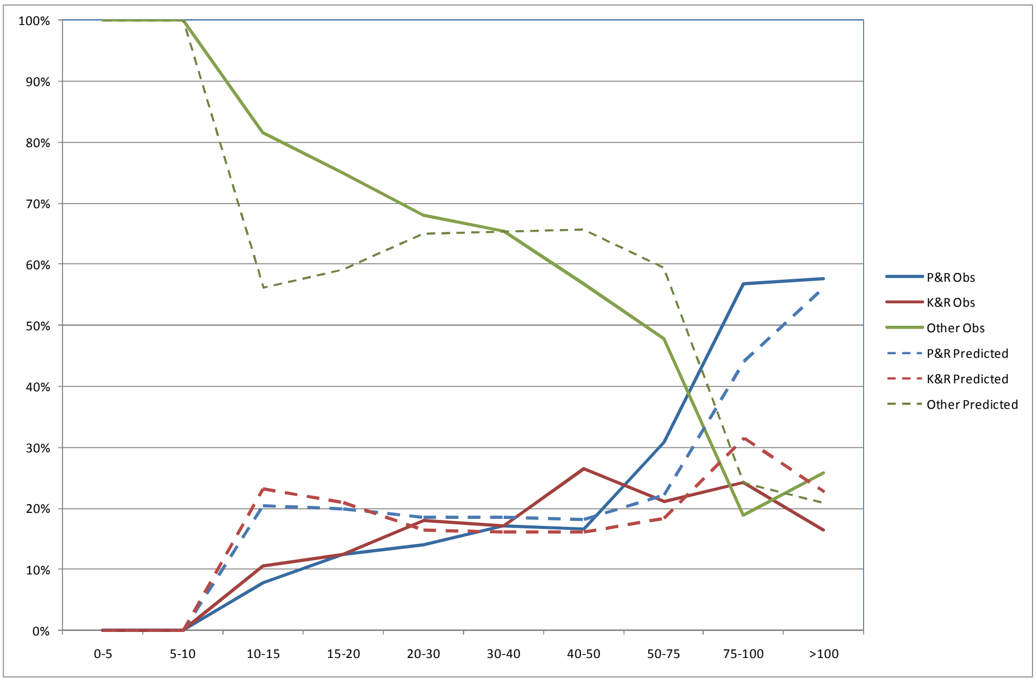


Figure 13: Commute Train Access Mode Shares with Distance Band (km), After Improvement



Comparison between Figure 12 and Figure 13 demonstrates a number of effects. For journeys of short distances, restricting the availability of P&R and K&R to tours over 10 km in length results in a significant improvement to the observed distributions for all three access modes. For P&R, the origin terms for Gosford-Wyong and Outer South Western Sydney result in an improvement at the long distance end of the P&R distribution, as commute train tours originating from these regions tend to be long distance tours to the CBD. Finally, the negative 75+ km term on the other access mode results in a significant improvement to the observed distribution for other travel.

Similar plots are presented in Appendix D for the other model purposes, which show the improved fit to the data achieved by the modifications.

7.7 Structural Tests

The final stage in the model estimation was to perform the structural tests to assess the relative sensitivity of the different choice decisions represented. The models are complex, with up to six possible choice decisions represented:

- Main mode choice
- Public transport nest
- Destination choice
- Access mode choice to train
- Station choice for train

- Toll road choice

As discussed in Section 6.4, each of the structural parameters defines the *relative* sensitivity of two choice decisions, and therefore up to five structural parameters were defined.

Section 7.7.1 summarises the results that have been obtained for each model purpose, and then plots the tree structures that follow from the results of the structural tests.

7.7.1 Results by Purpose

Due to the number of choices represented in the model structure, and the high number of model zones, the run times for the structural tests were high. Therefore, it was not feasible to run models for every possible model structure. Instead, tests were run using a likely initial model structure, and then the next candidate structure was identified on the basis of those results.

For commute, the results from four different model structures were analysed to determine the relative level of error in each choice decision relative to main mode choice. A lower error implies a higher sensitivity, and the aim is to place the most sensitive (lowest error) choices at the bottom of the tree. The results are summarised in Table 44.

Table 44: Commute Sensitivity Analysis

Choice	Mean Sensitivity
Main modes	1.000
Public transport nest	0.521
Destinations	0.845
Train access modes	0.831
Train stations	1.412
Toll road choice	0.406

Based on sensitivity alone, the candidate model structure would have train stations as the top level choice. However, some of the choices can only occur under other choices, specifically:

- The public transport nest must lie beneath main mode choice
- The train access modes must lie beneath the public transport nest
- The train stations must lie beneath train access modes.

Given these conditions, the most likely structure was identified as (top to bottom) modes, destinations, public transport nest, access modes, stations, toll choice. Table 45 shows the structural parameters obtained with this structure, and highlights how parameters were successively constrained to one in order to give an acceptable structure where no structural parameter exceeds one. Note that the t-ratios in Table 45, and the other tables of structural parameters in this section, are expressed relative to a value of one rather than a value of zero.

Some subsequent model development occurred after the structural tests were run as a result of the model validation tests. Therefore, the structural parameters in the final models are also presented in the tables below to show the values in the final model specifications. The values of the log-likelihood functions are not presented for these models as they are not directly comparable due to changes in the model specifications, in particular improvements to the model specifications so that the models better predict how train access mode shares vary with distance (see Section 7.6.3).

Table 45: Commute Structural Tests

Choice	Model 154 LL = -36980.2	Model 155 LL = -37030.1	Model 156 LL = -37042.5	Model 166 Final Model
Main modes				
Destinations	0.778 (5.1)	0.803 (4.5)	0.858 (3.2)	0.808 (4.5)
Public transport nest	0.729 (4.1)	1.369 (4.3)	1.000 (*)	1.000 (*)
Train access modes	2.676 (6.95)	1.000 (*)	1.000 (*)	1.000 (*)
Train stations	1.000 (*)	1.000 (*)	1.000 (*)	1.000 (*)
Toll road choice	0.223 (25.8)	0.312 (16.5)	0.418 (11.7)	0.512 (7.6)

It can be seen that because the access mode and station choice parameters implied a structure that was not possible, it was necessary successively to constrain some structural parameters until model 156 was run. The constraints led to a loss in log-likelihood of 62.3 points. The final structure has toll road choice as the most sensitive choice, which is a plausible result as this could be considered a type of route choice, and destination choice slightly more sensitive than main mode choice. No separate public transport nest has been identified, but by placing the public transport nest at the same level as destinations the model will reflect greater switching between train and bus than between public transport and other modes. The final structure represents the choices between train and bus, train access modes, and train stations as equally sensitive to changes in utility.

For business, a similar set of tests was undertaken, and the candidate structure identified was generally the same as for commute, except that the public transport nest and access modes were placed above destination choice. Table 46 summarises the tests made using this structure.

Table 46: Business Structural Tests

Choice	Model 26 LL = -26010.5	Model 29 LL = -26011.4	Model 30 LL = -26011.5	Model 40 Final Model
Main modes				
Public transport nest	0.523 (4.1)	0.526 (4.1)	0.534 (4.5)	0.524 (4.4)
Train access modes	1.062 (0.2)	1.043 (0.1)	1.000 (*)	1.000 (*)
Destinations	0.892 (0.5)	0.916 (0.4)	0.940 (0.4)	1.000 (*)
Train stations	1.605 (1.0)	1.000 (*)	1.000 (*)	1.000 (*)
Toll road choice	0.237 (7.7)	0.381 (10.2)	0.381 (10.4)	0.613 (6.7)

For business tours, only the station choice parameter was substantially greater than one, and therefore constraining structural parameters greater than one gives a slight loss of fit of only 1.0 log-likelihood point. The results show that business travellers are substantially more likely to switch between train and bus than between PT and non-PT modes. Public transport modes and train access modes are equally sensitive as the relevant structural parameter is fixed to one, and destination choice is just beneath in the structure in model 30, but not significantly so.

In later models, the destination parameter exceeded one and so was fixed to one. It is noted that the toll road choice parameter is significantly larger in the final model (model 40). The toll choice parameter increased in magnitude substantially when the distance effect was introduced into the toll utilities.

For primary education, neither park-and-ride nor toll road choice are modelled. Table 47 summarises the results of the structural tests.

Table 47: Primary Education Structural Tests

Choice	Model 13 LL = -10636.8	Model 14 LL = -10595.1	Model 15 Final Model
Main modes			
Public transport nest	1.000 (*)	0.741 (1.0)	0.741 (1.0)
Destinations	1.000 (*)	0.579 (2.1)	0.579 (2.2)

The improvement in likelihood in model 14 relative to model 13, with a multinomial structure, is significant according to a likelihood ratio test and therefore model 14 was selected, despite the low significance of the public transport nest structural parameter. The results are consistent with the Stage 2 estimation work, where a structure with destinations below modes was selected.

For secondary education, there are only a few car driver observations and therefore toll road choice is not modelled. The results of the structural tests are summarised in Table 48.

Table 48: Secondary Education Model Tests

Choice	Model 18 LL = -8871.9	Model 22 LL = -8909.2	Model 23 LL = -8910.8	Model 31 Final Model
Main modes				
Public transport nest	1.083 (0.6)	1.310 (1.6)	1.000 (*)	1.000 (*)
Train access modes	2.702 (3.1)	1.000 (*)	1.000 (*)	1.000 (*)
Destinations	0.259 (14.3)	0.577 (5.9)	0.689 (6.8)	0.712 (6.0)
Train stations	4.970 (2.9)	1.000 (*)	1.000 (*)	1.000 (*)

The final structure for secondary education includes stations and destinations at the lower level, and access and main modes at the higher level, and the structural parameter is strongly significant. It is noted that in the Stage 2 estimations, a structure with modes above destinations was also identified.

For tertiary education, toll road choice is not modelled. The candidate structure identified has destinations at the lowest level. Table 49 summarises the tests made using this structure.

Table 49: Tertiary Structural Tests

Choice	Model 24 LL = -4549.0	Model 25 LL = -4550.2	Model 26 LL = -4560.2	Model 29 LL = -4567.4
Main modes				
Public transport nest	1.035 (0.3)	1.194 (1.7)	1.000 (*)	1.000 (*)
Train access modes	1.306 (1.4)	1.000 (*)	1.000 (*)	1.000 (*)
Train stations	1.113 (0.6)	1.254 (1.4)	1.000 (*)	1.000 (*)
Destinations	0.879 (1.1)	0.898 (1.0)	1.196 (3.1)	1.000 (*)

In model 24, a number of the structural parameters are greater than one. However, given the constraints set out on the previous page, it is not possible to identify an alternative structure on the basis of these results. Therefore, parameters were successively constrained to one and this resulted in a multinomial structure with all choices represented at the same level (model 29). The final tertiary model (model 39, not presented in this section) also has a multinomial structure following the results of these tests.

It should be noted that the sample size for tertiary is small (948 observations), and that the structural tests in the Stage 2 estimations also yielded a structure with modes and destinations at the same level. Tertiary education is provided at a relatively low number of large locations, and this restriction on the number of possible destinations may limit the sensitivity of destination choice compared with other model purposes, where destinations are found to lie beneath modes.

For shopping tours, the model specification was changed slightly during the structural tests, and therefore log-likelihood values are not presented, as the values are not directly comparable between models.

Table 50: Shopping Structural Tests

Choice	Model 46	Model 47	Model 48	Model 52 Final Model
Main modes				
Public transport nest	0.959 (0.3)	1.033 (0.3)	1.000 (*)	1.000 (*)
Train access modes	1.378 (1.2)	1.000 (*)	1.000 (*)	1.000 (*)
Destinations	0.441 (6.0)	0.561 (7.4)	0.529 (17.3)	0.536 (17.2)
Train stations	1.000 (*)	1.000 (*)	1.000 (*)	1.000 (*)
Toll road choice	1.391 (1.6)	1.000 (*)	1.000 (*)	1.000 (*)

It can be seen that the public transport nest parameter was very close to one, and so fixing the parameter to a value of one in model 48 only results in a small loss in model fit. The final model structure has modes above destinations, which is consistent with the structure identified during the Stage 2 model estimation work.

For home–other, the sample size is substantial (over 29,000 observations) which in the structural tests resulted in substantial run times (up to one week). Therefore, random sampling was used to undertake the structural tests, using 25 per cent of the full sample. Once the candidate structure had been identified, the model was rerun with the full sample. Table 51 summarises the results obtained in the final tests. The access modes nest was fixed to one based on earlier model tests, which was consistent with the need to fix this parameter for other model purposes (it cannot appear above the public transport nest).

Table 51: Other Travel Model Tests

Choice	Model 35 LL = -36547.3	Model 36 LL = -36555.0	Model 38 Unsampled	Model 45 Final Model
Main modes				
Public transport nest	0.620 (3.6)	0.608 (3.5)	0.690 (6.4)	0.526 (10.3)
Train access modes	1.000 (*)	1.000 (*)	1.000 (*)	1.000 (*)
Destinations	0.628 (4.3)	0.630 (4.1)	0.554 (8.8)	0.730 (5.6)
Train stations	1.895 (3.1)	1.000 (*)	1.000 (*)	1.000 (*)
Toll road choice	1.000 (*)	1.000 (*)	1.000 (*)	1.000 (*)

The final structure for home other has modes above destinations, consistent with most other purposes and the Stage 2 structural tests for other travel. A public transport nest has also been identified, demonstrating that travellers are more likely to switch between train and bus than between PT and other modes.

For work-based business, neither park-and-ride nor toll road choice are modelled. Table 52 summarises the results of the structural tests.

Table 52: Work-Based Business Structural Tests

Choice	Model 5 LL = -3390.5	Model 6 LL = -3385.7	Model 7 LL = -3389.5	Model 10 Final Model
Main modes				
Public transport nest	1.000 (*)	1.530 (2.4)	1.000 (*)	1.000 (*)
Destinations	1.000 (*)	0.782 (3.0)	0.892 (1.4)	0.896 (1.5)

The final structure has modes above destinations, consistent with most of the home-based models. The structural parameter is not significantly different from one at a 95 per cent confidence interval, however given the resulting structure is consistent with the other purposes, and bearing in mind the sample size for work-based business is low, it was decided to retain the freely estimated parameter.

Table 53: Non-Home-Based Business Detour Structural Tests

Choice	Model 12 LL = -7677.3	Model 13 LL = -7677.3	Model 16 Final Model
Main modes			
Public transport nest	0.813 (1.6)	0.818 (1.7)	0.787 (2.1)
Destinations	1.007 (0.1)	1.000 (*)	1.000 (*)
Toll road choice	0.640 (14.1)	0.640 (14.1)	0.637 (14.2)

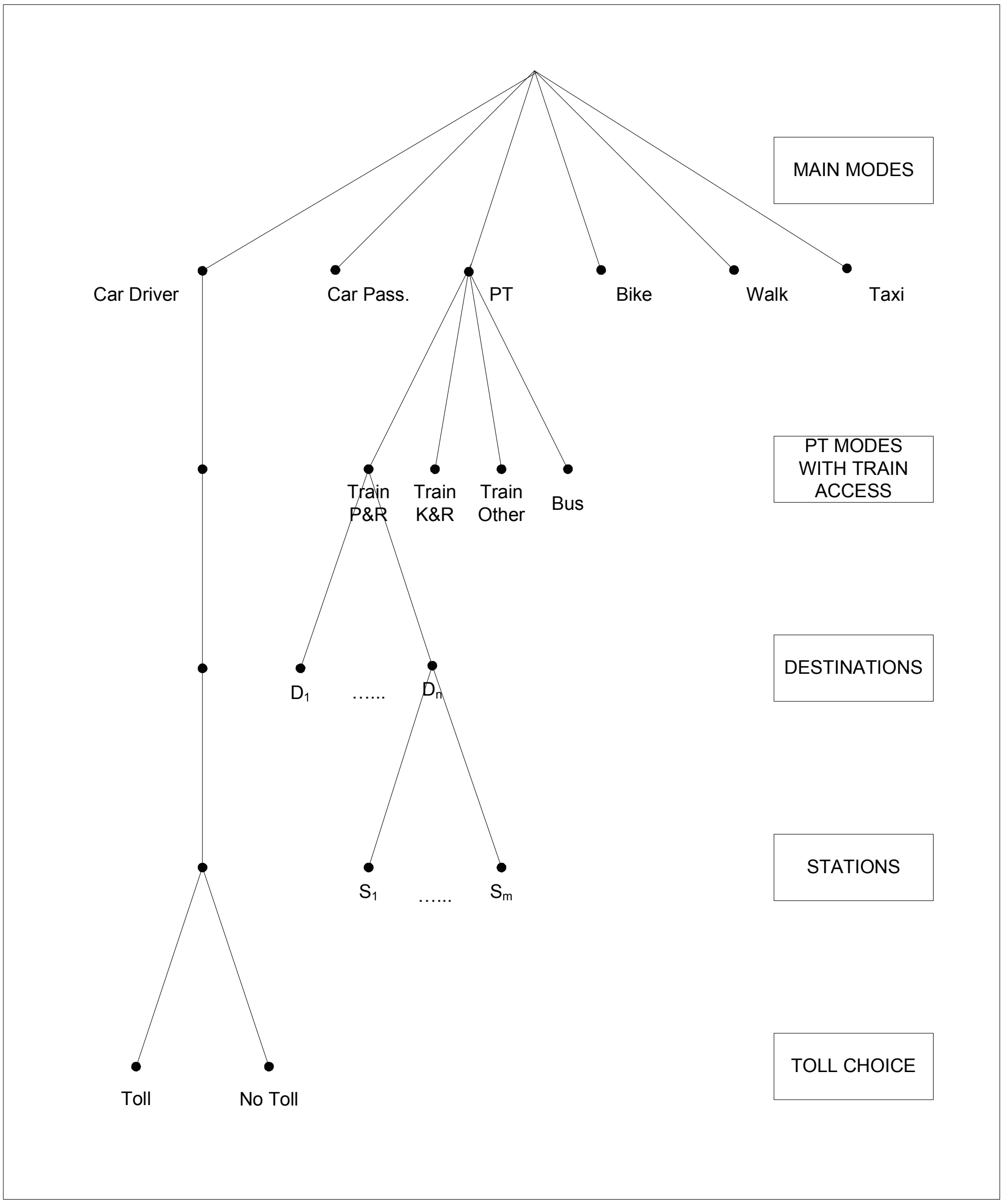
For non-home-based business detours, the final structure has main modes as the top level choice, public transport mode and destinations at the middle level and a toll road nest at the lowest level, which is consistent with the commute and home-based business models.

7.7.2 Tree Structures

From the results in Section 7.7.1 it is possible to identify four different tree structures that cover the nine travel purposes. It is possible to generalise in this way because a number of the choices have been identified to be equally sensitive to utility, and so can be plotted in different orders, subject to the condition that the structural parameter is fixed to one. For example, in the commute and business tests, destinations, public transport modes, train access modes and station choice are all at the equally sensitive to utility. Therefore, both can be described by the same generic tree structure, despite the fact that the order of these choices was different in the structural tests.

Figure 14 summarises the tree structure for commute, home–business, home–shopping and home–other travel.

Figure 14: Tree Structure 1, Home–Work, Business, Shopping and Other Travel



For commute and business, this structure collapses to a three level choice:

- Mode choice
- PT modes with train access, destinations and stations
- Toll choice.

For shopping, the structure collapses to a two level choice:

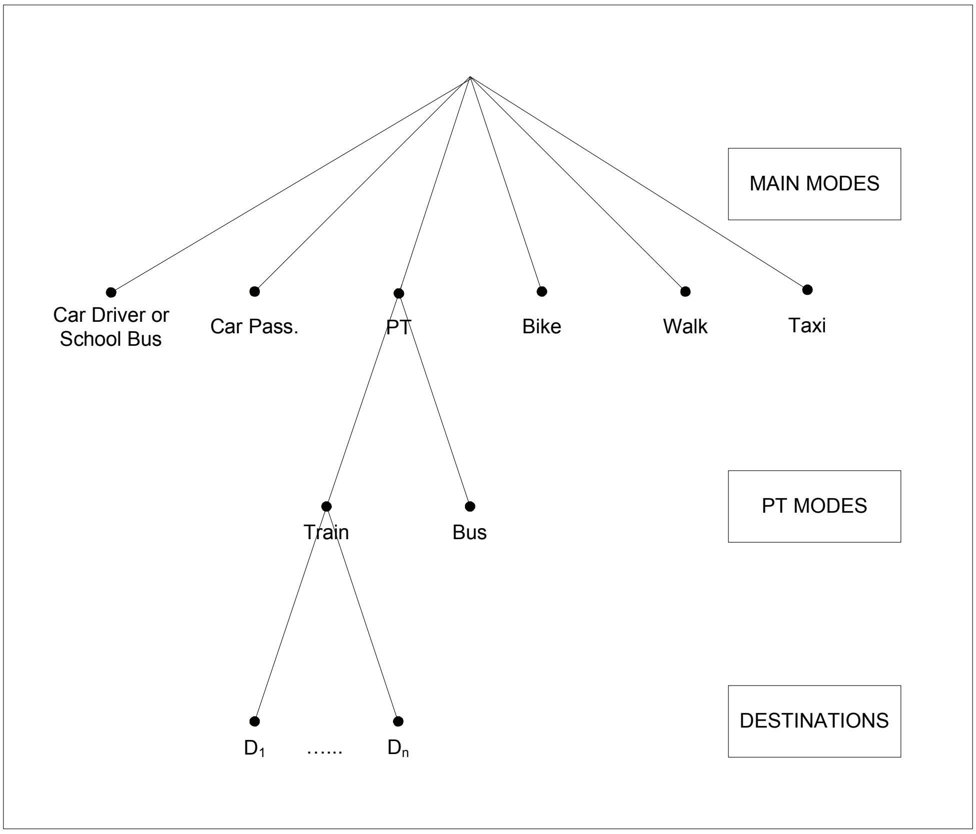
- Mode choice, PT modes with train access
- Destinations, stations and toll choice.

For other travel, the structure collapses to a different three level choice:

- Mode choice
- PT modes with train access
- Destinations, stations and toll choice.

For primary education and work-based business, the structure is simpler as neither the toll choice nor the access mode and station choices are modelled.

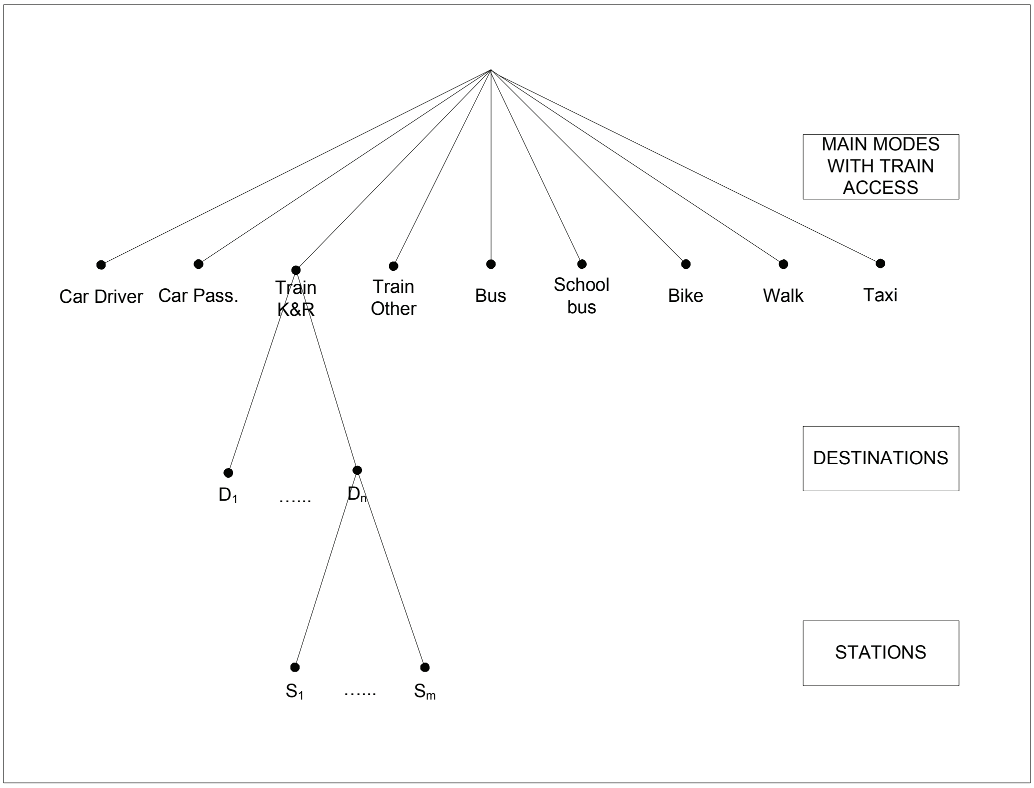
Figure 15: Tree Structure 2, Home–Primary, Work-Based Business



In primary education, both structural parameters have been identified, and so the structure has two levels as per Figure 15. For work-based business, main modes and PT modes appear on the same level so the structure reduces to a two-level choice.

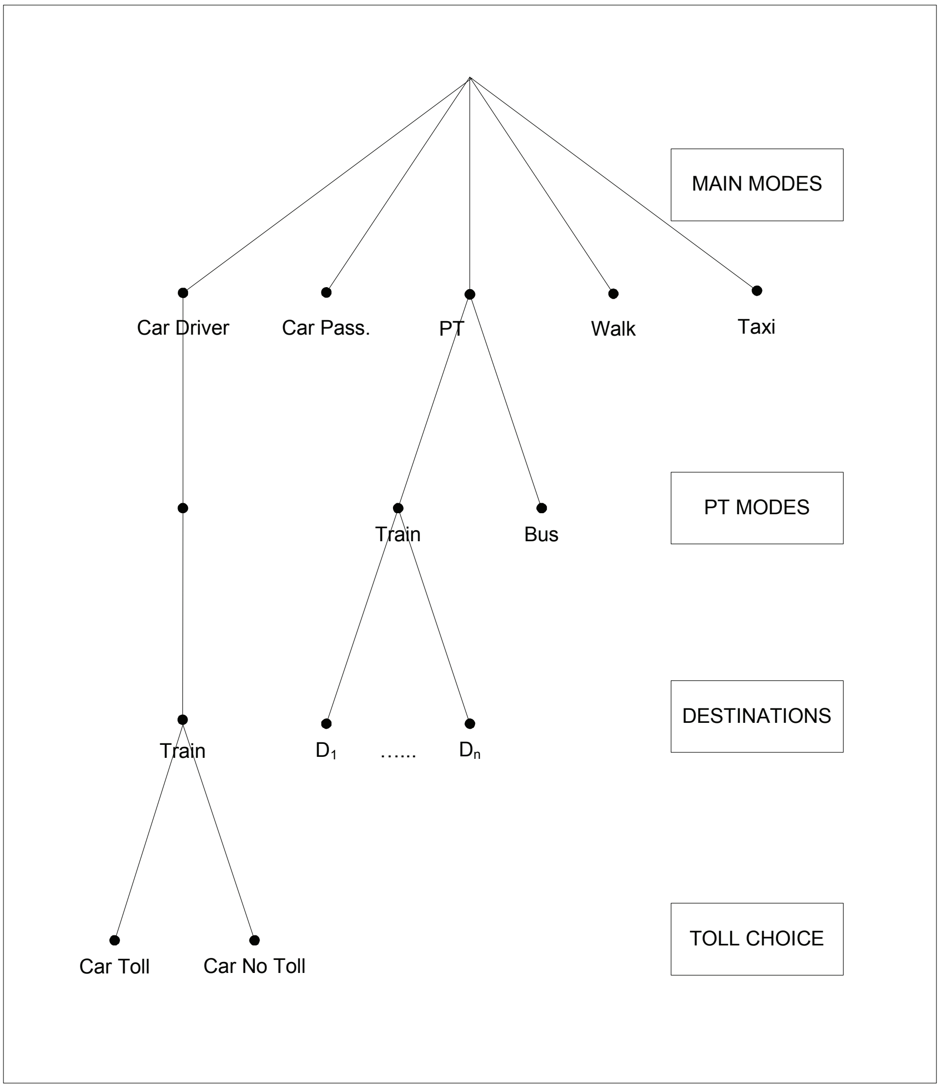
It should be noted that for primary education, car driver is not modelled but school bus is included, whereas for work-based business car driver is modelled but school bus is not. Finally, bike is not modelled for work-based business.

Figure 16: Tree Structure 3, Home–Secondary



Stations are plotted beneath destinations for clarity, but in fact they are equally sensitive to utility and so this is a two-level choice.

Figure 17: Tree Structure 4, Non-Home-Based Business



PT modes and destinations are plotted separately for clarity but are in fact equally sensitive to choice, so in terms of sensitivity the structure has three levels:

- Main modes
- PT modes and destinations
- Toll choice.

CHAPTER 8 Model Validation

Three sets of validation tests have been undertaken for the models. First, elasticity tests have been run to assess the responsiveness of the models to changes in key policy variables. Second, values of time have been analysed to check the relative sensitivity of time and cost in the models. Finally, observed and predicted tour length distributions have been compared.

8.1 Elasticity Tests

Fuel cost elasticities were calculated by applying a uniform 10 per cent increase to fuel costs for car driver and car passenger. Car costs for the access legs for P&R and K&R were held constant, and taxi fares are also assumed to remain fixed. The car toll and car no toll alternative may respond differentially to fuel cost changes, and therefore separate elasticity values were calculated for the car driver toll and car driver non-toll alternatives as well as for car driver demand in total. Car passenger elasticities are also presented, because for some purposes car passengers are modelled as paying a proportion of car costs (see Section 7.1.3). Finally, it should be noted that business fuel costs are not modelled directly; instead, the casual business kilometrage rate is represented, and so the elasticity for business is not a fuel cost elasticity, but is a kilometrage rate elasticity.

Note that costs are not represented in the home–primary education model, and so no cost elasticities are presented for this model.

Both tour and kilometre elasticities are presented in the following tables.

Table 54: Fuel Cost Elasticities, Tours

Purpose	Car Driver Toll	Car Driver Non-Toll	Car Driver Total	Car Passenger
Commute	-0.355	-0.062	-0.080	0.030
Home-Business	-0.026	-0.029	-0.028	0.149
Home-Secondary	n/a	n/a	-0.110	0.003
Home-Tertiary	n/a	n/a	-0.080	-0.181
Home-Shopping	-0.272	-0.055	-0.056	-0.131
Home-Other Travel	0.017	-0.045	-0.045	-0.076
Work-Based Business	n/a	n/a	-0.140	0.326
NHB Business Detours	0.142	-0.056	-0.042	0.162

Table 55: Fuel Cost Elasticities, Kilometrage

Purpose	Car Driver Toll	Car Driver Non-Toll	Car Driver Total	Car Passenger
Commute	-0.563	-0.280	-0.318	0.001
Home-Business	-0.106	-0.094	-0.096	0.167
Home-Secondary	n/a	n/a	-0.183	0.003
Home-Tertiary	n/a	n/a	-0.067	-0.168
Home-Shopping	-0.650	-0.168	-0.183	-0.190
Home-Other Travel	-0.106	-0.162	-0.158	-0.168
Work-Based Business	n/a	n/a	-0.114	0.378
NHB Business Detours	0.109	-0.049	-0.021	0.165

The fuel cost elasticities for the car driver toll alternatives are typically higher than those for the non toll alternatives, as the mean distances are substantially longer for toll tours.

The total car driver kilometrage elasticities are sensible, with the lowest values observed for business travel, as would be expected, and for tertiary education. The commute model has higher elasticity values than shopping and other travel, but mean tour lengths are significantly higher for commuting (30.9 km, compared with 10.8 km for shopping and 14.2 km for other) and therefore the commute value is judged to be acceptable. The higher kilometrage elasticity for home other relative to shopping is consistent with the higher tour lengths for other travel. For non-home-based business detours, increases in car costs lead to some shifting to the toll alternative, but overall car driver demand reduces.

The kilometrage elasticity for tertiary education is low relative to the other purposes, and the kilometrage elasticity is lower than the tour elasticity, which means that tour lengths increase in the fuel cost policy test. This unexpected outcome was investigated further by looking at how the percentage change in total car cost varied with distance. Fuel costs are only one component of total car costs; other vehicle operating costs, parking costs and tolls also contribute so that, on average, the 10 per cent increase in fuel cost results in a 7.4 per cent increase in total car cost. The model uses a log-cost form, and the correlation between the percentage change in log-cost and distance is -0.434, i.e. lower changes are observed for higher distances, and this results in the slight shift to longer tours. It is believed this negative correlation occurs because longer tours have higher mean speeds, which results in lower fuel consumption *per kilometre*, and as a result fuel costs represent a lower fraction of total car costs compared with shorter tours. It is noted that the car kilometrage associated with tertiary education travel is small, for purposes with more substantial fractions of car kilometrage combined linear and logarithmic forms were adopted to avoid these issues, as detailed in Section 7.1.1.

The car passenger elasticities depend on the cost sharing assumptions, as described in Section 7.1.3. For commuting, it is assumed that car passengers pay 50 per cent of the costs paid by drivers. With this assumption, the net impact on car passenger demand is close to zero when fuel costs are increased. For business purposes it is assumed drivers pay (and then reclaim) the car costs, and so car passenger demand increases when car costs increase. For tertiary education, where passengers are modelled as paying 50 per cent of the car costs paid by drivers, the car passenger elasticity is substantially higher than the car driver value; the much lower base share for car passenger explains this result. For home shopping and home other it is assumed that car passengers pay the same share of car costs as drivers, and furthermore car passenger shares are relatively high, consequently similar negative kilometrage elasticities are observed for drivers and passengers for these purposes.

For the car time elasticities, changes in travel time are applied to car driver, car passenger and taxi modes. Furthermore, car times for the access legs to P&R and K&R are increased to represent the impact of increases in travel times to stations.

Table 56: Car Time Elasticities, Tours

Purpose	Car Driver Toll	Car Driver Non-Toll	Car Driver Total	Car Passenger	Taxi
Commute	-1.263	-0.083	-0.154	-0.277	0.023
Home-Business	-1.019	0.069	-0.032	-0.150	-0.012
Home-Primary	n/a	n/a	n/a	-0.211	-0.429
Home-Secondary	n/a	n/a	-0.246	-0.227	-0.530
Home-Tertiary	n/a	n/a	-0.319	-0.407	-0.750
Home-Shopping	-4.325	-0.058	-0.074	-0.302	-0.161
Home-Other Travel	-0.517	-0.039	-0.045	-0.119	-0.117
Work-Based Business	n/a	n/a	-0.108	-0.614	-0.067
NHB Business Detours	-1.259	0.038	-0.046	-0.140	0.078

Table 57: Car Time Elasticities, Kilometrage

Purpose	Car Driver Toll	Car Driver Non-Toll	Car Driver Total	Car Passenger	Taxi
Commute	-1.904	-0.752	-0.901	-0.794	-0.179
Home-Business	-1.584	-0.631	-0.815	-0.800	-0.440
Home-Primary	n/a	n/a	n/a	-1.187	-1.264
Home-Secondary	n/a	n/a	-1.115	-0.617	-1.164
Home-Tertiary	n/a	n/a	-1.061	-0.895	-1.463
Home-Shopping	-6.574	-0.738	-0.880	-1.205	-0.467
Home-Other Travel	-0.813	-0.831	-0.829	-1.151	-0.613
Work-Based Business	n/a	n/a	-0.997	-1.546	-0.490
NHB Business Detours	-1.990	-0.830	-1.022	-0.698	-0.208

The car time elasticities for car driver toll are substantially higher than the non-toll values, particularly for shopping. Again, this is due to the significantly higher mean tour lengths for toll tours relative to non-toll tours. It is noted that in the future, it is more likely that non-toll alternatives would see larger increases in car times than toll alternatives; such a scenario would result in quite different patterns of changes between toll and non-toll alternatives.

Comparison of the tour and kilometrage values for total car driver demand demonstrates destination switching is a stronger response to mode shift in response to increases in car time. The kilometrage elasticities are consistent across purposes, at around -1.

For car passenger, the tour elasticities are typically higher, reflecting the lower base share for most purposes, but nonetheless there is again more destination switching than mode shift. The kilometrage values again lie around -1, although there is greater variation around this value compared with the car driver total values.

The public transport fare elasticity tests are run by applying a uniform 10 per cent increase to all rail and bus fares. Note that no change is made to car costs for the car access legs of P&R and K&R train tours.

Table 58: Public Transport Fare Elasticities, Tours

Purpose	Train P&R	Train K&R	Train Other	Train Total	Bus
Commute	-0.420	-0.331	-0.502	-0.449	-0.282
Home-Business	-0.147	-0.143	-0.230	-0.192	-0.197
Home-Secondary	n/a	-0.113	-0.224	-0.178	-0.230
Home-Tertiary	-0.111	-0.081	-0.199	-0.163	-0.204
Home-Shopping	-0.679	-0.681	-0.625	-0.637	-0.425
Home-Other Travel	-0.428	-0.428	-0.509	-0.482	-0.314
Work-Based Business	n/a	n/a	n/a	-0.535	-0.230
NHB Business Detours	n/a	n/a	n/a	-0.380	-0.129

Table 59: Public Transport Fare Elasticities, Kilometrage

Purpose	Train P&R	Train K&R	Train Other	Train Total	Bus
Commute	-0.508	-0.427	-0.621	-0.542	-0.410
Home-Business	-0.174	-0.176	-0.263	-0.215	-0.236
Home-Secondary	n/a	-0.122	-0.249	-0.182	-0.254
Home-Tertiary	-0.129	-0.085	-0.216	-0.170	-0.220
Home-Shopping	-0.879	-0.880	-0.734	-0.785	-0.637
Home-Other Travel	-0.575	-0.573	-0.610	-0.593	-0.533
Work-Based Business	n/a	n/a	n/a	-0.615	-0.529
NHB Business Detours	n/a	n/a	n/a	-0.466	-0.343

The P&R and K&R elasticities are consistently lower than those observed for other train tours, as there is no increase in cost for the car access legs of these journeys. The elasticities for total train demand and bus are usually similar for a given purpose.

Comparing the purposes, lower elasticities are observed for business, due to lower cost sensitivity, and the education models. The highest elasticity values are observed for shopping and home–other.

The public transport in-vehicle time elasticities are determined by applying a uniform 10 per cent increase in all rail and bus in-vehicle times. If bus is used as an access mode to train, the bus access time is also increased by 10 per cent. However, no increase is applied to the car times associated with the car access legs of P&R and K&R train tours.

Table 60: Public Transport In-Vehicle Time Elasticities, Tours

Purpose	Train P&R	Train K&R	Train Other	Train Total	Bus
Commute	-0.597	-0.346	-0.518	-0.518	-0.563
Home-Business	-0.265	-0.170	-0.476	-0.370	-0.341
Home-Primary	n/a	n/a	n/a	-1.202	-0.591
Home-Secondary	n/a	-0.688	-0.867	-0.793	-0.693
Home-Tertiary	-0.376	-0.507	-0.705	-0.626	-0.435
Home-Shopping	-0.926	-0.916	-0.749	-0.786	-0.262
Home-Other Travel	-0.647	-0.635	-0.648	-0.645	0.014
Work-Based Business	n/a	n/a	n/a	-0.743	-0.233
NHB Business Detours	n/a	n/a	n/a	-0.894	-0.259

Table 61: Public Transport In-Vehicle Time Elasticities, Kilometrage

Purpose	Train P&R	Train K&R	Train Other	Train Total	Bus
Commute	-0.978	-0.700	-0.856	-0.867	-1.012
Home-Business	-0.556	-0.455	-0.745	-0.630	-0.711
Home-Primary	n/a	n/a	n/a	-1.977	-1.163
Home-Secondary	n/a	-1.176	-1.499	-1.328	-1.230
Home-Tertiary	-0.760	-0.894	-1.178	-1.051	-0.918
Home-Shopping	-2.041	-2.033	-1.291	-1.549	-0.653
Home-Other Travel	-1.295	-1.278	-1.148	-1.120	-0.199
Work-Based Business	n/a	n/a	n/a	-1.331	-0.770
NHB Business Detours	n/a	n/a	n/a	-1.688	-0.913

It is noted that for home–other, the bus tour elasticity is (just) positive. This is because the rail time parameter is more than twice the magnitude of the bus time parameter, so there is a slight mode shift from rail to bus. However, bus kilometres decline in this test as would be expected.

Comparing the train total kilometrage values, the highest elasticity values are observed for primary education. Commute, shopping and home–other have values in the range -0.8 to -1.6, whereas home–business has a lower elasticity of -0.6.

The bus values are highest for commute and education purposes, and lowest for home–other.

8.2 Values of Time

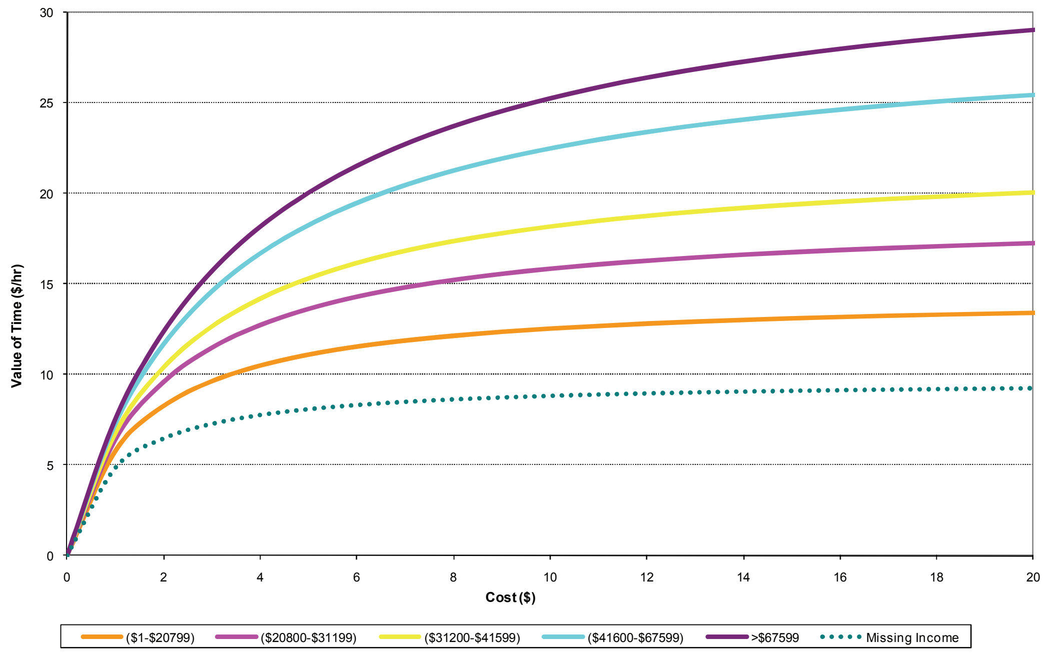
In a linear cost model, the implied values of time (VOTs) can be calculated directly from the ratio of the time and cost parameters. However, most of the models estimated have non-linear cost forms (see Section 7.1.1) and in these models, the VOTs vary according to the cost level according to the following formula:

$$VOT = \frac{\partial V / \partial Time}{\partial V / \partial Cost} = \frac{\beta_{Time}}{\beta_{Cost} + \frac{\beta_{LogCost}}{Cost}} \tag{8.1}$$

Therefore, the VOTs have been plotted over a range of plausible cost values, and the values obtained for the mean chosen cost compared with guidance values.

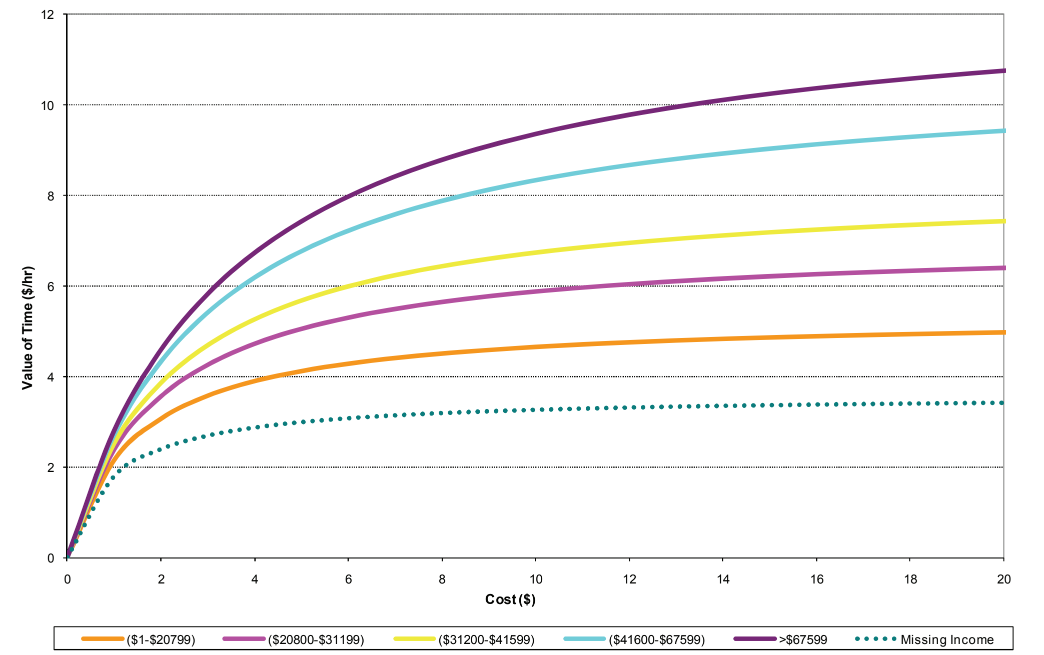
The VOTs for commute vary with income band as well as the cost level, and are plotted in the following figures.

Figure 18: Commute Car Values-of-Time



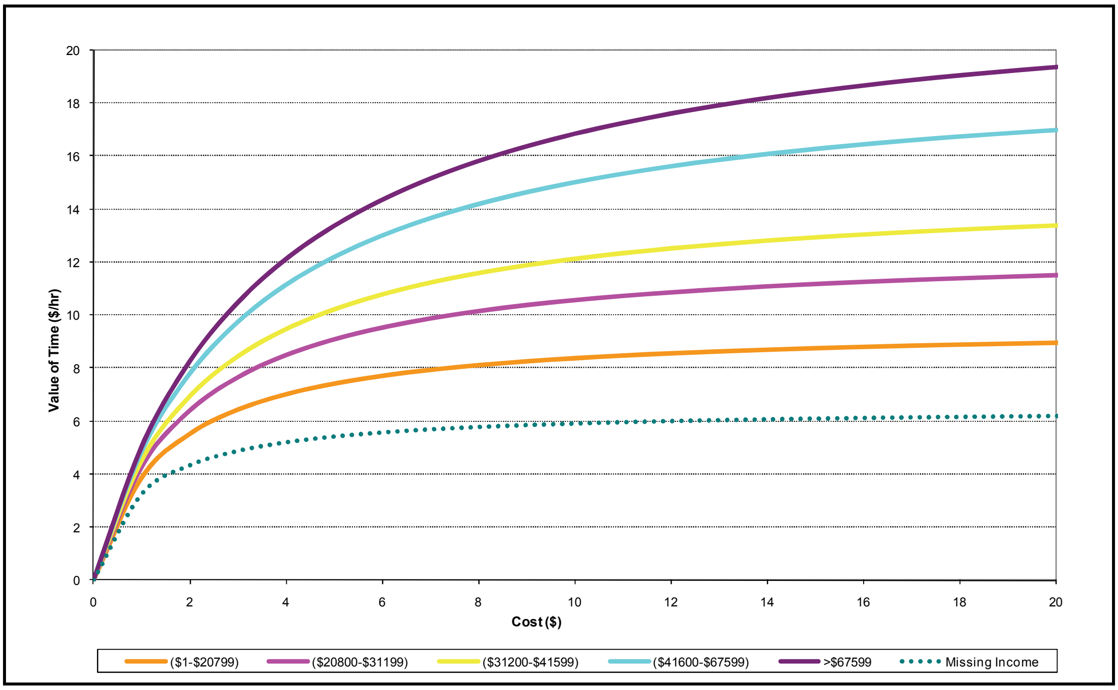
The mean car cost for respondents who choose to travel by car is $7.30, which gives implied values-of-time in the range $12–23/hr, depending on the income band. For comparison, the RTA Economic Analysis manual (RTA, 2007) gives a figure of $11.5/hr in 2007 prices. Given that commute trips would be expected to have higher VOTs than average, and that commute trip lengths are higher than those for other purposes, these higher VOTs are judged to be reasonable.

Figure 19: Commute Rail Values-of-Time



The mean rail cost for those travellers who choose to travel by rail is $8.80, which gives implied VOTs in the range $4.5–9/hr, lower than the guidance value of $11.20/hr (National Guidelines for Transport System Management in Australia). Thus, the rail VOTs are slightly low in this model.

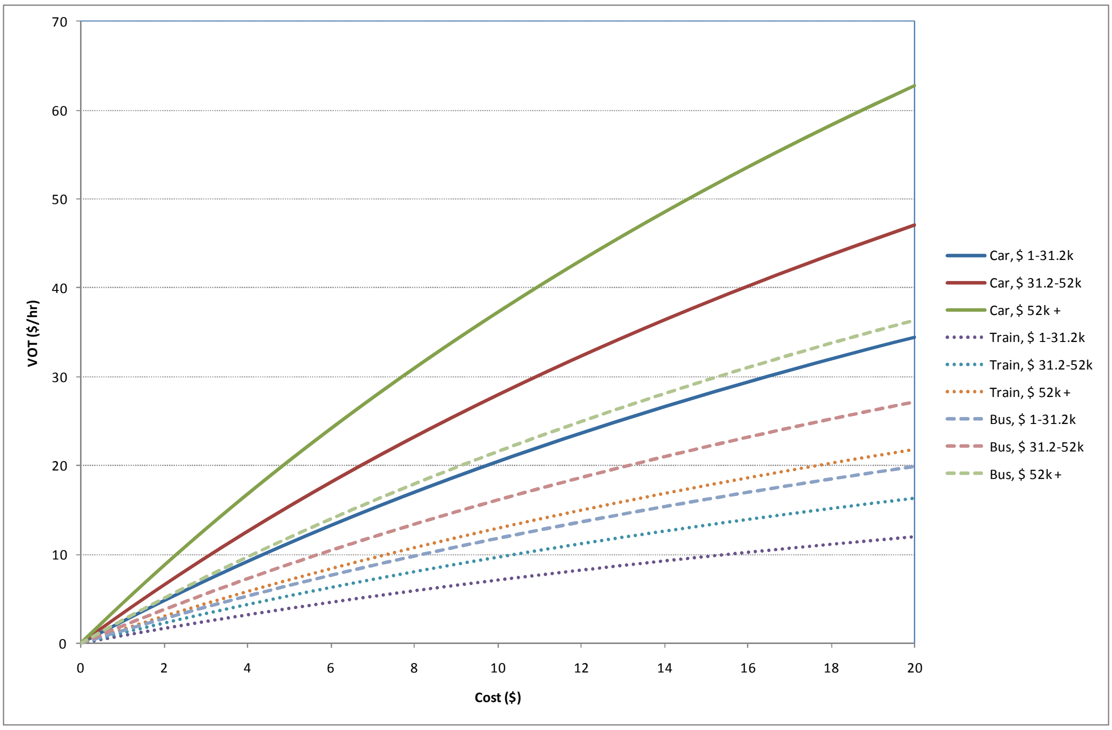
Figure 20: Commute Bus Values-of-Time



The mean bus cost for those travellers who choose to travel by bus is $6.15, which gives implied VOTs in the range $7–14.5/hr. These values lie around or above the guidance value of $9.35/hr (National Guidelines for Transport System Management in Australia). Given commuters would be expected to have higher than average VOTs, the values are judged to be reasonable.

The business VOTs, which vary with income band, are plotted in Figure 21.

Figure 21: Business Values-of-Time



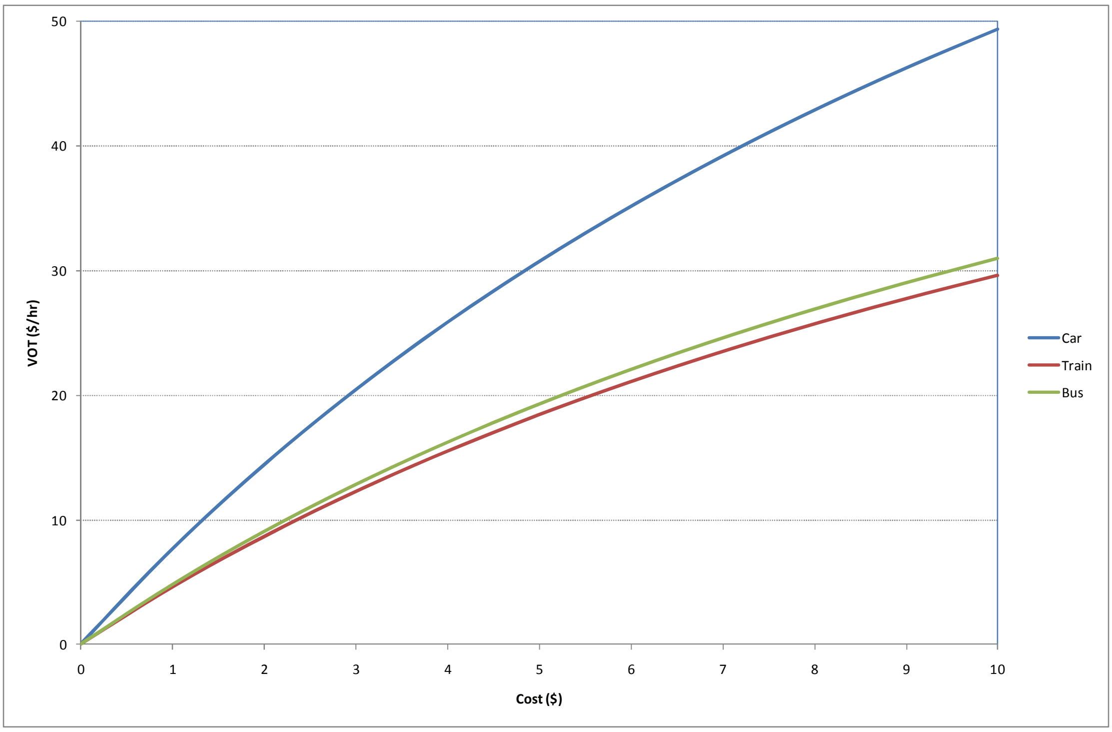
The mean car cost for car driver tours is $11.70, which gives VOTs in the range $22–43/hr. For train, the mean cost of $9.60 gives VOTs in the range $7–13/hr. For bus, the mean cost of $7.00 gives VOTs in the range $9–16/hr. It is noted that public transport usage is relatively low for home–business, with shares of 4.4 per cent for train and 2.1 per cent for bus.

The VOTs for car are approximately twice those observed for commuting, which is a reasonable difference. The VOTs for bus and rail are similar to those observed for commuting and are therefore on the low side. The low bus and rail VOTs follow from the fact that mean car costs are higher than those for train and bus because of the higher car costs assumed for business travellers in the modelling.

No costs have been represented for primary education, and therefore no VOTs can be calculated for the primary model.

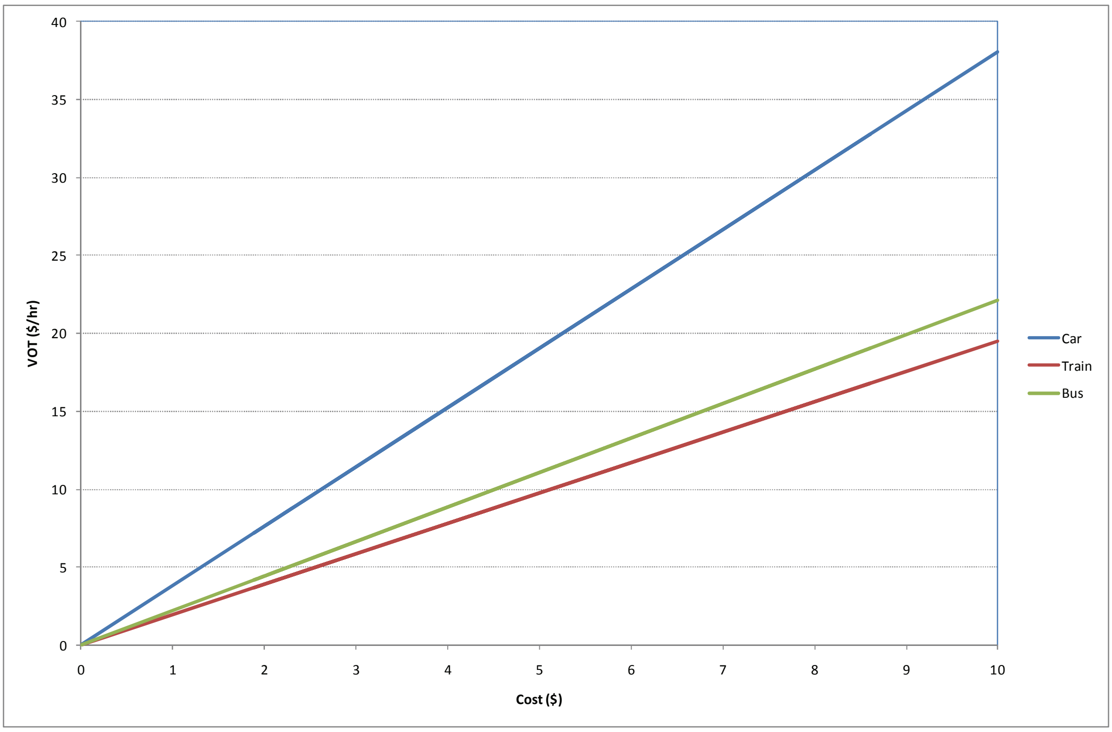
The secondary education VOTs are plotted in Figure 22.

Figure 22: Secondary Education Values-of-Time



The mean car driver cost is $3.60, which gives a high VOT of around $24/hr. It is noted that only 2 per cent of secondary education tours are made by car driver. The mean train cost is $4.30, and the mean bus cost is $4.00, which gives train and bus VOTs of $16.4/hr and $16.2/hr respectively. These values of time seem high and are a result of the low magnitudes of the cost parameters for secondary education, which have higher standard errors relative to the cost parameters for other model purposes. It is noted that no costs are modelled for school bus travel.

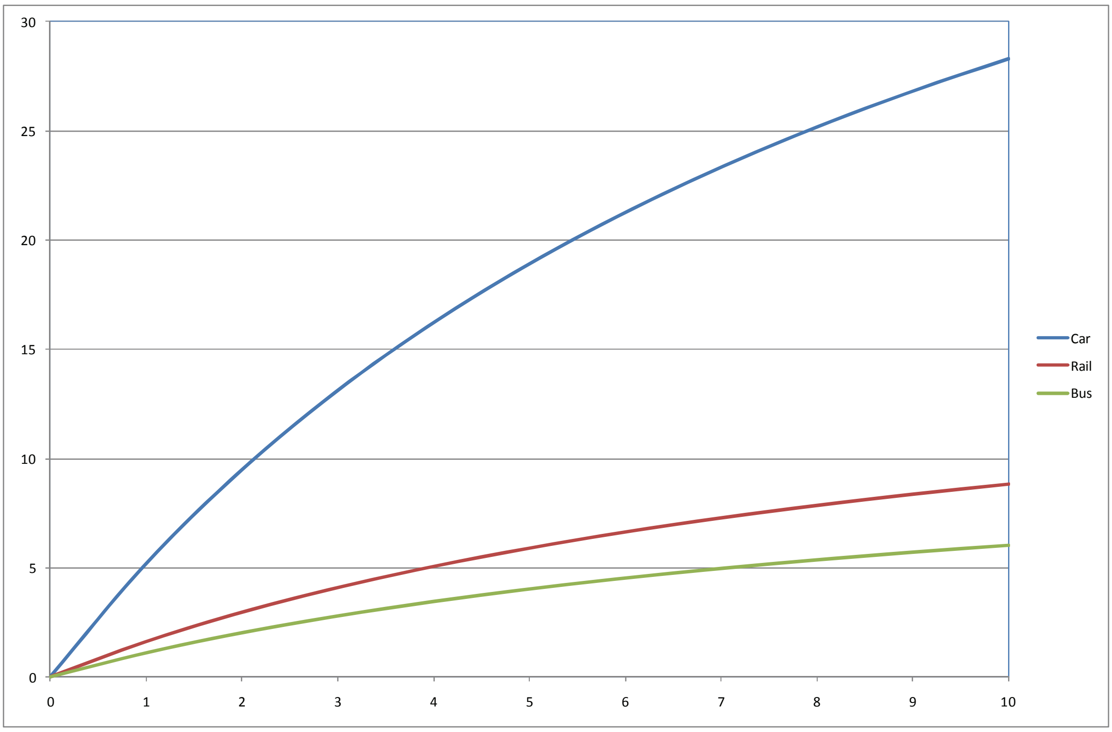
Figure 23: Tertiary Education Values-of-Time



The mean car costs for tertiary car driver tours are $8.60, which gives VOTs of $32.7/hr, which are high. The mean cost value includes parking costs for tertiary education tours to the ten centres where parking costs are modelled (see Section 3.1.2) and this increases the mean cost. If only fuel costs are included, the mean cost is $5.20 and the VOTs are correspondingly lower.

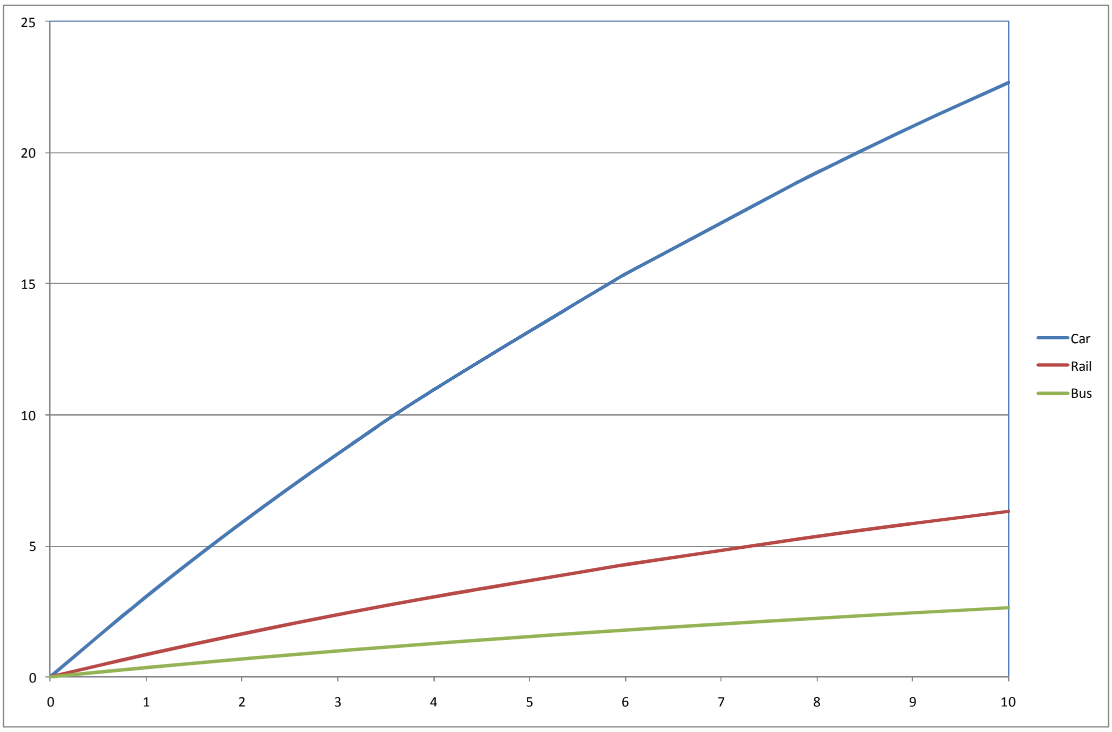
For train, the mean cost of $6.0 gives VOTs of $11.7/hr, which are reasonable. For bus, the mean cost of $4.0 gives VOTs of $8.9/hr, and again this value is reasonable.

Figure 24: Shopping Values-of-Time



It can be seen that the car VOTs are substantially higher than the rail and bus values for a given cost value. However, mean car costs are substantially lower. The mean car cost of $2.00 gives a VOT of $9.50/hr – a plausible value. The mean train cost is $5.34, giving a VOT of $6.18/hr, or around two-thirds the value for car. The mean bus cost is $3.50, giving a VOT of $3.14/hr, which is around one-third of the value for car.

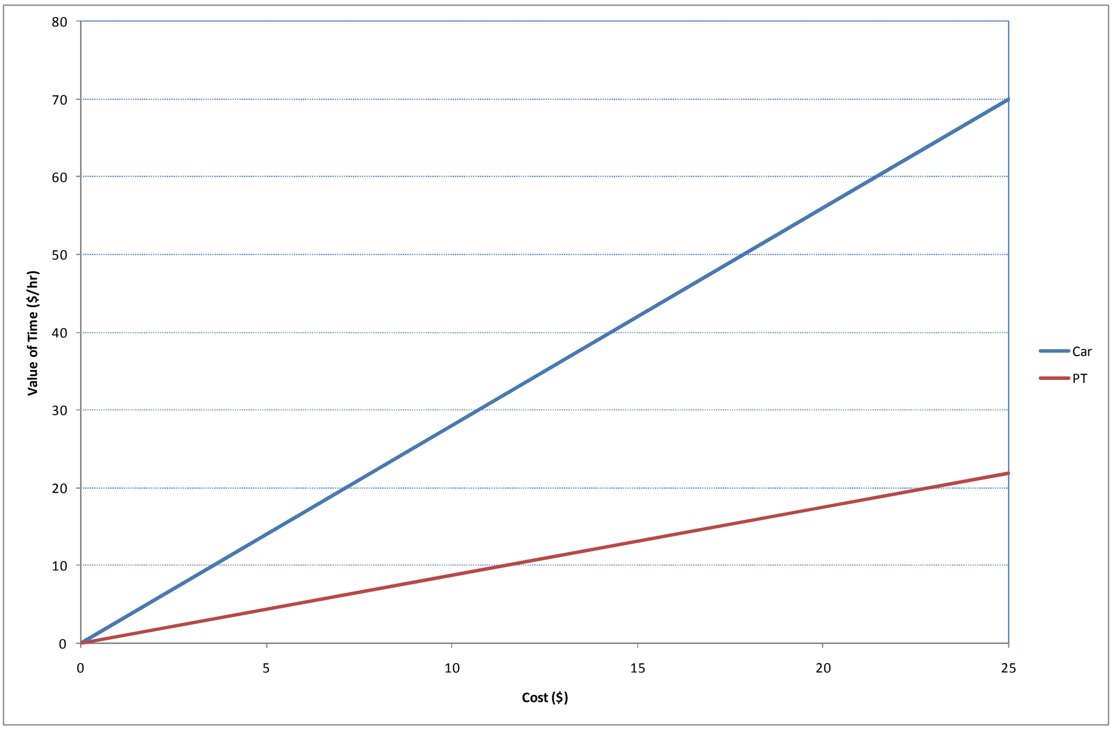
Figure 25: Other Travel Values-of-Time



As per the shopping model, the car VOTs are substantially higher than the rail and bus values for a given cost value. The mean car cost is $2.50, which gives a VOT of $7.20/hr – a reasonable value. For train, the mean cost is $7.80, which gives a VOT of $5.30/hr, or about three-quarters of the car value. For bus, the mean cost is $5.90, giving a low VOT of $1.80/hr. The VOTs obtained at the mean chosen costs are similar to those calculated for the shopping model.

For work-based business, rail and bus use a common generalised PT time term, and therefore the VOTs for a given cost level are the same. Figure 26 plots the variation in VOT for car and public transport modes with cost.

Figure 26: Work Based Business Values-of-Time

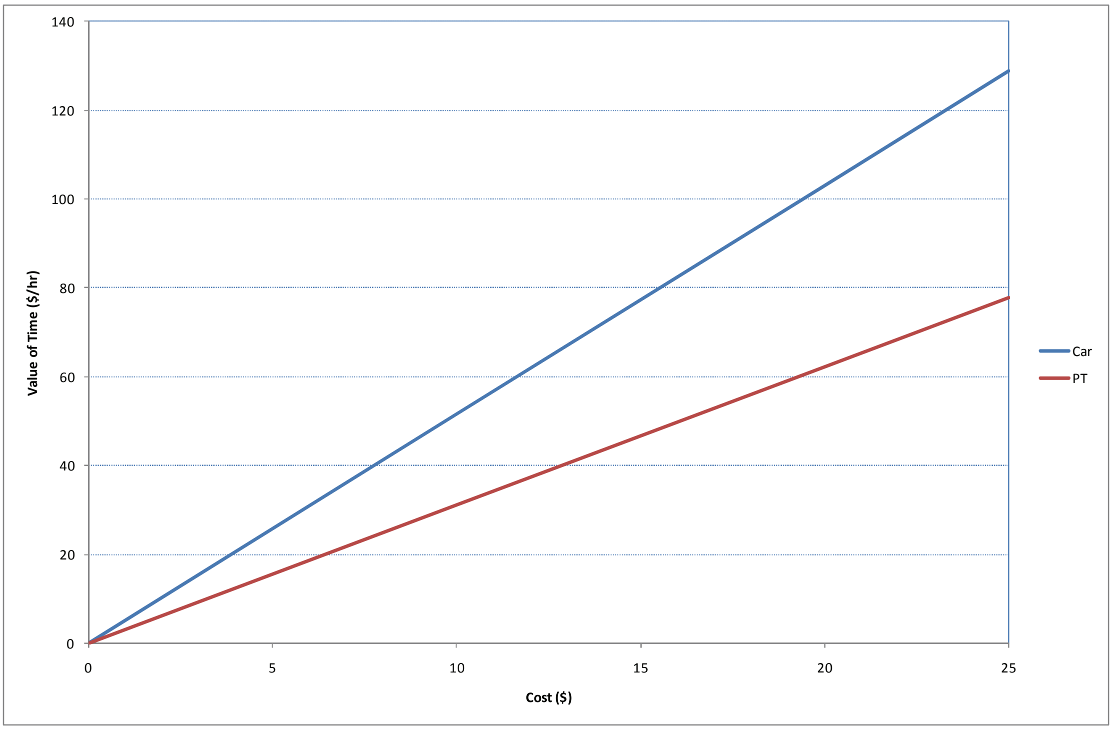


The mean car cost for work-based business tours is $23.10, which gives VOTs of $65/hr. However, a substantial component of this mean is due to high parking costs in CBD zones, which apply to a higher fraction of work-based business tours compared with other purposes. The mean kilometrage-based cost for is $16.30, which gives VOTs of $46/hr, in line with the values observed for the top income group for home-based business.

The mean train cost is $7.05, and the mean bus cost is $8.80. These give much lower VOTs of $6.20 and $6.70/hr respectively. The volume of PT data in work-based business is low, and as a result the PT parameter is not well estimated, which results in low VOTs.

For non-home-based business detours, rail and bus use a common generalised PT time term, and therefore the VOTs for a given cost level are the same. Figure 27 plots the variation in VOT for car and public transport modes with cost. It is also noted that for non-home-based business, the costs relate to a single detour, rather than a return tour.

Figure 27: Non-Home-Based Based Business Detour Values-of-Time



The mean chosen car cost is $10.70, which gives a VOT of $55.20/hr, slightly higher than the VOTs observed for the top income band in the home–business model. For train, the mean cost is $5.80, which gives a VOT of $18/hr, higher than the value for home–business, but reasonable for business travel. There is only a single bus observation in the model, with a cost of $2.70, which gives a VOT of $8.40/hr.

In summary, the car VOTs are typically consistent with guidance values at the mean cost values, except for education where high values are observed. Rail and bus VOTs are consistent with guidance for commute, tertiary and non-home-based business detours, high for secondary, and low for home–business, shopping, home–other and work-based business.

8.3 Tour Lengths

The ability of the models to replicate the tour length distributions observed in the HTS data has been investigated. Mean observed and predicted tour lengths have been compared for each main and access mode represented in the models, and observed and predicted tour length distributions have been compared. This section presents the analysis of mean tour lengths, and summarises the findings from the tour length distributions analysis. The tour length distributions themselves are presented in Appendix D.

Initially, the tour length distributions were investigated by grouping main modes as follows:

- Car modes (car driver, car passenger, taxi)
- Public transport (train, bus).

Mean tour lengths are much shorter for walk and cycle, and so distributions were not plotted for these modes.

In some cases, tour length distributions were investigated for individual modes where the mean tour lengths suggested discrepancies. For the train access modes, the tour length validation revealed a consistent tendency to over-predict short park-and-ride and kiss-and-ride tours, and over-predict long tours for other (bus and walk) access. Therefore, a number of terms were added to the model specification to improve the predictions for these access modes (see Section 7.6). The distributions plotted for these access modes in Appendix D are for the final model specifications that incorporate these additional terms.

Table 62 compares observed and predicted mean tour lengths for commute.

Table 62: Commute Tour Lengths (km)

Mode	Observed	Predicted	Error
Car driver toll	66.1	66.5	0.7 %
Car driver no toll	28.5	28.6	0.2 %
Car driver total	30.8	31.0	0.7 %
Car passenger	22.5	22.5	-0.2 %
Train park-and-ride	74.1	75.7	2.2 %
Train kiss-and-ride	55.1	58.5	6.3 %
Train other	40.3	43.2	7.2 %
Train total	51.5	54.2	5.3 %
Bus	18.5	16.8	-8.9 %
Bike	11.1	11.3	1.6 %
Walk	3.1	3.1	-0.7 %
Taxi	17.5	9.9	-43.2 %
Total	30.2	30.5	1.1 %

Tour lengths are predicted well for car driver and car passenger modes, and the tour length distribution for car modes plotted in Appendix D demonstrates a good match, despite the under-prediction of taxi tour lengths (the taxi mode share is just 0.4 per cent).

The tour lengths for train are predicted well, with a slightly better match to the mean for P&R compared with K&R and other access. The tour length distributions for the train access modes are plotted in Appendix D. The match is good for P&R, though there is some over-prediction of tours in the 10–30 km range. For K&R, the match is reasonable, and for other access, which has the largest share of the three access modes, the match is good. As demonstrated in Section 7.6, the fit for these three access modes was substantially improved by adding new model parameters following validation of earlier model specifications.

There is some under-prediction of bus tour lengths, which is due to an under-prediction of tours in the 50–75km band. Bike and walk tour lengths are predicted accurately due to the use of distance terms, and as noted above taxi tour lengths are significantly under-predicted.

Table 62 compares observed and predicted mean tour lengths for business.

Table 63: Business Tour Lengths (km)

Mode	Observed	Predicted	Error
Car driver toll	88.3	85.2	-3.6 %
Car driver no toll	36.5	36.5	-0.1 %
Car driver total	41.4	41.2	-0.6 %
Car passenger	39.2	38.8	-1.1 %
Train park-and-ride	77.7	76.9	-1.0 %
Train kiss-and-ride	51.2	60.8	18.7 %
Train other	44.8	48.4	8.1 %
Train total	56.4	59.6	5.5 %
Bus	20.8	19.4	-6.6 %
Bike	8.8	8.0	-9.4 %
Walk	3.8	4.4	16.2 %
Taxi	17.6	25.8	47.1 %
Total	40.4	40.3	-0.3 %

Tour lengths are predicted accurately for car driver and car passenger. Furthermore, the observed tour length distribution (plotted in Appendix D) is matched well for highway modes, despite the over-prediction of taxi distances.

Train tour lengths are predicted well for P&R access, and reasonably well for train other access. For K&R, access distances are over-predicted, but there are only 18 observed tours, and this results in a lumpy observed distribution (plotted in Appendix D). The fit to the other access tour length distribution is good.

It is noted that the fit to the observed distributions for the train access modes has been substantially improved by making P&R and K&R unavailable for tours under 10 km in length, adding a constant for P&R tours originating in Gosford-Wyong, and a term to reflect the lower likelihood of using other access for tours over 100 km in length. The improved fit is demonstrated well in Appendix D, which plots observed and predicted access mode shares by distance band before and after making these modifications to the model specification. These show that the key patterns of higher P&R usage for longer distances, and correspondingly lower train other access, are predicted well by the model following modification.

There is a small under-prediction of bus tour lengths, but Appendix D demonstrates that the observed tour length distribution is matched fairly well. Bike and walk tour lengths are predicted reasonably well, and as noted earlier taxi tour lengths are over-predicted.

Table 64: Primary Education Tour Lengths (km)

Mode	Observed	Predicted	Error
Car passenger	7.8	8.0	1.9 %
Train	24.4	29.3	19.8 %
Bus	14.1	16.9	19.7 %
School bus	12.3	11.2	-8.7 %
Public transport total	13.4	13.7	2.8 %
Bike	3.9	3.4	-13.9 %
Walk	2.3	2.3	1.9 %
Taxi	12.7	9.5	-25.1 %
Total	7.2	7.3	1.8 %

The modes with the largest mode shares for primary education are car passenger (69 per cent) and walk (20 per cent). Tour lengths are predicted accurately for these two modes. For public transport modes, overall tour lengths are predicted well, but train and bus are over-predicted, and school bus under-predicted.

The tour length distributions plotted in Appendix D show a good match for car modes (car passenger and taxi), and a fairly good match for public transport modes, though there is some under-prediction of the shortest tours.

Table 65: Secondary Education Tour Lengths (km)

Mode	Observed	Predicted	Error
Car driver	17.4	22.1	27.5 %
Car passenger	12.2	12.2	-0.3 %
Train kiss-and-ride	37.2	41.7	12.2 %
Train other	21.5	26.2	22.3 %
Train total	27.9	32.6	16.8 %
Bus	17.1	19.3	13.2 %
School bus	18.7	18.3	-2.3 %
Bike	4.5	4.5	-1.1 %
Walk	2.9	2.9	0.3 %
Taxi	35.3	19.9	-43.7 %
Total	14.6	15.4	5.5 %

For secondary education tours, car driver tour lengths are over-predicted, however only 2 per cent of secondary tours are made by car driver. Car passenger accounts for 36 per cent of observed tours, and for this mode tour lengths are predicted accurately. The observed tour length distribution is matched well for highway modes (plotted in Appendix D) due to the good fit for the car passenger mode.

Both train and bus tour lengths are over-predicted somewhat. The tour length distributions plotted in Appendix D show that for train K&R the observed distribution is lumpy and therefore difficult to reproduce exactly. For train other access, the observed distribution has a marked lump in the 5–15 km band that the model is unable to predict, and following this the model tends to over-predict tours in the higher distance bands. The plot of access shares by distance band in Appendix D demonstrates more clearly the lumpiness in the observed data. Nonetheless, following modification the model is able to predict the shift to K&R as the largest access mode for tours over 40 km in length.

For bus and school bus, there is some under-prediction of tours in the 5–10 and 10–15 km bands, but overall the shape of the observed distribution is matched well. For school bus, which has a 21 per cent mode share, the observed tour length is matched accurately.

For bike and walk the observed tour lengths are matched well due to the distance terms. Taxi is significantly under-predicted, however there are just four taxi observations in the observed data so this is not an important mode for secondary education travel.

Table 66: Tertiary Education Tour Lengths (km)

Mode	Observed	Predicted	Error
Car driver	34.1	35.5	4.0 %
Car passenger	22.3	22.5	0.5 %
Train park-and-ride	66.9	54.2	-18.9 %
Train kiss-and-ride	60.3	59.3	-1.7 %
Train other	39.1	44.3	13.4 %
Train total	46.8	48.7	4.2 %
Bus	17.6	19.3	9.6 %
Bike	7.9	7.9	0.0 %
Walk	2.9	2.9	0.0 %
Taxi	1.9	29.6	1457.1 %
Total	28.7	29.8	4.0 %

Car driver has the largest mode share (40 per cent), and tour lengths for this mode are predicted fairly accurately. Car passenger tour lengths are predicted closely due to the car passenger distance parameter. The observed tour length distribution for highway modes (Appendix D) is matched well by the model.

For train P&R access, mean tour lengths are under-predicted by one-fifth. Examination of the tour length distribution plotted in Appendix D reveals that an under-prediction of the longest tours is a key reason for this under-prediction, and also highlights the limited sample of observed data (21 obs.). Train K&R tour lengths are predicted more closely, and the observed distribution is matched quite well by the model. For train other access, there is some over-prediction of mean tour lengths. Appendix D demonstrates that this is due to an over-prediction of the longest tours; however, the shape of the observed distribution is matched well by the model.

Examining the variation in access mode share with distance, the pattern is for increasing car access shares with distance, and corresponding reductions in the other access share. Appendix D demonstrates that the model replicates this overall pattern successfully following the modifications described towards the end of Section 7.6.

Bus distances are predicted well, and Appendix D shows that the predicted distribution matches the shape of the observed distribution reasonably well.

Observed taxi distances are substantially over-predicted, but it should be noted that the observed figure is based on a single observation, and the predicted value is in line with the predicted tour lengths for car driver and car passenger.

Table 67: Shopping Tour Lengths (km)

Mode	Observed	Predicted	Error
Car driver toll	74.2	71.8	-3.2%
Car driver no toll	10.6	10.5	-1.1%
Car driver total	10.9	10.8	-1.2%
Car passenger	13.2	13.4	1.5%
Train park-and-ride	64.0	60.5	-5.4%
Train kiss-and-ride	80.7	60.0	-25.7%
Train other	31.6	30.4	-3.7%
Train total	44.2	39.1	-11.6%
Bus	10.9	11.4	4.5%
Bike	4.4	4.3	-3.0 %
Walk	2.0	2.1	2.4 %
Taxi	9.2	6.7	-27.1 %
Total	10.0	9.9	-0.7 %

The substantially higher mean distance observed for car driver toll observations is highlighted by these figures. The model predicted mean tour lengths for the car driver and car passenger modes accurately.

Mean distances for train P&R are predicted well. Appendix D demonstrates that the observed tour length distribution for P&R is lumpy, based on only 15 observations. The story for K&R is similar, with the observed distribution based on only 12 observations. For K&R the mean observed distance is under-predicted, but the observed value looks high – for commute and business where the P&R and K&R sample sizes are much larger the mean K&R distance is less than the mean P&R distance as would be expected. For other access, the mean observed distance is predicted well, and the shape of the observed tour length distribution is reproduced reasonably well.

The plot of access mode shares with distance in Appendix D demonstrates that following modification the model predictions fit well to the overall pattern in the observed data, bearing in mind the lumpiness caused by the low numbers of observations for the car access modes.

For bus, the mean observed tour length is matched well. The tour length distribution plotted in Appendix D shows a peak in the observed distribution for the 5–10 km band that the model does not predict.

Bike and walk distances are predicted quite well: for taxi there is an under-prediction of observed distances but there are only 12 taxi observations in the data.

Table 68: Other Travel Tour Lengths (km)

Mode	Observed	Predicted	Error
Car driver toll	69.5	67.8	-2.4 %
Car driver no toll	14.2	13.5	-4.8 %
Car driver total	15.0	14.3	-4.7 %
Car passenger	16.6	16.4	-1.0 %
Train park-and-ride	78.6	78.7	0.2 %
Train kiss-and-ride	69.5	78.4	12.9 %
Train other	41.9	48.4	15.6 %
Train total	51.2	58.6	14.4 %
Bus	19.2	20.3	5.7 %
Bike	5.6	6.3	11.8 %
Walk	2.4	2.4	-0.8 %
Taxi	10.5	11.9	12.8 %
Total	13.8	13.6	-1.4 %

Mean car toll distances, which like those for shopping are significantly higher than no toll distances, are predicted well thanks to the car toll distance parameter. No-toll distances are predicted quite well too, though there is a slight under-prediction. The predicted tour length distribution for car modes (driver, passenger and taxi) plotted in Appendix D shows a good match to the observed.

Train P&R access tour lengths are predicted precisely, a result that follows from modifications to the model to restrict the availability to tours of 10 km and above, and to add origin dummies for regions where use of car access modes is higher than average. Appendix D demonstrates a reasonable match to the observed tour length distribution for P&R. Train K&R access tours are over-predicted somewhat; Appendix D shows that some over-prediction of the longest tours (>100 km) is an important factor here. Train other access tour lengths are also over-predicted.

It should be emphasised that the match to the observed distances and tour length distributions for the three access modes has been significantly improved following the modifications to the model specification described in Section 7.6. Furthermore, the plot of access mode shares with distance in Appendix D demonstrates that the model predicts the patterns of variation well, with car access used more for longer tours, and that the observed distributions are influenced by some lumpiness.

For bus, there is a slight over-prediction of mean tour lengths. There is a peak in the observed tour length distribution in the 5–10 km band that the model is unable to replicate, and following this the model tends to over-predict tours for higher distance bands, resulting in the overall slight over-prediction.

Mean observed walk distances are predicted accurately, and distances for bike and taxi are predicted reasonably closely.

Table 69: Work-Based Business Tour Lengths (km)

Mode	Observed	Predicted	Error
Car driver	20.2	20.0	-1.0 %
Car passenger	36.5	31.1	-14.8 %
Train	31.2	43.7	39.7 %
Bus	18.0	8.3	-54.1 %
Public transport total	27.6	34.0	23.0 %
Walk	1.7	1.9	10.3 %
Taxi	11.1	11.3	1.9 %
Total	16.6	16.3	-2.0 %

Car driver is the largest mode with a 63 per cent share, and tour distances are predicted accurately. Car passenger distances are under-predicted somewhat. Appendix D demonstrates a fairly good fit to the observed tour length distribution for car modes (car driver, car passenger, taxi).

The observed train and bus samples are eight and three tours respectively, and so the model has only limited information for these modes. Therefore, the significant differences between observed and predicted tour lengths for public transport modes are not surprising. Appendix D clearly demonstrates the lumpiness in the observed tour length distribution for public transport modes.

Mean tour lengths for walk and taxi tours are predicted well.

Table 70: Non-Home-Based Business Detour Lengths (km)

Mode	Observed	Predicted	Error
Car driver toll	37.5	37.2	-0.8 %
Car driver no toll	13.4	13.2	-1.8 %
Car driver total	15.1	14.9	-1.7 %
Car passenger	21.0	17.8	-15.0 %
Train	9.9	9.8	-0.9 %
Bus	1.9	2.6	34.3 %
Public transport total	0.6	1.0	76.0 %
Walk	3.8	2.6	-31.5 %
Taxi	9.9	10.5	6.5 %
Total	13.5	13.3	-1.3 %

Detour distances are predicted accurately for the car driver modes, but for car driver there is some under-prediction. Appendix D shows that the fit to the observed tour length distribution for car modes (car driver toll and no toll, car passenger and taxi) is good.

Observed train distances are predicted accurately, bus distances are over-predicted but the observed value is based on a single observation. The public transport tour length distribution is plotted in Appendix D but it should be noted that it is based on only nine observations.

Walk distances are under-predicted while taxi distances are slightly over-predicted.

CHAPTER 9 **Summary**

Model Specification

The mode-destination model specifications identified during Stages 1 and 2 of the STM development work have been re-estimated using more recent Household Travel Survey (HTS) data to reflect the year 2006 as the base year. A more detailed zoning system has been used, with the number of zones approximately tripling in number, and the geographical coverage of the model has been extended to include Newcastle and Wollongong.

The scope of the models has also been extended in the re-estimation work explicitly to model the choice of toll roads, and to represent access mode and station choice for train Table 71 summarises which of these choices have been modelled for each journey purpose, and then the text below the table summarises how the model specification was extended to represent these choices.

Table 71: Summary of Model Specification by Purpose

Purpose	Toll Roads	Train Access Mode and Station Choice
Commute	Yes	Yes
Business	Yes	Yes
Primary Education	No	No
Secondary Education	No	Yes (no P&R)
Tertiary Education	No	Yes
Shopping	Yes	Yes
Other Travel	Yes	Yes
Work-Based Business	No[23]	No
NHB Business Detours	Yes	No

Toll Roads

The models now explicitly model the choice between tolled and untolled roads, where such a choice exists. This allows the models to predict how toll road usage would respond to changes in toll charges, and to predict usage under future scenarios where levels of congestion are higher.

To model toll road choice, it was necessary to develop appropriate toll and no-toll networks. For the toll networks, tests revealed it was necessary to use a high value of time

[23] It is assumed work-based business tours use toll routes if the toll skims identify them as an option.

of $180/hr to ensure there was sufficient demand for the toll alternatives. At lower VOTs, a substantial proportion of demand was lost from toll roads and this would have introduced a bias into the model estimation. To create the no-toll network, tolled alternatives were removed with the exception of the Harbour crossings. The Harbour crossings were retained because for most users of these crossings there is no realistic no-toll alternative.

The HTS data record whether toll roads were used for car trips, and if so which toll roads were used. If an individual was observed to use a toll road for any trip in their tour, they were modelled as a toll road user. Information on whether the individual paid a toll was also recorded in the HTS. For toll routes where not all users have to pay, this information was used to classify individuals into toll and no-toll choosers. For toll routes where all drivers have to pay, it was assumed the individual had to pay, even if they stated otherwise.

Train Access Mode and Station Choice

In the Stage 1 and 2 models, it was assumed all access to train was by walk or bus, and as such park-and-ride (P&R) and kiss-and-ride (K&R) usage was not modelled. The models have now been extended to model the choice of access mode to train, differentiating P&R, K&R and other (walk and/or bus) access, and for P&R and K&R the choice of access station. This enables the model to predict demand for existing and proposed P&R sites, as well as giving better predictions of demand for train in areas such as Gosford-Wyong where the majority of train tours use car access.

The P&R alternative is defined as anyone who arrives in a car that is parked at the station, which may include passengers as well as drivers. Correspondingly, K&R is defined as anyone who is dropped at a station by a car that then drives away.

For P&R and K&R, the choice of access station has also been modelled, with up to five stations represented for a given origin-destination pair. These stations are identified by a pre-processing run as the most attractive options, based on the level of service for both the car access and train legs. So instances where individuals trade off between driving to their nearest station where they board a stopping service to the CBD, and driving further to access a faster service to the CBD, are explicitly modelled.

Initially, the choice of access station for bus and walk access was also explicitly modelled. However, tests revealed that the ability of the pre-processing run to identify the stations actually chosen was relatively poor. Subsequent testing demonstrated that using Emme to determine the chosen station for a given origin-destination pair gave more acceptable results, and therefore this approach was used in the final models for bus and other access.

Model Results

The detailed model parameter results are provided in Appendix B. This section describes the key findings from the estimations.

Treatment of Cost

In the Stage 1 and 2 models, cost was represented in the utilities in logarithmic form, which was shown to give a significant improvement in fit compared with a linear form.

Recent RAND Europe experience has demonstrated that using both linear and logarithmic terms together can give an improved fit to the data, as well as greater elasticity to cost changes, whereas logarithmic only formulations tend to result in relatively low cost elasticities. Therefore, tests of combined linear and logarithmic forms were made during the re-estimation work.

For commute, both linear and logarithmic terms were freely estimated from the data, and the model yielded plausible values of time and elasticities. For the other purposes, it was not possible to estimate both linear and logarithmic cost terms simultaneously, and log-only models gave a better fit to the data. However, these models were inelastic to cost changes, and therefore a logarithmic and linear mixture was imported. By introducing a small linear cost effect, significantly higher and more plausible cost elasticities were obtained for only a small loss of fit to the data.

Variation in cost sensitivity with income was also investigated. Significant variations in cost sensitivity with personal income were identified for commute and home–business travel. For the other purposes, no significant variations were identified.

Cost sharing between car drivers and passengers was tested during the re-estimation work, whereas the Stage 1 and 2 models assumed all car costs were borne by the driver. These tests demonstrated an improved fit to the data for commute and tertiary education if passengers were assumed to pay 50 per cent of the costs paid by drivers. For shopping and other travel, the best results were obtained assuming drivers and passengers pay an equal share of the car costs.

Level of Service Terms

Separate valuations of first and other wait time were identified for commute and shopping purposes. For the other purposes combined wait time terms were adopted. The valuations of wait time and access and egress time relative to train and bus in-vehicle time are relatively high for commuting and business, and lower (but still plausible) for shopping and other travel. The valuations are low for the education purposes, where the smaller estimation samples make it more difficult to identify significant out of vehicle terms.

For tertiary education, a special term was introduced to account for high public transport usage to the model zone containing the University of New South Wales (UNSW). Shuttle buses to the campus from Central Station carry substantial numbers of students, and the attractiveness of this service to UNSW students was not adequately described by the level of service data alone.

Socio-Economic Terms

The most important socio-economic terms are the car availability terms, which account for significant variations in the likelihood of choosing car driver or passenger according to car ownership and licence holding. The key effects identified during the Stage 1 and 2 modelling, namely that car driver is less likely to be chosen if there is competition for the car(s) in the household, and that car passenger is more likely to be chosen if someone else in the household is able to offer a lift, have been retained.

A number of other socio-economic terms are used in the model to take account of variations in mode choice by gender, age and adult category (full-time worker, full-time student, retired etc.). Most of the terms identified during the Stage 1 and 2 estimation work have been retained, and only a few new terms have been identified during the re-estimation work.

Destination Effects

Building on the Bureau of Transport Statistics' experience in applying the old STM model, income segmented employment data were used for commuting to better predict high income commuters to the CBD. However, while introducing income segmented attractions resulted in a significant improvement in fit to the data, travel to some other centres was under-predicted, and there was a general tendency to under-predict travel from the west to the east. As a result, a number of destination constants were added to the models for these centres. These constants applied in addition to the CBD terms identified during the Stage 1 estimation work.

For primary and secondary education, terms have been estimated to account for higher school bus usage in Newcastle. The secondary education model also includes terms reflecting higher school bus usage in Wollongong and outer Sydney.

In the shopping model, destination constants have been added to reflect the high attractiveness of large shopping centres (> 35,000 m^2) and other shopping centres. The effect is stronger in magnitude for the large shopping centres. In addition to these terms, the dummies to reflect higher car usage in the middle and outer rings of Sydney identified during the Stage 2 estimations were retained.

The re-estimated other travel model also retains a dummy for higher car usage in the outer ring of Sydney identified during the Stage 2 estimation work. However, a negative destination population density term present in the Stage 2 model was insignificant in the re-estimated model and therefore was not retained.

Toll Road Specification

A number of tests were made to determine the appropriate model specification for representing the toll road choice. The initial tests for the commute model represented the cost and travel time associated with toll and non-toll options, allowing the higher toll cost to be traded off against the travel time savings offered by the toll route, and incorporated a constant on the toll alternative. The *a priori* expectation for this constant was that it would be positive, reflecting factors such as the increased travel time reliability associated with roll roads. However, a significant negative toll road constant was identified, and investigations were made to understand this result.

A substantial reduction in the toll constant was achieved by imposing a minimum toll threshold of $1.00. Multi-routing in the assignment was resulting in a lot of origin-destination pairs with low toll values, caused by combinations of toll and no-toll paths. Imposing a minimum toll threshold of $1.00 made toll roads unavailable for these less likely paths, and by removing a large number of rarely chosen alternatives from the choice set a significant reduction in the constant was achieved. However, the constant remained negative, and it became clear that a substantial number of toll alternatives remained available that were rarely chosen.

Further investigation of the toll road travellers revealed that they have significantly higher tour lengths than non-toll users for all model purposes. Model formulations with a combination of a toll constant and a distance effect gave a substantial improvement in fit to the data, and reflect that travellers tend only to be prepared to pay to use toll roads to save time for longer tours. The distance formulation was therefore retained in the final model specifications.

When the toll road constant and distance effect are combined in the commute model, then at the mean tour distance they give a 'toll bonus' effect equivalent to three minutes of car time, which is a plausible result. For shopping, a higher valuation of 15 minutes of car time is observed. For business a slight negative effect was identified (-1 minute of car time) and for other travel, where toll road usage is low, the effect is equivalent to -12 minutes of car time. Finally, for NHB business detours a toll bonus effect equivalent to one minute of car time is observed.

Train Access Mode and Station Choice

Models of train access mode and station choice have been incorporated in the commute, business, secondary education, tertiary education, shopping and other travel. There is little train data for primary education, where most public transport tours are made by bus or school bus, and for the non-home-based purposes there is also little train data. Therefore, for primary education and the non-home-based purposes access mode and station choice is not modelled.

Tests for commute demonstrated that the procedure that selects the top ranked stations for P&R and K&R selected the chosen station as rank 1 in over half of cases, and selected the chosen station in ranks 1 to 5 in 88 per cent of cases. Similar percentages were achieved for the other model purposes, although in the case of tertiary education and shopping just two station choice alternatives were sufficient.

The access mode and station choice models yield estimates of the sensitivity to car access time, which can be compared with the sensitivities to bus and walk access, as well as to rail in-vehicle time. For commute and business the results were plausible, with car access time valued somewhat higher than bus access time, but not as high as walk access time. In both cases, car access time was valued substantially higher than rail time, indicating that travellers seek to minimise the car access leg relative to the rail leg. For other purposes, where there was less observed data, it was not possible to estimate a significant car access term, so that term was fixed to be equal to car time (as a main mode) based upon the commute and business results.

While the station choice models were able to identify the top ranked stations successfully, comparison of observed and predicted tour length distributions by access mode revealed a pattern of under-predicting tour lengths for P&R and K&R, and over-predicted tour lengths for the other access mode, which has the largest overall share. A number of changes were made to the models to provide substantial improvements in the model predictions. First, P&R and K&R were set to be unavailable for tours under 10 km (i.e. 5 km one-way) in length on the basis of the observed data. Second, a number of origin-specific access mode share effects were added, in particular a strong preference for P&R usage for tours originating in Gosford-Wyong, an area where the rail line is 10 km inland from the population centres along the coast. Finally, constants were added to reflect a lower likelihood of using other access for the longest train tours.

Structural Tests

The structural tests were undertaken using the final model structure to investigate the relative sensitivity of the different choice decisions. Choices at the top of the structure are the least sensitive to changes in utility, while those at the bottom are the most sensitive.

Following the extension to the scope of the models, up to six different choices were represented for a given model purpose: main mode choice, public transport nest choice, destination choice, access mode choice, station choice and toll road choice. Testing each possible combination of these choices was not feasible, and indeed the experience from the estimations was that it was not possible to identify so many effects simultaneously.

A number of patterns did emerge from the structural tests, however. For all purposes except tertiary education, mode choice was higher than destination choice in the structure. Where identified, the toll road choice was the most sensitive choice, which seems a sensible result as it can be viewed as a route choice decision. However, a significant structural parameter was only identified for commute and business, where the volumes of toll road data are larger.

The station choice and access mode structure is subject to a number of logical constraints, with access modes having to lie beneath main modes, and stations having to lie beneath access modes. In part because of these restrictions, a number of these structural parameters were fixed to one in the final models. However, in the secondary education, shopping and other travel models, the final structure has station choice as significantly more sensitive than access mode choice.

Once parameters have been fixed to one, four generic tree structures can be identified that cover all nine travel purposes. It is noteworthy that the same generic tree structure applies to commute, home–work, home–shopping and home–other travel, which together account for a significant proportion of total travel. The tree structures are plotted in Section 7.7.2.

Model Validation

Elasticities

As noted above, cost was represented in both linear and logarithmic forms in most of the models in order to achieve reasonable cost elasticities. The resulting fuel cost kilometrage elasticities were judged to be reasonable, with commute travel fairly elastic at -0.33, consistent with the higher tour lengths for this purpose, and lower values of -0.18 and -0.25 for shopping and other travel tours, which are typically shorter. The lowest values were obtained for business purposes, which would be expected, and tertiary education.

The car time elasticities show that the dominant response to increases in car time is destination shifting, so that while the mode choice elasticities lie in the range -0.04 to -

0.36, the kilometrage elasticities range between -0.83 and -1.23, though only education purposes have values exceeding one.

The public transport fare elasticities are higher for train than bus, reflecting the higher mean tour distances. Focusing on kilometrage, commute, shopping and other travel, which cover the majority of public transport tours, have train fare elasticities in the range -0.59 to -0.76, and bus fare elasticities in the range -0.42 to -0.63. Lower values are obtained for business and education purposes.

The public transport in-vehicle time elasticities are highest for education purposes. For commute, shopping and other travel, the kilometrage elasticities range from -0.79 to -0.96 for train, and from -0.34 to -1.0 for commute.

Values of Time

In all of the re-estimated models, the values of time (VOTs) increase with the cost (distance) of the journey, and therefore variation in VOT with cost was plotted. The mean costs for the chosen alternatives were used to give validation values for the VOTs, but the actual VOT for a given journey may vary substantially from those validation values.

In summary, the car VOTs are typically consistent with guidance values, except for tertiary where high values are observed. Rail and bus VOTs are consistent with guidance for commute, tertiary and work-based business, high for secondary, and low for home–business, shopping, other travel and non-home-based business detours. However, the range of values resulting from the range of tour costs mean that it is difficult to say exactly what the VOTs should be.

Tour Length Distributions

Car driver has the largest mode share for most purposes, and mean tour distances are predicted accurately for this mode, so a good fit to the observed tour length distributions is observed. Mean distances for toll road users are substantially higher than average, and the models predict these higher distances accurately due to toll road distance terms.

Car passenger distances are typically shorter than those for car driver, and in most cases these distances are predicted well due to specific distance terms.

For train, the validation terms initially revealed that while overall train tour lengths were predicted well, the fit for the individual access modes was less good. As summarised above, a number of changes were made to the model specification to improve the model performance in this respect, and significant improvements were achieved so that the key pattern of the likelihood of using car access (P&R or K&R) increases as total tour distances increase.

Mean bus distances are predicted well for most purposes, though there is a tendency in a number of purposes to under-predict short bus tours in the 5–10 km band.

Bike and walk distances are predicted well due to mode-specific distance terms.

There are significant differences between observed and predicted taxi distances for a number of model purposes; however, typically the observed samples sizes are small and so the impact of these differences on total car kilometrage will be minimal.

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APPENDICES

Appendix A: Model Exclusions

Commute

Commute tours	6560	100.0 %
Half tours	322	4.9 %
Car toll chosen, no licence	10	0.2 %
Car toll chosen, no cars in household	1	0.0 %
Car non-toll chosen, no licence	212	3.2 %
Car non-toll chosen, no cars in household	5	0.1 %
Main mode aircraft	1	0.0 %
Train, school bus or taxi access	4	0.1 %
Destination outside model area	18	0.3 %
Car toll chosen, no toll skim, no detours	13	0.2 %
Car toll chosen, no toll skim, 1+ detours	50	0.8 %
Car toll chosen, toll < $1	46	0.7 %
Car toll chosen, intrazonal	1	0.0 %
Train chosen, intrazonal	1	0.0 %
Train chosen, chosen station not in ranks 1-5	68	1.0 %
Train P&R or K&R chosen, no car in household	2	0.0 %
Train other, no path in skims	111	1.7 %
Bus chosen, intrazonal	1	0.0 %
Bus chosen no path in skims	5	0.1 %
Estimation sample	5689	86.7 %

Home–Business

Business tours	4176	100.0 %
Half tours	175	4.2 %
Car toll chosen, no cars in household	3	0.1 %
Car non-toll chosen, no licence	1	0.0 %
Car non-toll chosen, no cars in household	1	0.0 %
Main mode aircraft	15	0.4 %
Train, school bus or taxi access	1	0.0 %
Train, access mode not modelled	1	0.0 %
Destination outside model area	36	0.9 %
Car toll chosen, no toll skim, no detours	10	0.2 %
Car toll chosen, no toll skim, 1+ detours	102	2.4 %
Car toll chosen, toll < $1	38	0.9 %
Car toll chosen, intrazonal	1	0.0 %
Train chosen, chosen station not in ranks 1-5	16	0.4 %
Train other, no path in skims	27	0.6 %
Bus chosen, intrazonal	1	0.0 %
Bus chosen no path in skims	2	0.0 %
Estimation sample	3746	89.7 %

Home–Primary Education

Primary education tours	3708	100.0%
Half tours	3	0.1%
Main mode 'other'	17	0.5%
Destination outside model area	2	0.1%
Train chosen, no path in skims	5	0.1%
Bus chosen, intrazonal	23	0.6%
Bus chosen, no path in skims	36	1.0%
Zero attraction variable at chosen destination	427	11.5%
Estimation sample	3195	86.2%

Home–Secondary Education

Secondary education tours	2540	100.0%
Half tours	3	0.1%
Car driver, no licence	3	0.1%
Main mode aircraft	1	0.0%
Main mode 'other'	7	0.3%
Train, school bus or taxi access	6	0.2%
Train, access mode 'other'	1	0.0%
Destination outside model area	3	0.1%
Train chosen, no path in skims	49	1.9%
Bus chosen, intrazonal	2	0.1%
Bus chosen, no path in skims	39	1.5%
Taxi chosen, intrazonal	5	0.2 %
Zero attraction variable at chosen destination	363	14.3 %
Estimation sample	2058	81.0 %

Home–Tertiary Education

Tertiary education tours	1053	100.0 %
Half tours	3	0.3 %
Car driver, no licence	2	0.2 %
Car driver, no car in household	1	0.1 %
Main mode 'other'	1	0.1 %
Train, school bus or taxi access	1	0.1 %
Destination outside model area	1	0.1 %
Train chosen, chosen station not in ranks 1-2	16	1.5 %
Train other, no path in skims	39	3.7 %
Bus chosen, intrazonal	1	0.1 %
Bus chosen no path in skims	7	0.7 %
Zero attraction variable at chosen destination	24	2.3 %
Estimation sample	957	90.9 %

Home–Shopping

Shopping tours	8919	100.0 %
Half tours	1	0.0 %
Car non-toll chosen, no licence	10	0.1 %
Car non-toll chosen, no cars in household	13	0.1 %
Main mode 'other'	10	0.1 %
Train, school bus or taxi access	4	0.0 %
Train, access mode 'other' or none	1	0.0 %
Destination outside model area	10	0.1 %
Car toll chosen, no toll skim, no detours	1	0.0 %
Car toll chosen, no toll skim, 1+ detours	15	0.2 %
Car toll chosen, toll < $1	7	0.1 %
Train chosen, intrazonal	1	0.0 %
Train chosen, chosen station not in ranks 1-5	11	0.1 %
Train other, no path in skims	34	0.4 %
Bus chosen, intrazonal	3	0.0 %
Bus chosen no path in skims	43	0.5 %
Taxi chosen, intrazonal	1	0.0 %
Estimation sample	8754	98.2 %

Home–Other Travel

Other travel tours	31689	100.0%
Half tours	1533	4.8%
Car toll chosen, no licence	1	0.0%
Car toll chosen, no cars in household	1	0.0%
Car non-toll chosen, no licence	36	0.1%
Car non-toll chosen, no cars in household	52	0.2%
Main mode monorail	1	0.0%
Main mode aircraft	5	0.0%
Main mode 'other'	87	0.3%
Train, school bus or taxi access	7	0.0%
Destination outside model area	33	0.1%
Outward time period info missing	1	0.0%
Car toll chosen, no toll skim, no detours	23	0.1%
Car toll chosen, no toll skim, 1+ detours	43	0.1%
Car toll chosen, toll < $1	18	0.1%
Train chosen, intrazonal	7	0.0%
Train chosen, chosen station not in ranks 1-5	54	0.2%
Train P&R or K&R, no cars in household	4	0.0%
Train other, no path in skims	122	0.4%
Bus chosen, intrazonal	2	0.0%
Bus chosen, no path in skims	45	0.1%
Estimation sample	29614	93.5%

Work-Based Business

Work based business tours	604	100.0 %
Car chosen, no cars in household	1	0.2 %
Main mode aircraft	1	0.2 %
Main mode 'other'	4	0.7 %
Train other, no path in skims	2	0.3 %
Estimation sample	596	98.7 %

Non-Home-Based Business Detours

NHB business detours	1338	100.0 %
Car driver chosen but unavailable	12	0.9 %
Main mode bike	2	0.1 %
Main mode aircraft	4	0.3 %
Main mode 'other'	6	0.4 %
Primary destination outside model area	13	1.0 %
Detour location outside model area	4	0.3 %
Car toll chosen, no toll skim	34	2.5 %
Car toll chosen, toll < $1	14	1.0 %
Train chosen, intrazonal	3	0.2 %
Train, no path in skims	2	0.1 %
Bus chosen, no path in skims	1	0.1 %
Estimation sample	1243	92.9 %

Appendix B: Final Model Parameters

This section presents the final model parameters for the seven home-based and two non-home-based model purposes. For each model purpose, model summary information is presented first:

- File: the model name followed by the '.F12' extension
- Converged: whether the model converged
- Observations: the number of observations
- Final log (L): the log-likelihood at the final parameter values
- D.O.F.: the degrees of freedom, i.e. the number of parameters estimated
- $Rho^2(0)$: the rho-square measure, relative to a model with all parameters zero
- Estimated: the date the model was estimated.

The model parameters are presented beneath the model summary information. The t-ratios for the model parameters (the parameter divided by its standard error) are presented in brackets. An asterisk for the t-ratio indicates that the parameter was constrained to the value indicated.

Commute

File	COM_166.F12
Converged	True
Observations	5689
Final log (L)	-36883.8
D.O.F.	55
$Rho^2(0)$	0.393
Estimated	16 Aug 10

Cost and Level of Service Terms:		
cost13	-0.00248	(-6.8)
cost4	-0.00189	(-6.8)
cost5	-0.00160	(-6.8)
cost67	-0.00122	(-6.7)
cost810	-0.00105	(-6.5)
cost	-0.00368	(-3.9)
LogCost	-0.3683	(-4.5)
CarTime	-0.05956	(-7.9)
RlTime	-0.02207	(-5.9)
BusTime	-0.03977	(-6.8)
FWaitTm	-0.09765	(-5.3)
OWaitTm	-0.07280	(-6.4)
AcEgTm	-0.06018	(-6.1)
CrAcEgTm	-0.07144	(-6.1)
CarPDist	-0.04651	(-5.4)
BikeDist	-0.3194	(-5.7)
WalkDist	-1.125	(-7.5)
Toll Choice Terms:		
TollBonus	-0.7381	(-4.3)
CarTDist	0.01370	(5.4)
Train Access Mode Distance Fit Terms:		
OrigGW	4.436	(5.3)
OrigSWS	0.8710	(1.6)
TRnOthG75	-2.722	(-4.9)
Car Availability Terms:		
CarComp	-3.948	(-7.0)
CmpCrDr	1.745	(5.3)
PassOpts	4.004	(5.3)
Prfr2pcar	0.5896	(1.3)
Prcarcomp	-2.389	(-3.9)
KRPassopts	4.016	(2.7)
PRLicence	2.544	(4.2)
Other Socio-Economic Terms:		
MaleCrDr	0.4846	(2.6)
MaleBike	5.378	(3.9)
FTwrkdist	0.01214	(4.5)
Mode Constants:		
CarP	-11.23	(-7.1)
Train	-1.545	(-3.7)
TrainPR	-9.205	(-7.1)
TrainKR	-11.78	(-5.8)
Bus	-2.114	(-4.7)
Bike	-16.33	(-6.5)
Walk	-3.236	(-4.6)
Taxi	-9.707	(-6.3)
Destination Constants:		
Pmatta	1.055	(4.6)
Cwood	1.333	(4.3)
SLC	1.156	(4.5)
NSyd	1.747	(5.9)
ISyd	0.9182	(6.2)
Esub	1.010	(4.9)
Nbeach	0.6903	(3.3)
CBDRail	1.643	(5.2)

CBDBus	1.002	(4.0)
Intrazonal Constants:		
CrDNoTllIZ	-0.6883	(-2.0)
CarPIZ	0.1050	(0.2)
WalkIZ	1.184	(3.5)
BikeIZ	0.5615	(0.4)
Attraction Term:		
TotEmp	1.000	(*)
Structural Parameters:		
Theta_MD	0.8082	(19.0)
Theta_PT	1.000	(*)
Theta_Acmd	1.000	(*)
sta_ch	1.000	(*)
Theta_Toll	0.5116	(8.0)

Home–Business

File	BUS_40.F12
Converged	True
Observations	3746
Final log (L)	-26370.9
D.O.F.	38
Rho²(0)	0.343
Estimated	25 Aug 10

Cost and Level of Service Terms:		
GCost14	-0.00415	(-6.4)
GCost56	-0.00304	(-6.2)
GCost710	-0.00227	(-6.0)
GCostX	-0.00524	(-5.0)
CarTime	-0.03775	(-7.8)
RlFrTime	-0.01313	(-3.4)
BusTime	-0.02186	(-3.8)
WaitTm	-0.05293	(-4.3)
AcEgTm	-0.05494	(-4.0)
CarAccTime	-0.05233	(-3.9)
CarPDist	-0.01372	(-3.1)
WalkDist	-0.6102	(-5.7)
BikeDist	-0.3399	(-4.1)
Toll Choice Terms:		
TollBonus	-0.8534	(-5.7)
CarTDist	0.00906	(6.1)
Train Access Mode Distance Fit Terms:		
OrigGW	4.115	(3.4)
TrnOthG100	-2.089	(-2.3)
Car Availability Terms:		
CarComp	-3.348	(-4.4)
CmpCrDr	2.477	(4.0)
PassOpts	2.341	(3.0)
PRCarComp	-1.152	(-1.8)
Other Socio-Economic Terms:		
CarPu25	2.690	(3.5)
TrnManProf	2.247	(4.3)
Mode Constants:		
CarP	-15.86	(-5.6)
Train	-7.070	(-4.3)
TrainPR	-4.898	(-5.7)
TrainKR	-6.900	(-6.1)
Bus	-6.669	(-4.2)
Bike	-16.87	(-5.0)
Walk	-11.09	(-4.7)
Taxi	-14.76	(-4.6)
Destination Constants:		
CBDRail	0.9944	(3.1)
Intrazonal Constants:		
CrDNoTllIZ	0.9458	(3.9)
CarPIZ	2.954	(4.1)
BikeIZ	2.553	(2.1)
WalkIZ	2.219	(3.6)
Attraction Term:		
TotEmp	1.000	(*)
Structural Parameters:		
Theta_M_P	0.5237	(7.4)
Theta_P_A	1.000	(*)
Theta_A_D	1.000	(*)
Theta_D_S	1.000	(*)
Theta_S_T	0.6130	(7.0)

Home–Primary Education

File	PRIM_15.F12	
Converged	True	
Observations	3195	
Final log (L)	-10595.1	
D.O.F.	25	
Rho²(0)	0.631	
Estimated	14 May 10	
Level of Service Terms:		
CarTime	-0.1485	(-55.2)
RlFrTime	-0.04523	(-4.3)
BusTime	-0.03665	(-8.4)
ScBusTime	-0.07567	(-3.9)
WaitTm	-0.01533	(-2.4)
AcEgTm	-0.01054	(-4.0)
SBusdist	-0.05179	(-1.9)
BikeDist	-0.4658	(-5.1)
WalkDist	-0.8192	(-21.3)
Car Availability Terms:		
Passopts	5.556	(6.3)
CarP_Ccar	0.4590	(2.7)
Other Socio-Economic Terms:		
CarP<8	1.193	(4.9)
Bike_Male	2.819	(2.8)
Mode Constants:		
Train	-3.556	(-2.7)
Bus	-1.856	(-2.9)
Scbus	-0.3720	(-0.7)
Bike	-5.182	(-4.2)
Walk	4.810	(6.8)
Taxi	-6.645	(-5.2)
Destination Constants:		
SCB_NC	1.218	(1.7)
Intrazonal Constants:		
CarPIZ	0.4681	(6.2)
BikeIZ	1.613	(2.6)
WalkIZ	0.8204	(5.8)
Attraction Term:		
TotEnrol	1.000	(*)
Structural Parameters:		
Theta_M_P	0.7412	(2.8)
Theta_P_D	0.5785	(3.0)

Home–Secondary Education

File	SEC_31.F12
Converged	True
Observations	2058
Final log (L)	-8848.2
D.O.F.	33
Rho²(0)	0.505
Estimated	7 Sep 10

Cost and Level of Service Terms:		
LogCost	-0.3528	(-4.6)
Cost	-2.28e-4	(-0.8)
CarTime	-0.04773	(-7.8)
RlFrTime	-0.02864	(-11.4)
BusTime	-0.02997	(-14.0)
SBusTime	-0.05310	(-5.7)
WaitTm	-0.00972	(-3.2)
AcEgTm	-0.00661	(-6.7)
CarAccTime	-0.01733	(-3.7)
CrP_dist	-0.08797	(-8.5)
SBus_dist	-0.03665	(-2.9)
BikeDist	-0.4812	(-6.1)
WalkDist	-0.7714	(-17.5)
Train Access Mode Distance Fit Terms:		
OCWS	1.517	(3.8)
OIWS	1.387	(3.0)
OCantB	1.305	(3.3)
TrnOthGt30	-1.492	(-5.5)
Car Availability Terms:		
PassOpts	3.400	(5.3)
Mode Constants:		
CrD	5.577	(6.6)
Train	3.343	(4.4)
TrainKR	-2.836	(-9.3)
Bus	3.819	(5.2)
ScBs	1.117	(1.8)
Bike	0.8045	(1.1)
Walk	5.006	(7.8)
Taxi	-2.415	(-2.2)
Destination Constants:		
ScB_OutRng	0.6261	(3.5)
SCB_NEW	1.606	(5.5)
SCB_WNG	2.093	(7.1)
Intrazonal Constants:		
CarPIZ	-0.4552	(-2.2)
BikeIZ	-0.7731	(-1.1)
WalkIZ	-0.2898	(-1.5)
Attraction Term:		
TotEmp	1.000	(*)
Structural Parameters:		
Theta_M_P	1.000	(*)
Theta_P_A	1.000	(*)
Theta_A_D	0.7122	(14.8)
Theta_D_S	1.000	(*)

Home–Tertiary Education

File	TER_40.F12
Converged	True
Observations	957
Final log (L)	-4570.6
D.O.F.	26
Rho²(0)	0.515
Estimated	15 Sep 10

Cost and Level of Service Terms:		
LogCost	-0.4282	(-7.6)
CarTime	-0.02717	(-15.6)
RlFrTime	-0.01389	(-6.8)
BusTime	-0.01580	(-7.2)
WaitTm	-0.02387	(-5.2)
AcEgTm	-0.00449	(-1.7)
CarPDist	-0.01612	(-2.7)
BikeDist	-0.2074	(-5.0)
WalkDist	-0.5842	(-11.6)
Train Access Mode Distance Fit Terms:		
OrigGW	4.251	(6.7)
TrnothG50	-0.7760	(-3.1)
Car Availability Terms:		
CarComp	-1.040	(-5.6)
CmpCrDr	0.4394	(1.7)
PassOpts	2.118	(4.5)
Mode Constants:		
CarP	-4.804	(-9.7)
Train	-0.6778	(-2.6)
Bus	-1.179	(-5.0)
Walk	-1.155	(-3.0)
Bike	-4.860	(-9.2)
Taxi	-6.663	(-6.6)
TrainPR	-3.379	(-13.2)
TrainKR	-2.116	(-10.3)
Destination Constants:		
PT_UNSW	0.9982	(6.3)
Intrazonal Constants:		
CrDNoTllIZ	-2.578	(-2.5)
CarPIZ	-1.108	(-1.1)
WalkIZ	0.5669	(2.0)
Attraction Term:		
TotEmp	1.000	(*)

Home–Shopping

File	SHP_52.F12
Converged	True
Observations	8754
Final log (L)	-33473.3
D.O.F.	46
Rho²(0)	0.627
Estimated	9 Sep 10

Cost and Level of Service Terms:		
Gcost	-0.01716	(-30.8)
CarTime	-0.08036	(-41.2)
RlFrTime	-0.02517	(-7.6)
BusTime	-0.01716	(-6.9)
AcEgTm	-0.02281	(-5.9)
FWaitTm	-0.04507	(-5.0)
OWaitTm	-0.02322	(-1.8)
Boardings	-0.4062	(-4.9)
CarPDist	0.02240	(8.1)
BikeDist	-0.4629	(-7.9)
WalkDist	-1.085	(-41.3)
Toll Choice Terms:		
TollBonus	-2.593	(-8.1)
CarTdist	0.05053	(14.1)
Train Access Mode Distance Fit Terms:		
CarADist	0.02726	(5.4)
Car Availability Terms:		
CarComp	-1.266	(-9.6)
CmpCrDr	0.7602	(4.9)
PassOpts	3.376	(13.2)
Other Socio-Economic Terms:		
CarD<20	-0.8392	(-2.1)
CarP_Male	-1.671	(-10.2)
CarP<10	3.347	(6.5)
Ret_CarP	0.9011	(6.2)
Bus_Male	-1.252	(-5.2)
Bus_Pens	1.217	(5.3)
Bike_Male	1.567	(2.8)
Bike_10_19	1.676	(2.7)
Mode Constants:		
CarP	-7.369	(-18.6)
Train	-4.599	(-8.7)
TrainPR	-4.981	(-8.1)
TrainKR	-5.449	(-8.2)
Bus	-4.124	(-9.7)
Walk	-3.730	(-14.2)
Bike	-13.32	(-16.2)
Taxi	-9.155	(-10.8)
Destination Constants:		
Dest_CBD	-0.9477	(-5.2)
CBDRail	1.454	(4.8)
CBDBus	0.8122	(3.1)
Car_MidRng	0.1973	(3.1)
Car_OutRng	0.3763	(5.2)
Dest_PopDn	2.93e-5	(2.0)
regional	0.4469	(12.2)
HiQualShps	0.2583	(8.3)
Intrazonal Constants:		
CrDNoTllIZ	-2.440	(-21.2)
CarPIZ	-2.516	(-15.7)
WalkIZ	0.3047	(3.9)
BikeIZ	0.7129	(1.6)

Attraction Term:

TotEmp	1.000	(*)

Structural Parameters:

Theta_M_P	1.000	(*)
Theta_P_A	1.000	(*)
Theta_A_D	0.5358	(19.8)
Theta_D_S	1.000	(*)
Theta_S_T	1.000	(*)

Home–Other Travel

File	OTH_45M.F12
Converged	True
Observations	29614
Final log (L)	-149080.0
D.O.F.	46
Rho²(0)	0.527
Estimated	5 Sep 10

Cost and Level of Service Terms:		
Gcost	-0.01573	(-67.2)
CarTime	-0.05198	(-65.8)
RlFrTime	-0.01452	(-12.6)
BusTime	-0.00608	(-5.6)
WaitTm	-0.01242	(-4.1)
AcEgTm	-0.00285	(-4.1)
Boardings	-0.1805	(-6.0)
CarPDist	0.01182	(13.3)
BikeDist	-0.2286	(-17.9)
WalkDist	-0.7706	(-67.9)
TaxiDist	0.01935	(1.7)
Toll Choice Terms:		
TollBonus	-2.543	(-14.6)
CarTDist	0.02734	(16.3)
Train Access Mode Distance Fit Terms:		
OrigGW	3.233	(7.0)
OrigCNS	1.320	(4.0)
CarADist	0.01560	(8.0)
Car Availability Terms:		
CarComp	-1.330	(-10.6)
CmpCrDr	0.4453	(3.8)
PassOpts	4.787	(15.1)
Other Socio-Economic Terms:		
CarP_Male	-1.322	(-10.5)
CarP<10	3.887	(15.5)
CarPFTPTW	-1.253	(-9.5)
Bike_Male	3.403	(8.0)
Bike_10_19	2.852	(8.2)
Walk_Male	-0.7470	(-6.7)
Sub-Purpose Mode Terms:		
CarD_Drpu	3.671	(14.6)
CarP_Enter	2.022	(12.3)
PT_Enter	2.644	(11.1)
Walk_Recr	5.300	(16.7)
Mode Constants:		
CarP	-8.456	(-17.8)
Train	-8.056	(-14.9)
TrainPR	-4.242	(-14.9)
TrainKR	-3.833	(-15.1)
Bus	-8.743	(-16.5)
Bike	-18.45	(-19.6)
Walk	-6.170	(-20.0)
Taxi	-11.00	(-12.7)
Destination Constants:		
Car_OutRng	0.1681	(5.3)
Intrazonal Constants:		
CrDNoTllIZ	-3.150	(-49.8)
CarPIZ	-2.825	(-42.8)
BikeIZ	1.829	(11.5)
WalkIZ	0.5173	(12.7)
Size Variable Terms:		

L_S_M	1.000	(*)
Retail	0.9995	(19.5)
Pop	-1.002	(-29.3)

Structural Parameters:

Theta_M_P	0.5257	(11.4)
Theta_P_A	1.000	(*)
Theta_A_D	0.7302	(15.1)
Theta_D_S	1.000	(*)
Theta_S_T	1.000	(*)

Work-Based Business

File	WkBs_10.F12
Converged	True
Observations	596
Final log (L)	-3505.7
D.O.F.	15
Rho²(0)	0.391
Estimated	10 Sep 10

Cost and Level of Service Terms:		
LogCost	-0.7112	(-12.5)
CarTime	-0.03320	(-13.1)
GenPTTime	-0.01036	(-3.2)
WalkDist	-0.6062	(-10.0)
TaxiDist	-0.02732	(-1.7)
Home-Based Tour Mode Constants:		
CarDCarD	1.988	(5.4)
Socio-Economic Terms:		
WalkMale	-1.246	(-4.5)
Mode Constants:		
CarP	-5.586	(-10.9)
Train	-1.678	(-2.0)
Bus	-3.884	(-4.6)
Walk	-0.5412	(-1.1)
Taxi	0.4478	(1.1)
Intrazonal Constants:		
CrDIZ	-0.3809	(-1.6)
WalkIZ	0.8801	(3.7)
Attraction Term:		
TotEmp	1.000	(*)
Structural Parameters:		
Theta_M_PT	1.000	(*)
Theta_PT_D	0.8961	(12.9)

Non-Home-Based Business Detours

File	BusDetour_16.F12
Converged	True
Observations	1243
Final log (L)	-7671.4
D.O.F.	21
Rho²(0)	0.365
Estimated	26 Aug 10

Cost and Level of Service Terms:		
Logcost	-0.9606	(-14.6)
CarTime	-0.08252	(-15.7)
GenPTTime	-0.04977	(-3.8)
CarPDist	-0.05143	(-3.8)
WalkDist	-2.307	(-11.0)
TaxiDist	-0.1481	(-1.7)
Toll Choice Terms:		
TollBonus	-0.4598	(-1.7)
CarTDist	0.01533	(2.4)
Home-Based Tour Mode Constants:		
CarDCarD	7.205	(5.7)
CarPCarP	4.722	(4.1)
WalkWalk	3.819	(2.3)
Car Availability Terms:		
CarDCCar	1.475	(3.3)
Other Socio-Economic Terms:		
CarPA1625	3.360	(4.5)
WalkMale	-1.614	(-3.1)
Mode Constants:		
CarP	-4.000	(-4.5)
Train	4.476	(2.7)
Bus	-1.930	(-1.0)
Walk	4.468	(4.3)
Taxi	1.492	(1.3)
Attraction Term:		
TotEmp	1.000	(*)
Structural Parameters:		
Theta_M_PT	0.7873	(7.9)
Theta_PT_D	1.000	(*)
Theta_D_T	0.6373	(24.9)

Appendix C: Shopping Centres Definition

Large Shopping Centres (> 35,000 m^2)

Shopping Centre	Retail m^2
Blacktown WestPoint	100,000+
Parramatta	138,823
Bondi Junction	131,641
Warringah Mall (Brookvale)	127,445
Miranda Fair (Miranda)	110,404
Castle Towers	109,000
Hornsby	101,231
Erina Fair	98,600
Macquarie	98,438
Macarthur Square	95,200
Bankstown	93,859
Liverpool Shopping Centre	93,785
Penrith	85,600
Eastgardens (Pagewood)	85,496
Tuggerah	82,792
Chatswood	78,523
Top Ryde City (Spring 2009)	78,000
Burwood	64,975
Hurstville Shopping Centre	64,783
Kotara	64,068
Rouse Hill Town Centre	63,400
Roselands Shopping Centre	61,750
Mount Druitt Shopping Centre	60,675
Warrawong	57,504
Glendale	54,967
Wetherill Park	51,267
Chatswood Chase	49,365
Charlestown Square	49,000
Broadway	48,910
Shellharbour Square	39,277
Wollongong Central	39,000
Lake Haven Shopping Centre	38,760

Other Shopping Centres (< 35,000 m^2)

Shopping Centre	Retail m^2
Carlingford Court	33,000
Rhodes	32,586
Green Hills	32,004
Bay Village	29,176
Southgate	28,084
Ashfield	25,300
Marrickville Metro	23,087
Warriewood Square	22,516
Salamander Bay	22,162
Dapto Mall	21,820
Winston Hills Mall	21,779
North Rocks Shopping Centre	21,760
Merrylands	21,383
Nepean	21,011
Bonnyrigg Plaza	21,000
Jesmond	20,999
Figtree	20,362
Casula Mall	20,000
Deepwater Plaza	18,355
Plumpton Market Place	18,337
Richmond Market Place	18,238
Fairfield Forum	18,132
Menai Market Place	16,485
St Marys Village Centre	16,170
Nowra Fair	16,015
Stanhope Village	15,451
Eastgate Shopping Centre	15,151
Lake Macquarie (Mt Hutton)	14,924
Maitland Hunter Mall	14,542
Raymond Terrace	7,232
Narellan Town Centre	6,000 (St 1)
Auburn Central	
Bass Hill Plaza	
Camden Central	
Campbelltown	
Campsie Centre	
Carnes Hill Marketplace (Horningsea Pk)	
Chullora Market Place	
Ingleburn Fair	
Katoomba	
Leichhardt Market Place	
Neeta City	
Rockdale South Side Plaza	
Winmalee Village Centre	
Highlands Marketplace, Mittagong	
Cessnock Market Place	
Waratah Village	

Appendix D: Tour Length Distributions

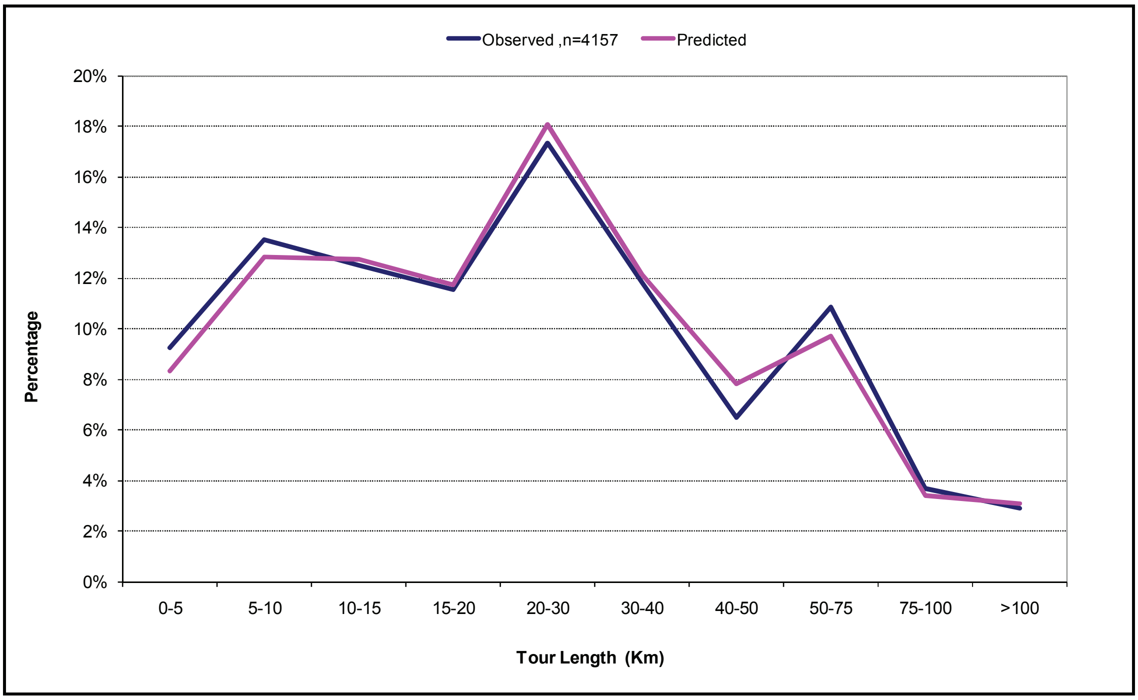
This Appendix presents tour length distributions for the seven home-based and two non-home-based model purposes. For each model purpose, the following distributions are presented to compare observed and predicted data:

- Tour length distributions for car modes (car driver, car passenger, taxi)
- Tour length distributions for train P&R access (where modelled)
- Tour length distributions for train K&R access (where modelled)
- Tour length distributions for train other access (where modelled)
- Train access mode shares by distance (where modelled), both before and after additional terms were added to improve the model predictions
- Bus.

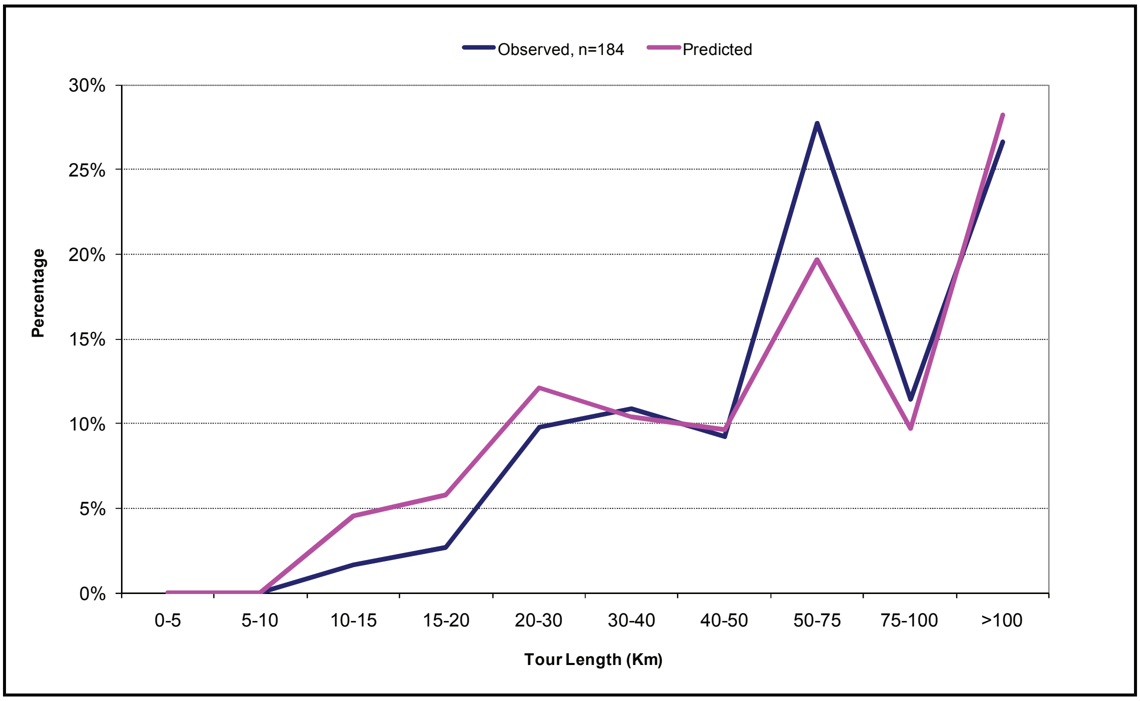
The high level of output generated for the train access modes follows from the additional analysis of train access mode shares by distance described in Section 7.6.3.

Commute

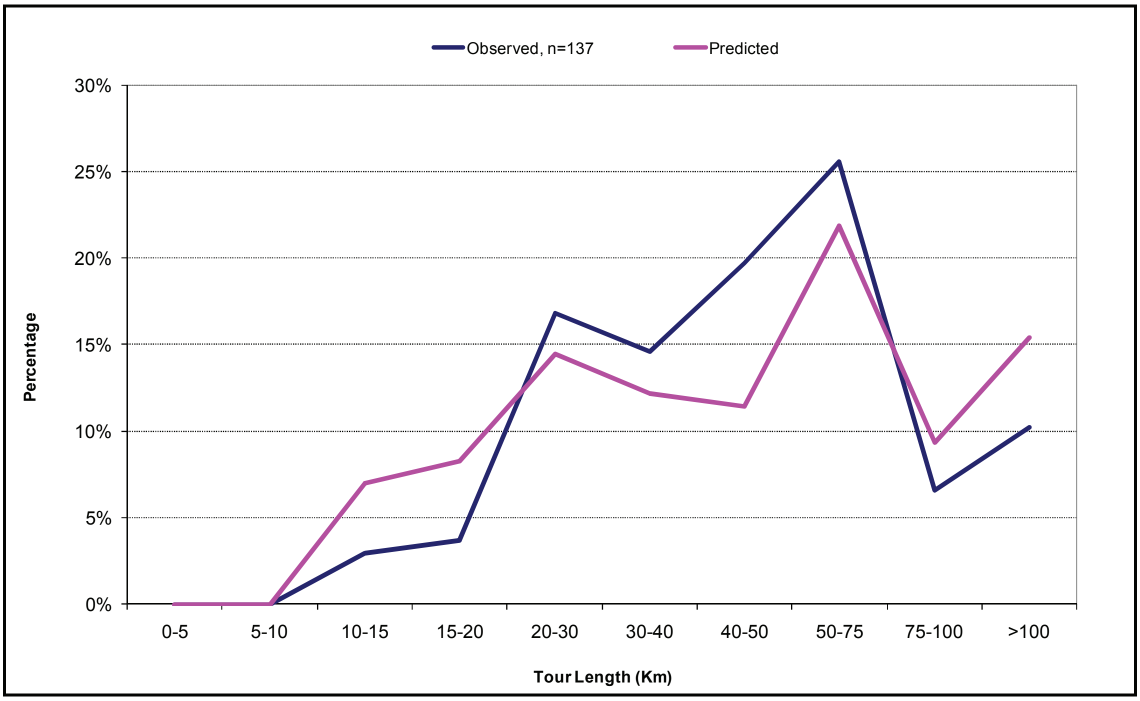
Car modes (car driver, car passenger, taxi)



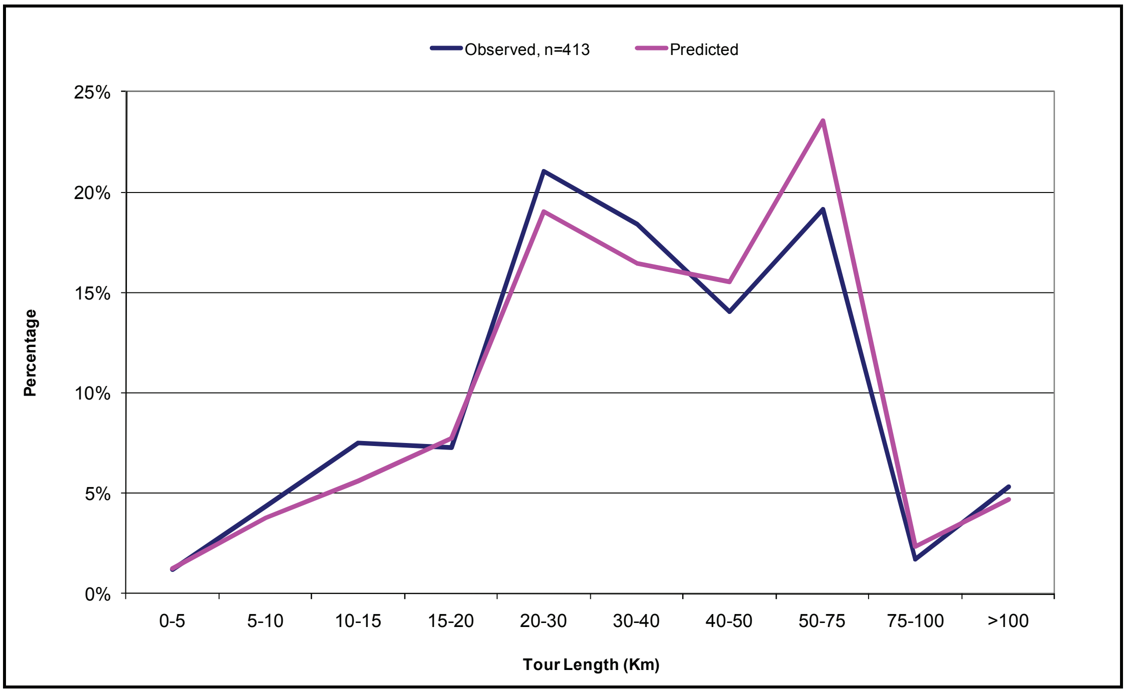
Train, Park-and-Ride Access



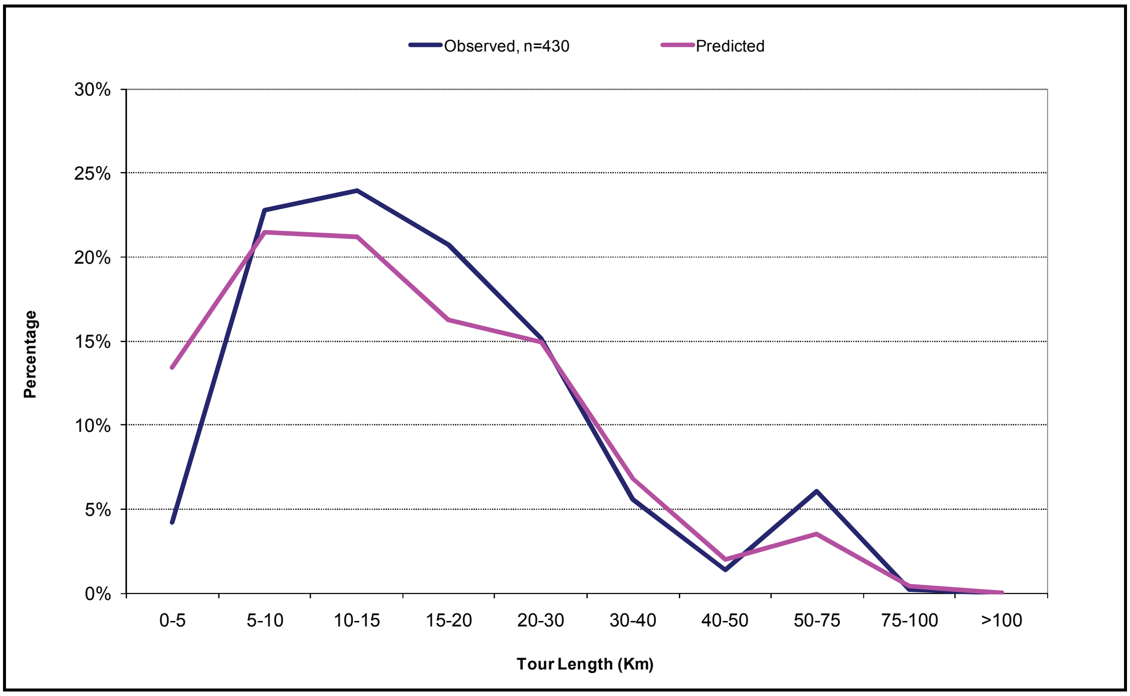
Train, Kiss-and-Ride Access



Train, Other Access

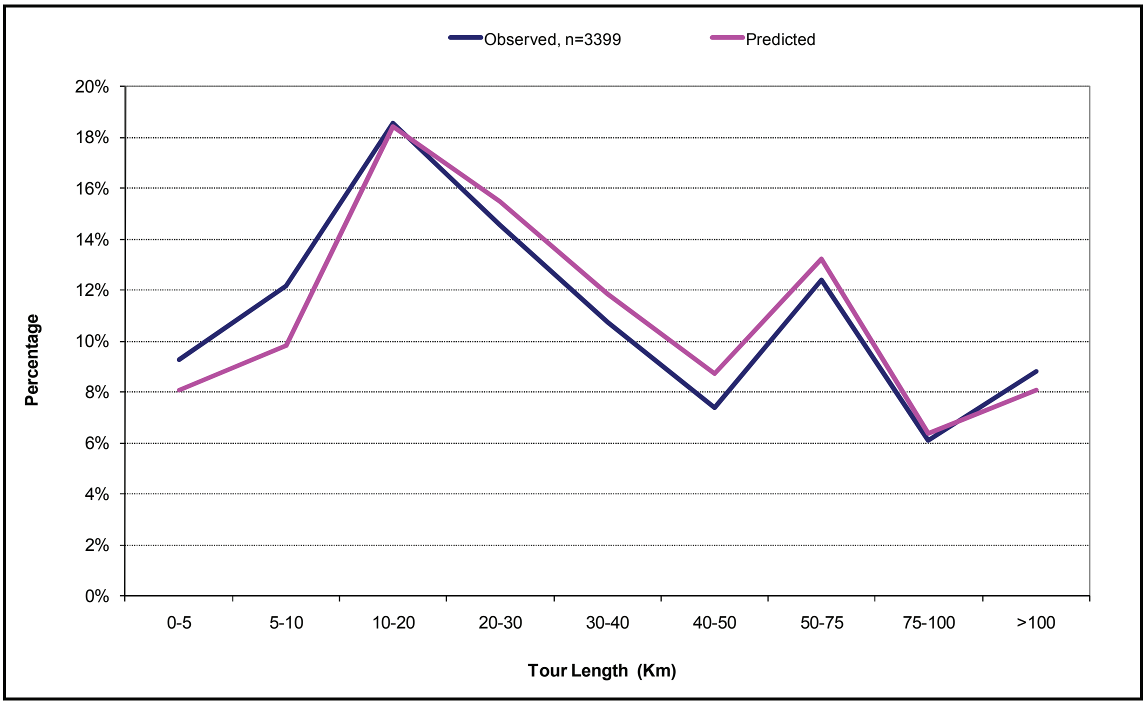


Bus

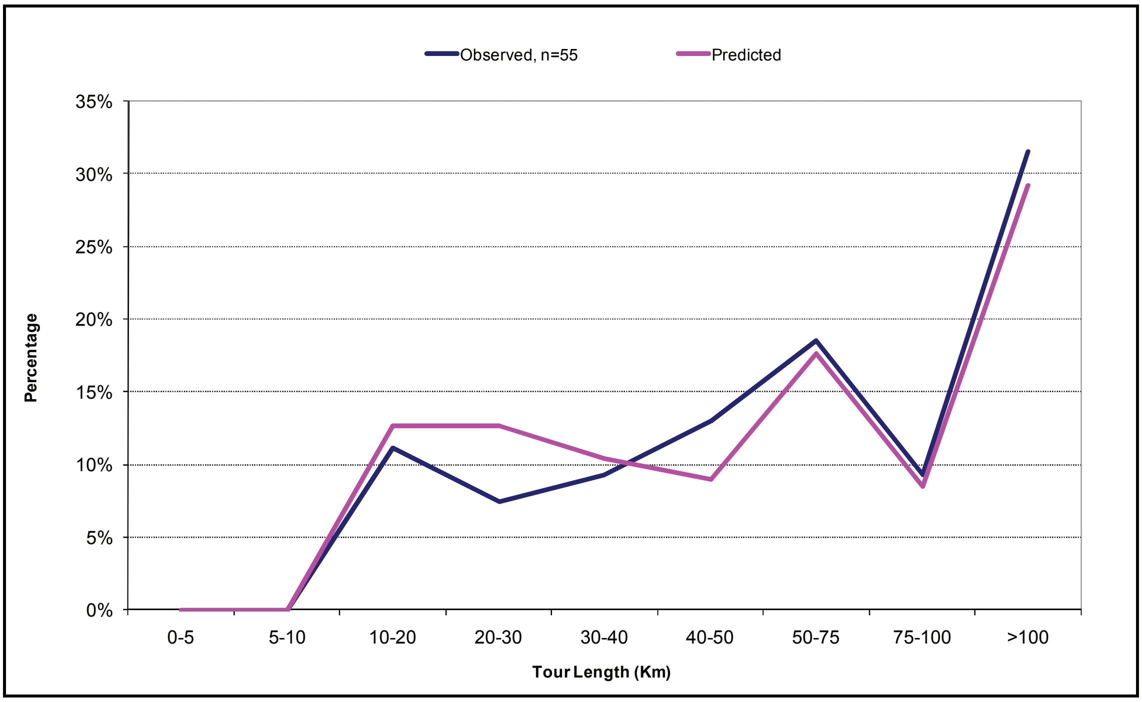

Observed, n=430
Predicted
30%
25%
20%
15%
10%
5%
0%
Percentage
0-5
5-10
10-15
15-20
20-30
30-40
40-50
50-75
75-100
>100
Tour Length (Km)

Business

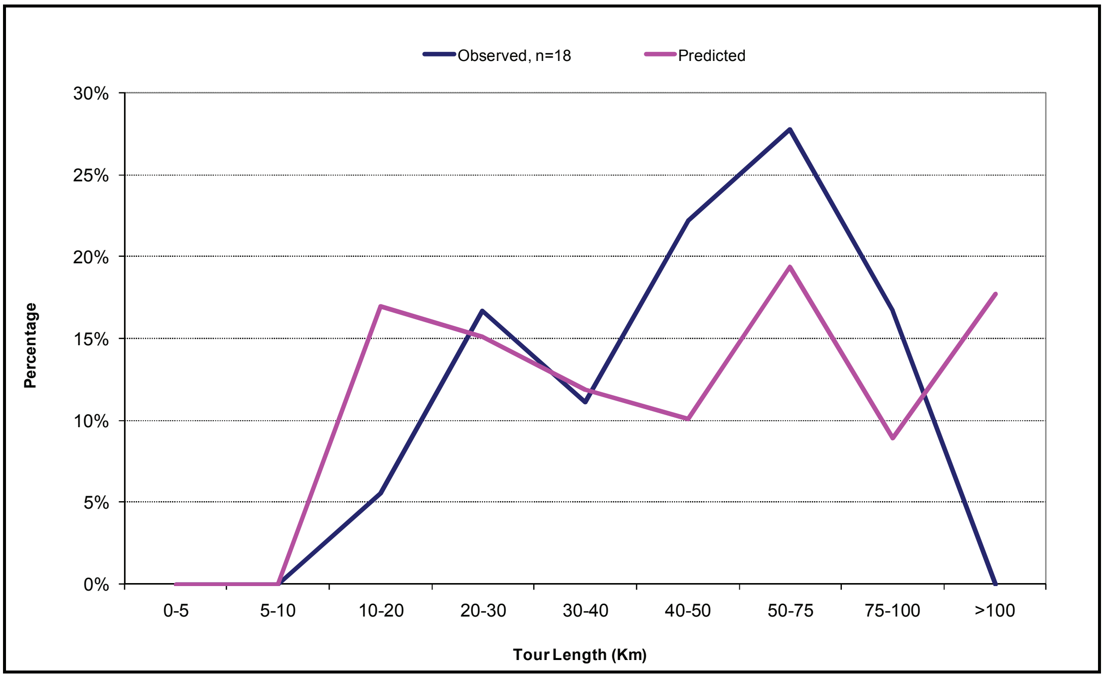
Car modes (car driver, car passenger, taxi)



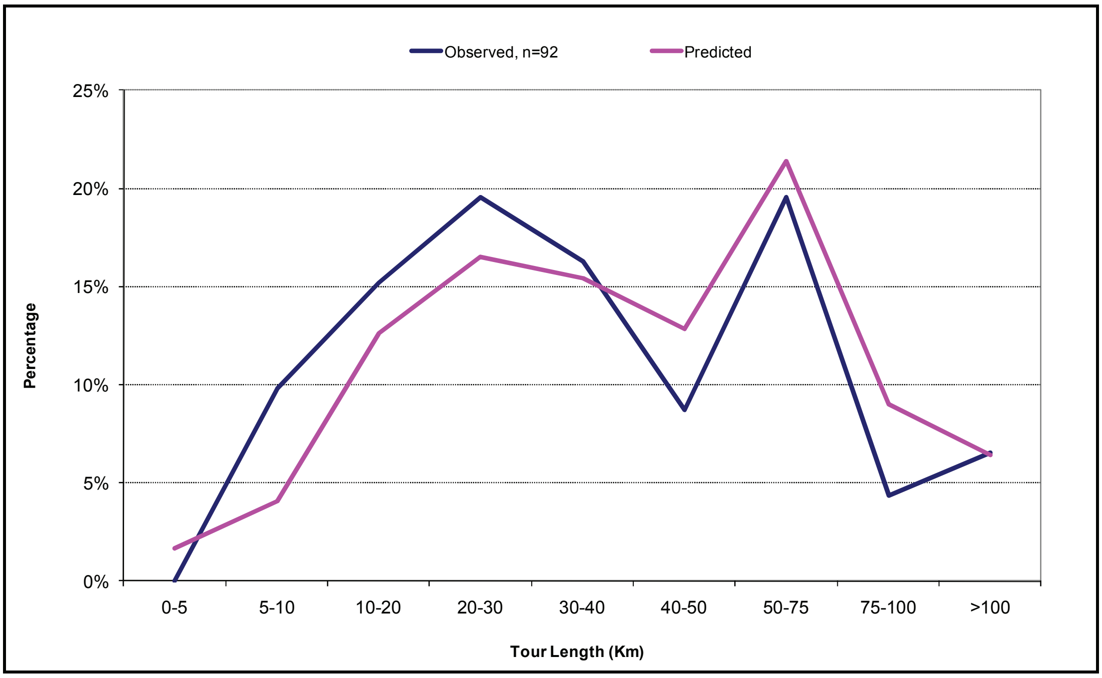
Train, Park-and-Ride Access



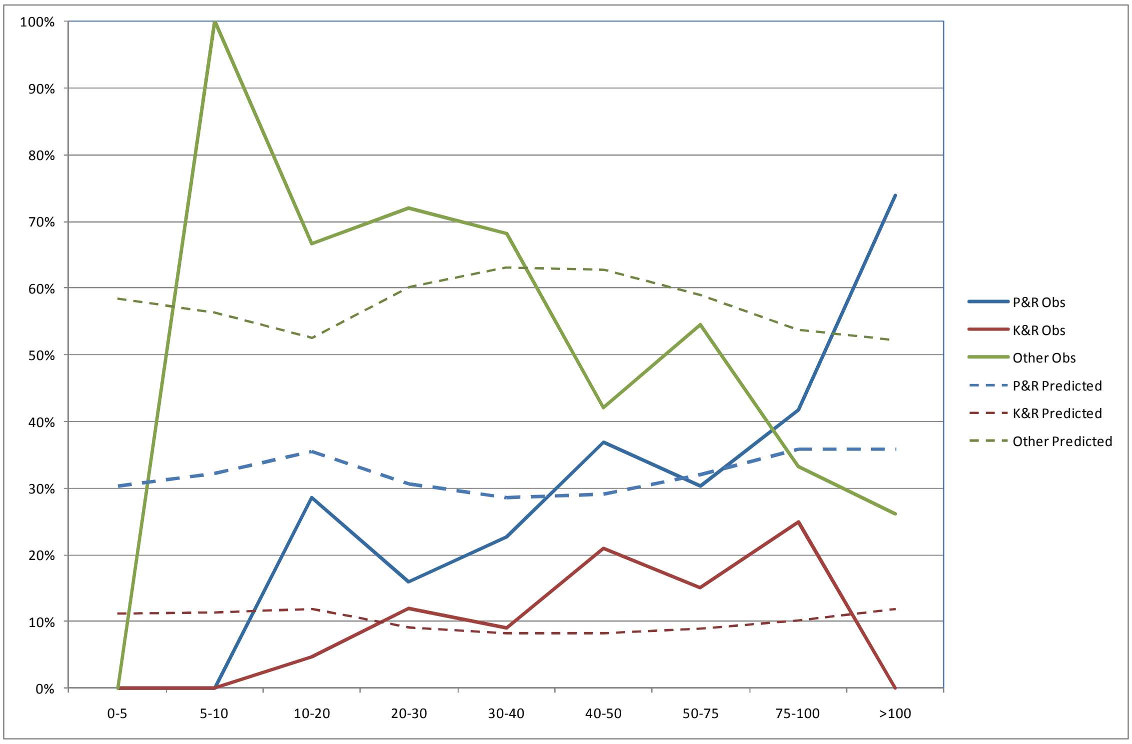
Train, Kiss-and-Ride Access



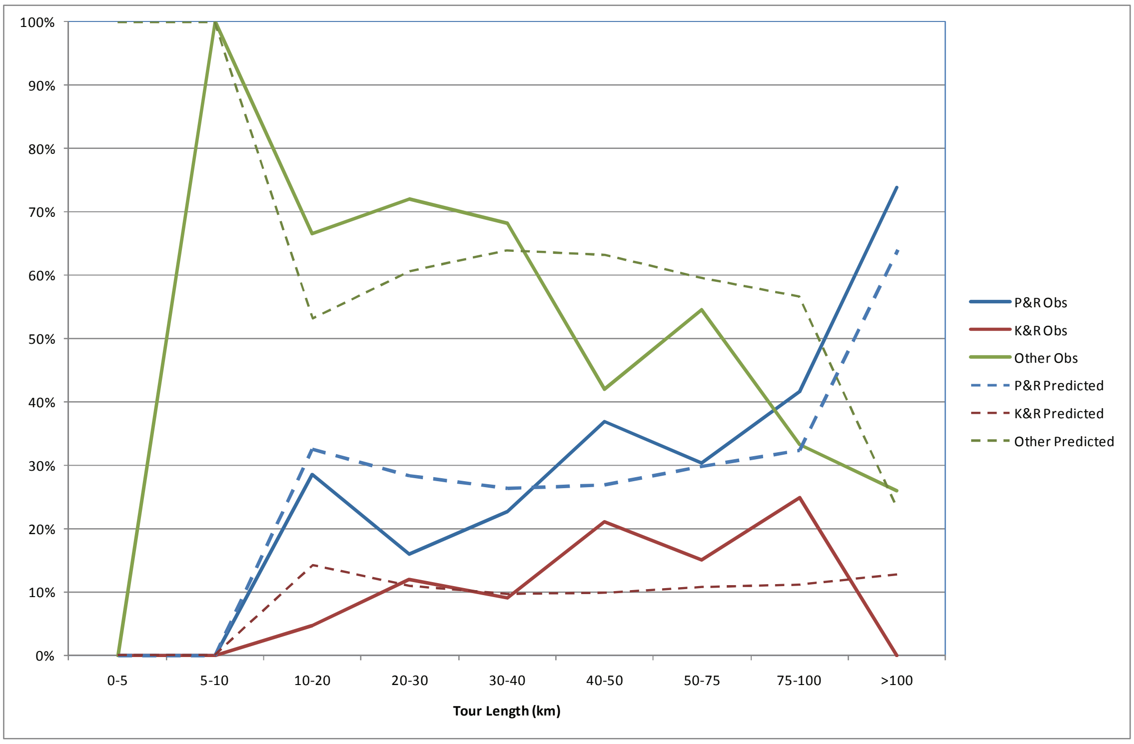
Train, Other Access



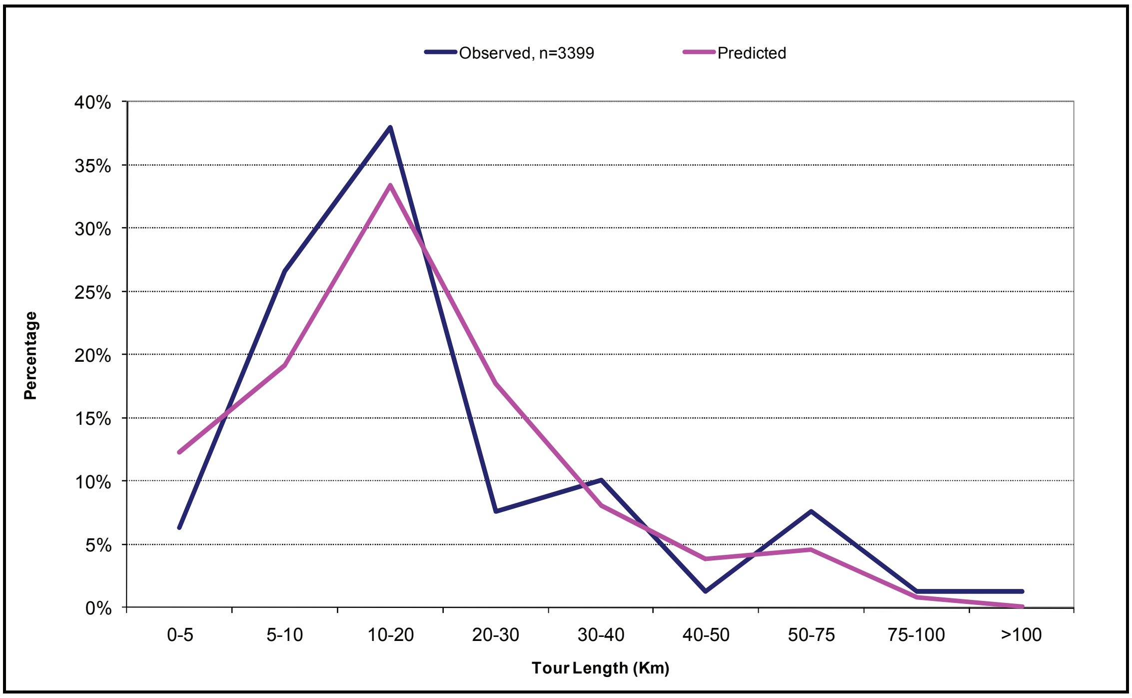
Train, Access Mode Shares by Distance, Before Modification



Train, Access Mode Shares by Distance, After Modification

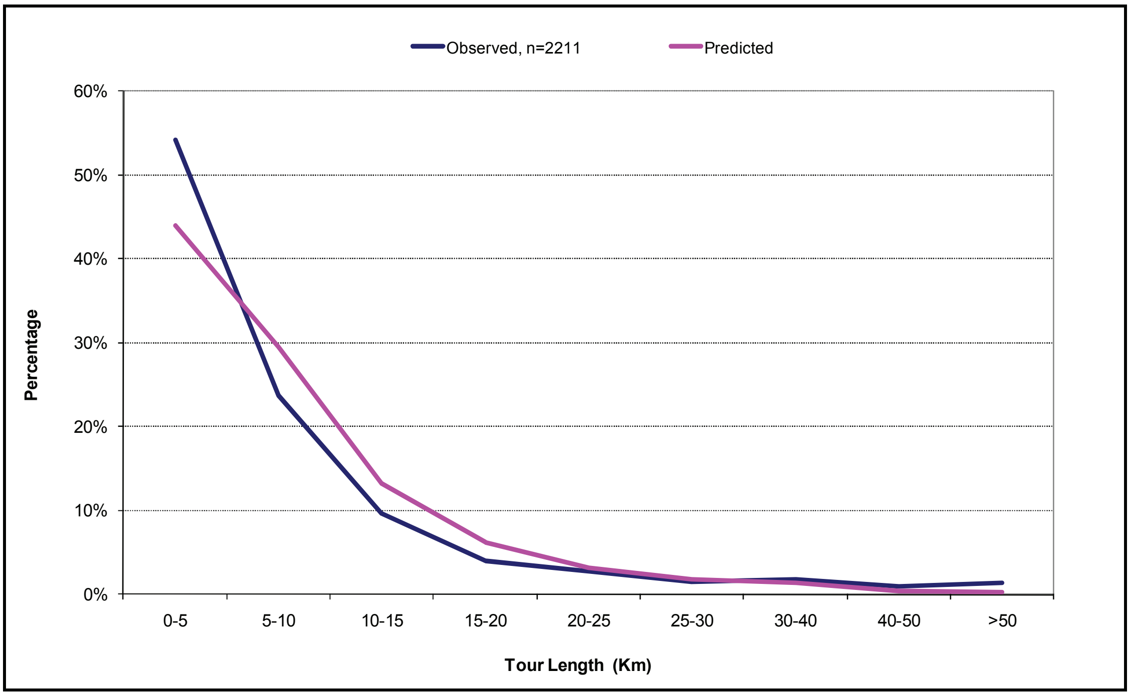


Bus

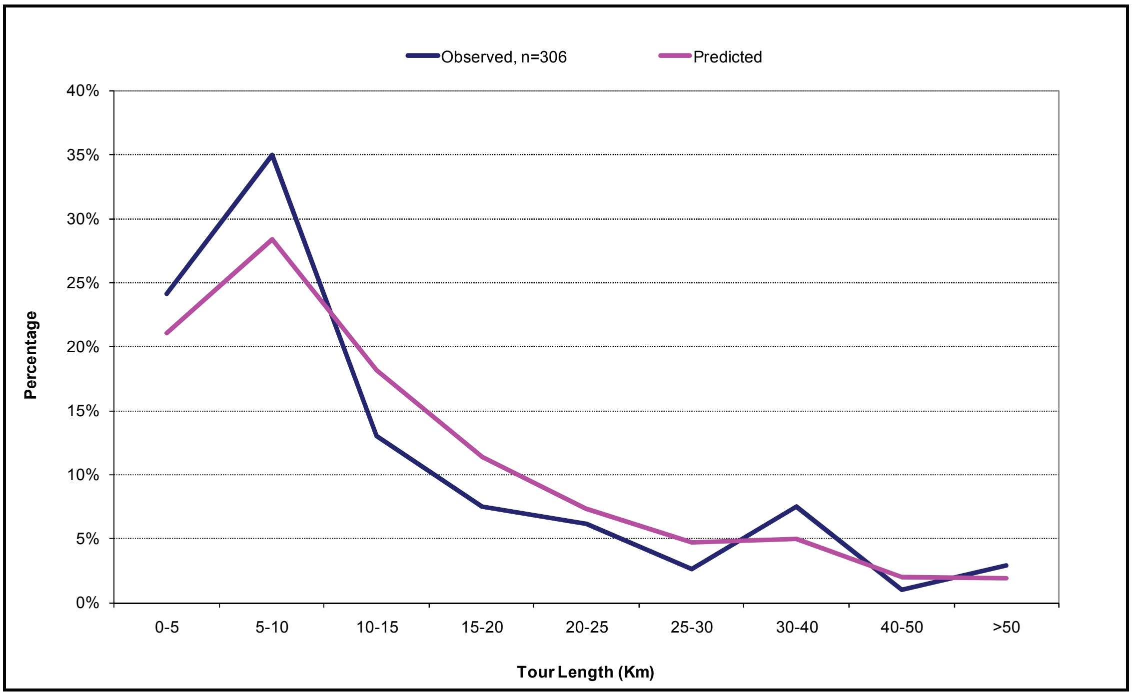


Primary Education

Car modes (car passenger, taxi)

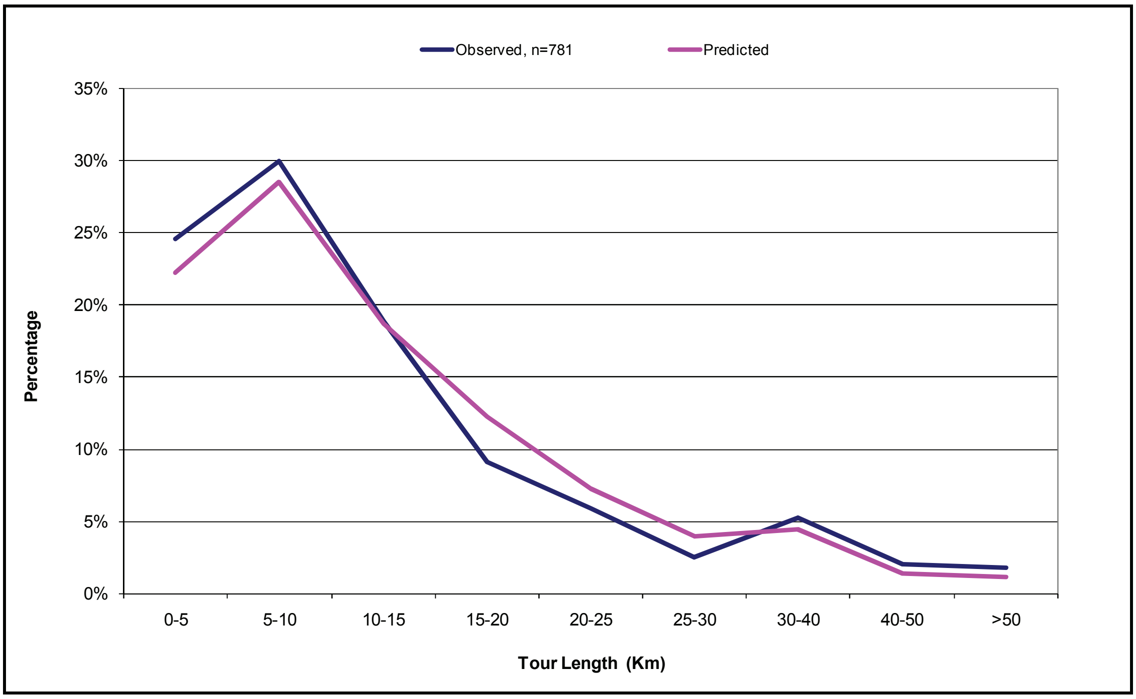


PT Modes (train, bus, school bus)

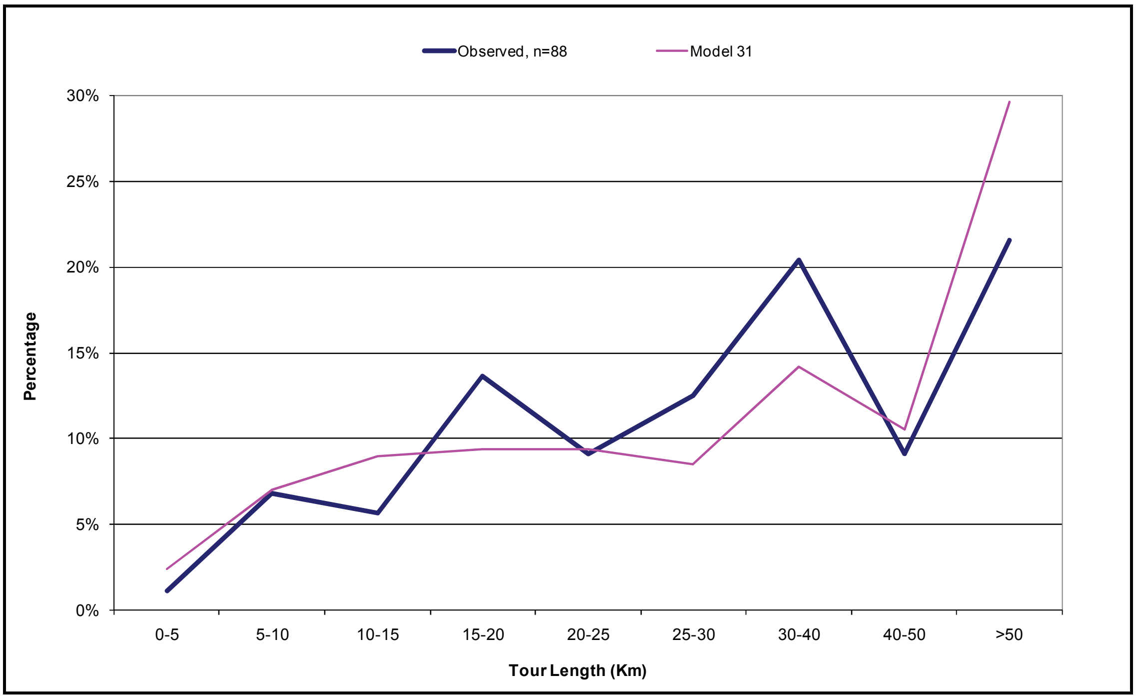


Secondary Education

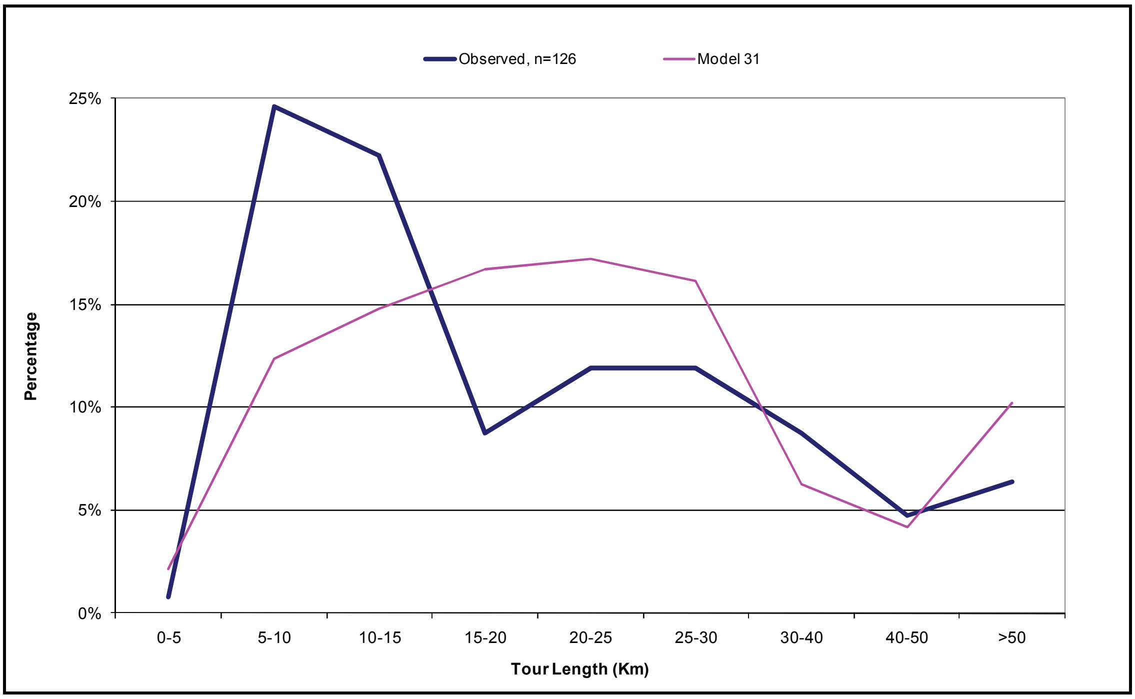
Car modes (car driver, car passenger, taxi)



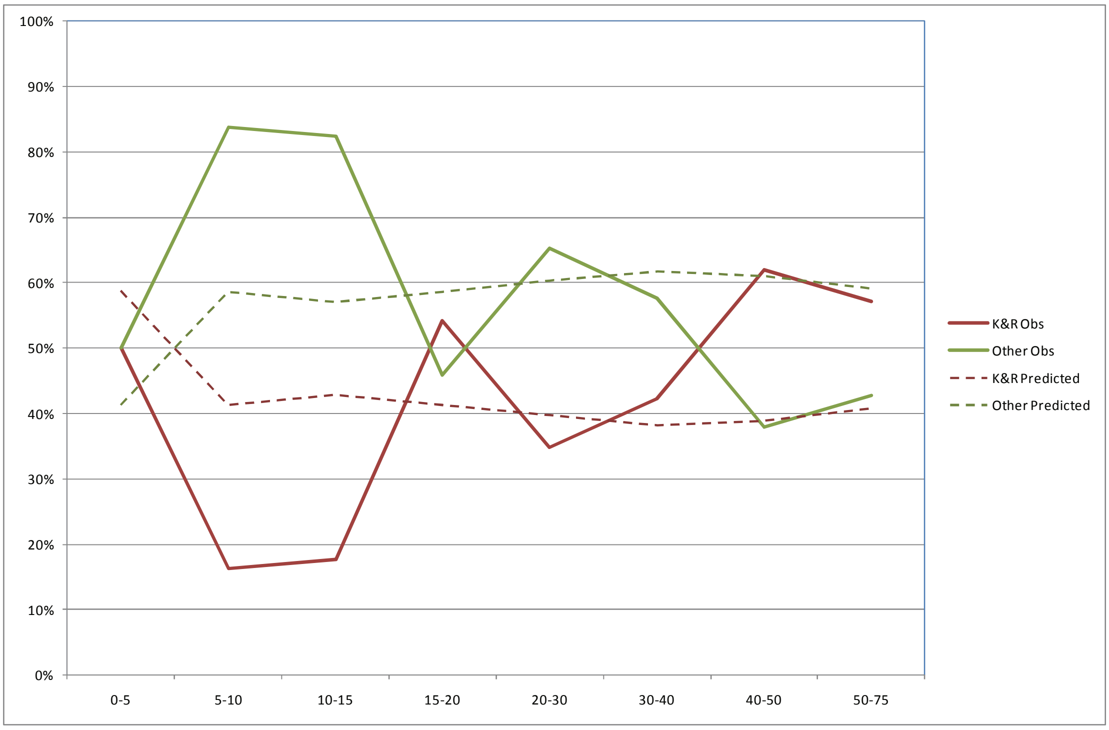
Train, Kiss-and-Ride Access



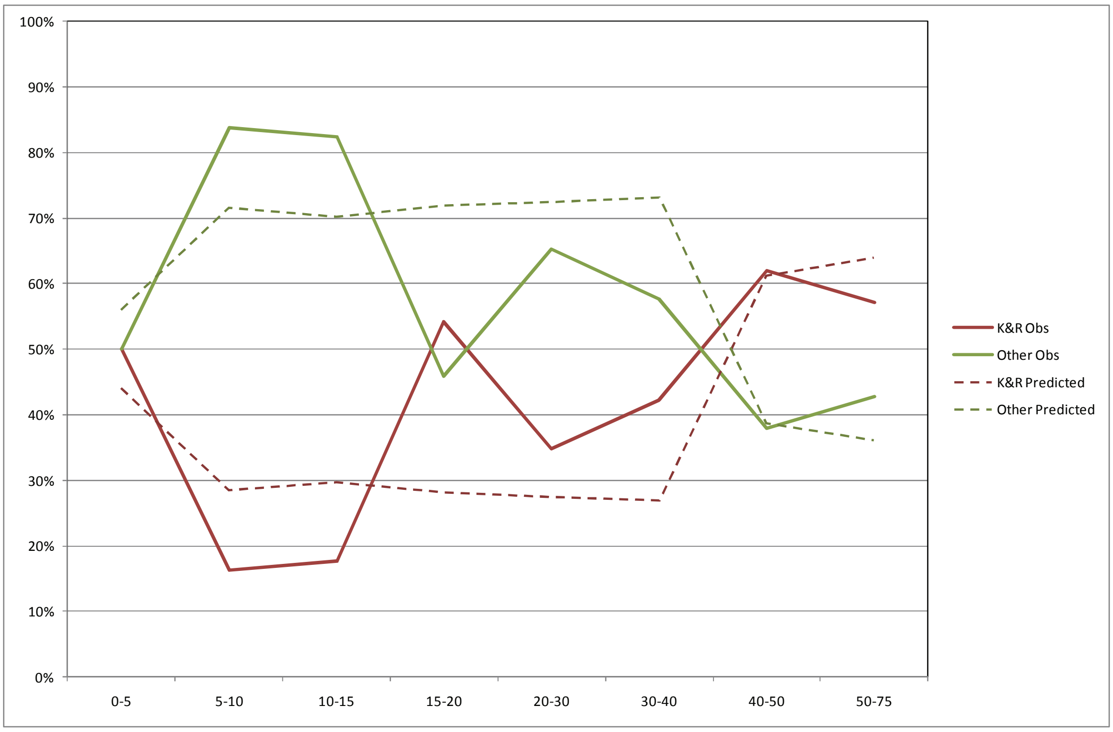
Train, Other Access



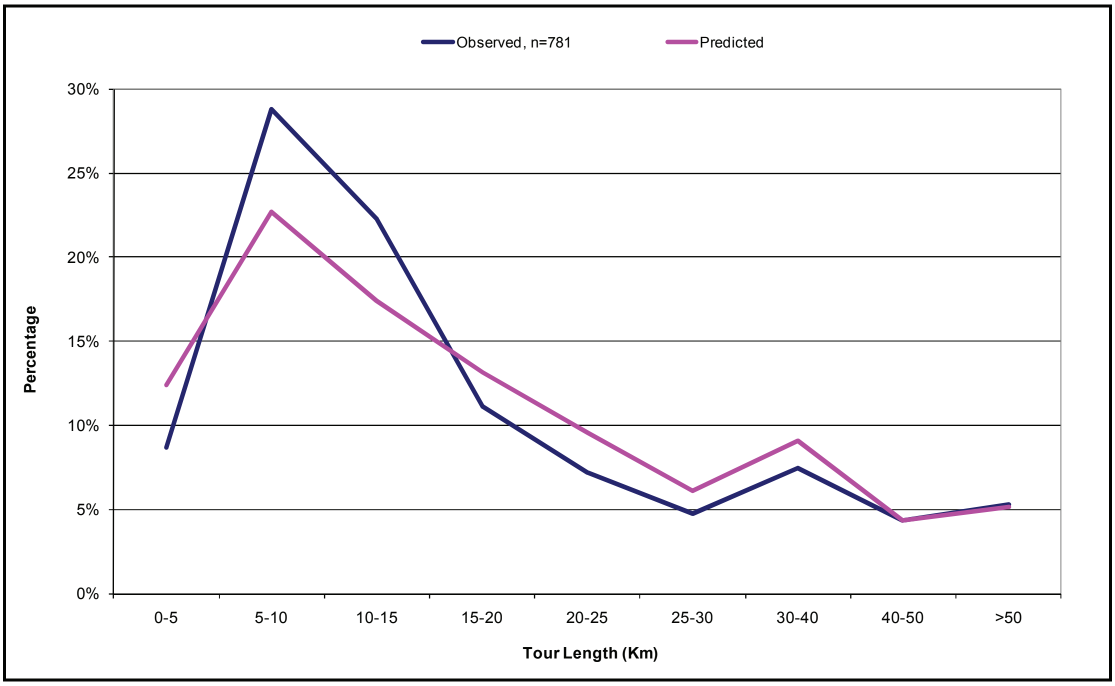
Train, Access Mode Shares by Distance, Before Modification



Train, Access Mode Shares by Distance, After Modification

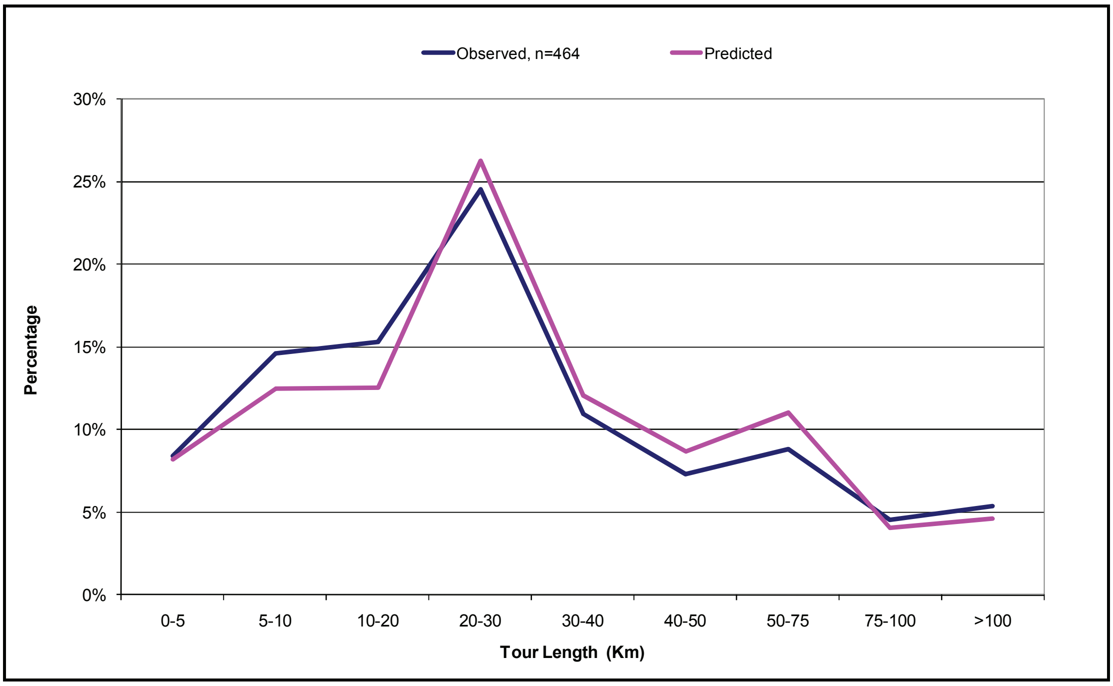


Bus and School Bus

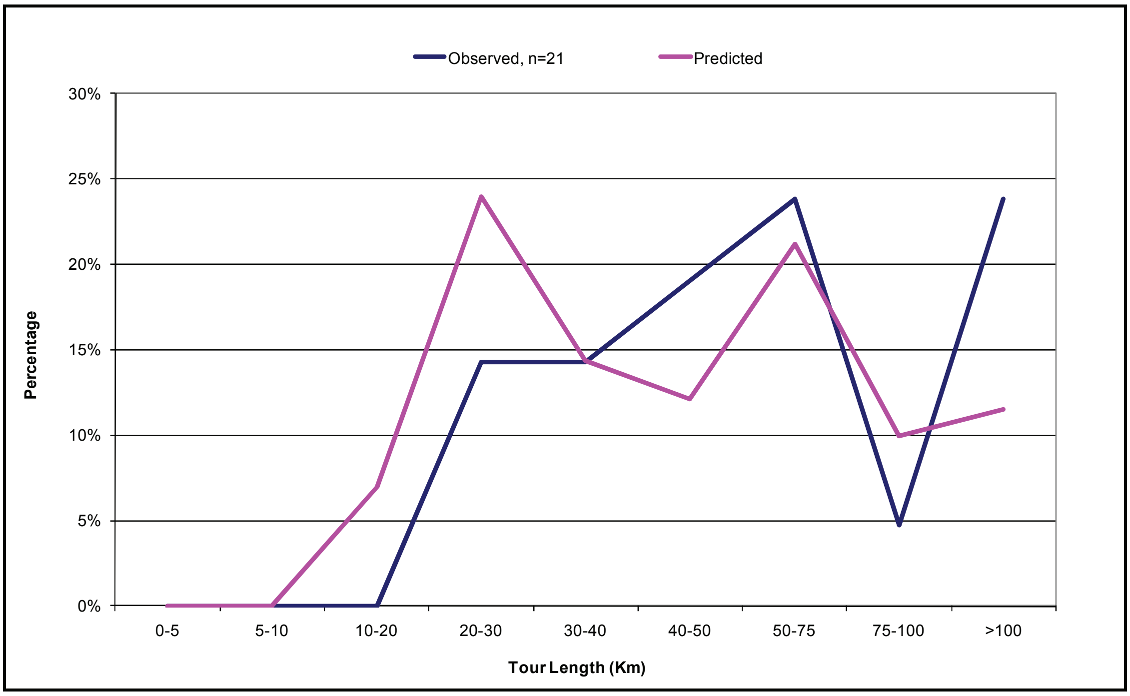


Tertiary Education

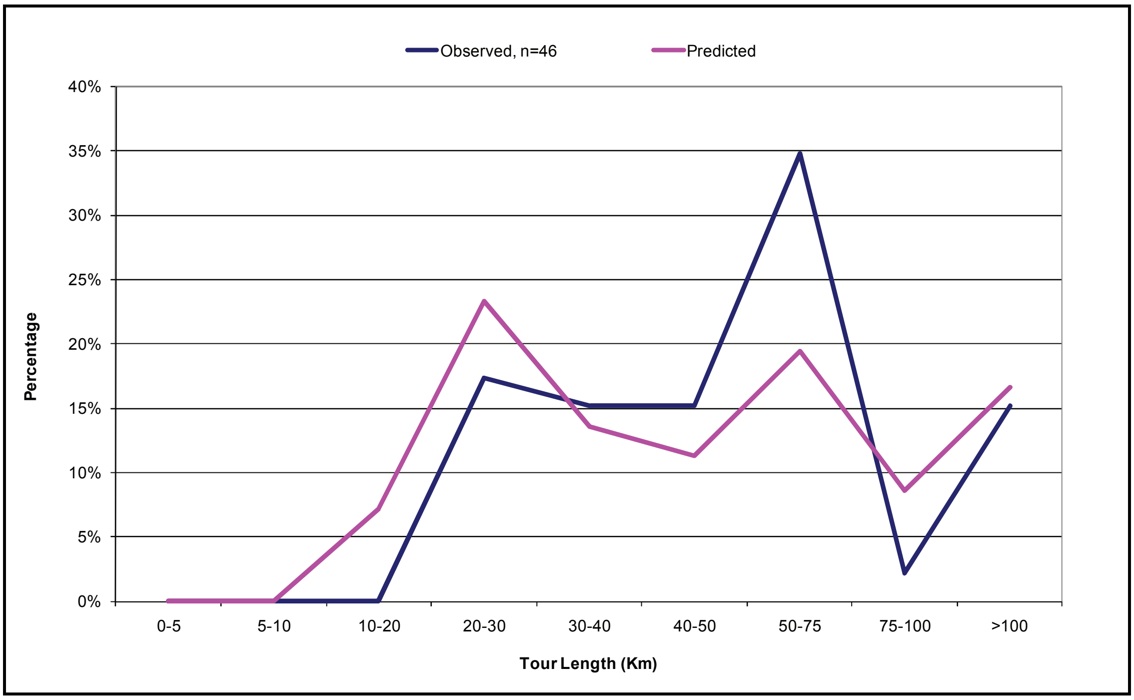
Car modes (car driver, car passenger, taxi)



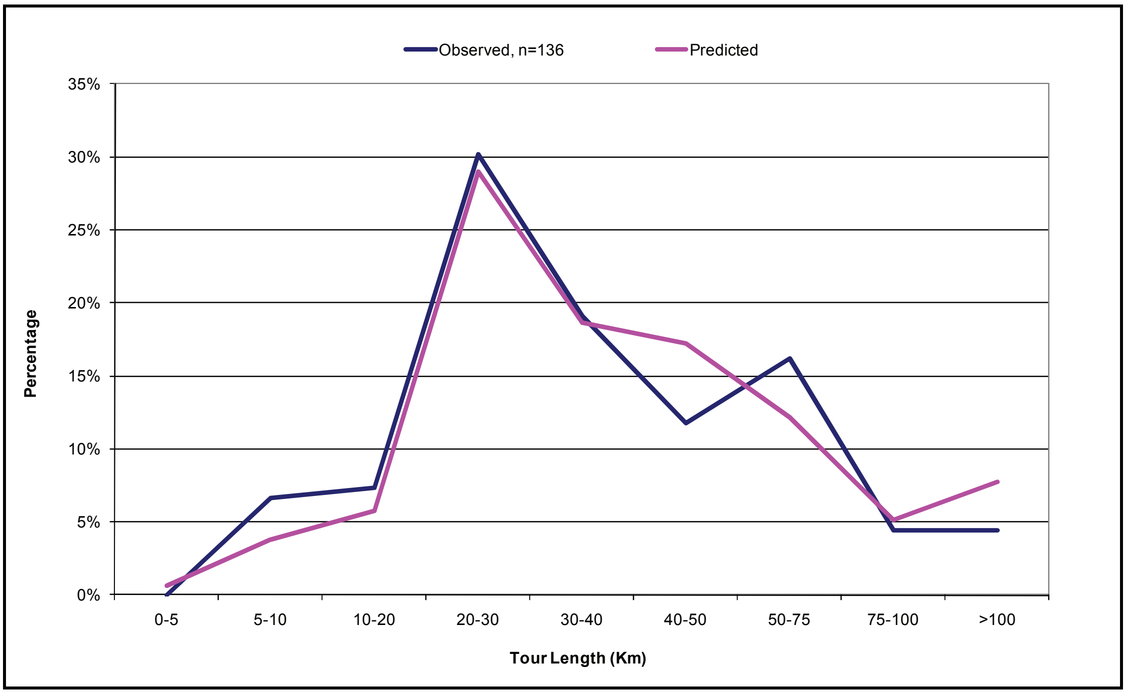
Train, Park-and-Ride Access



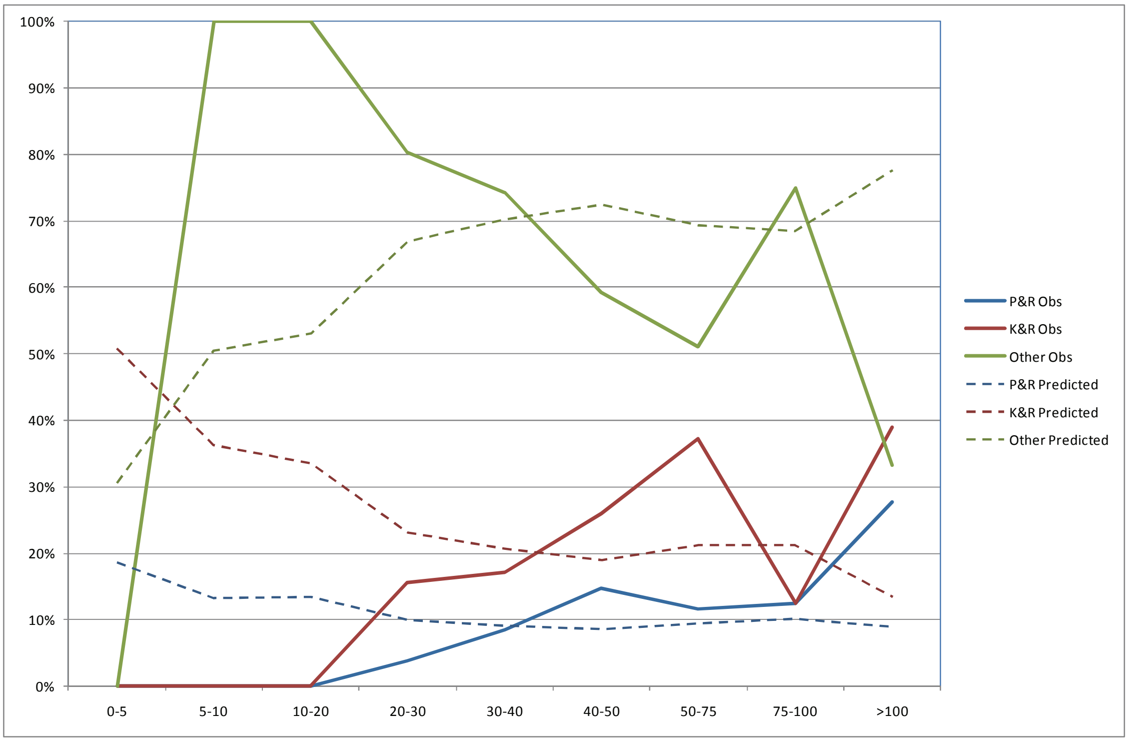
Train, Kiss-and-Ride Access



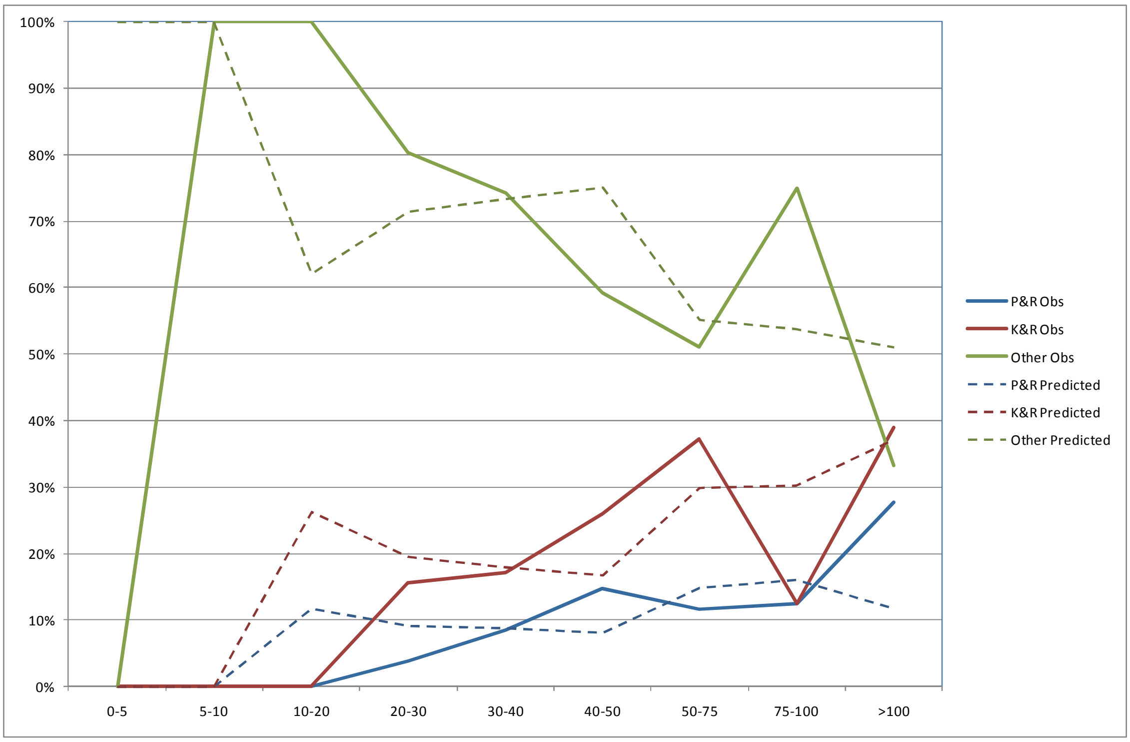
Train, Other Access



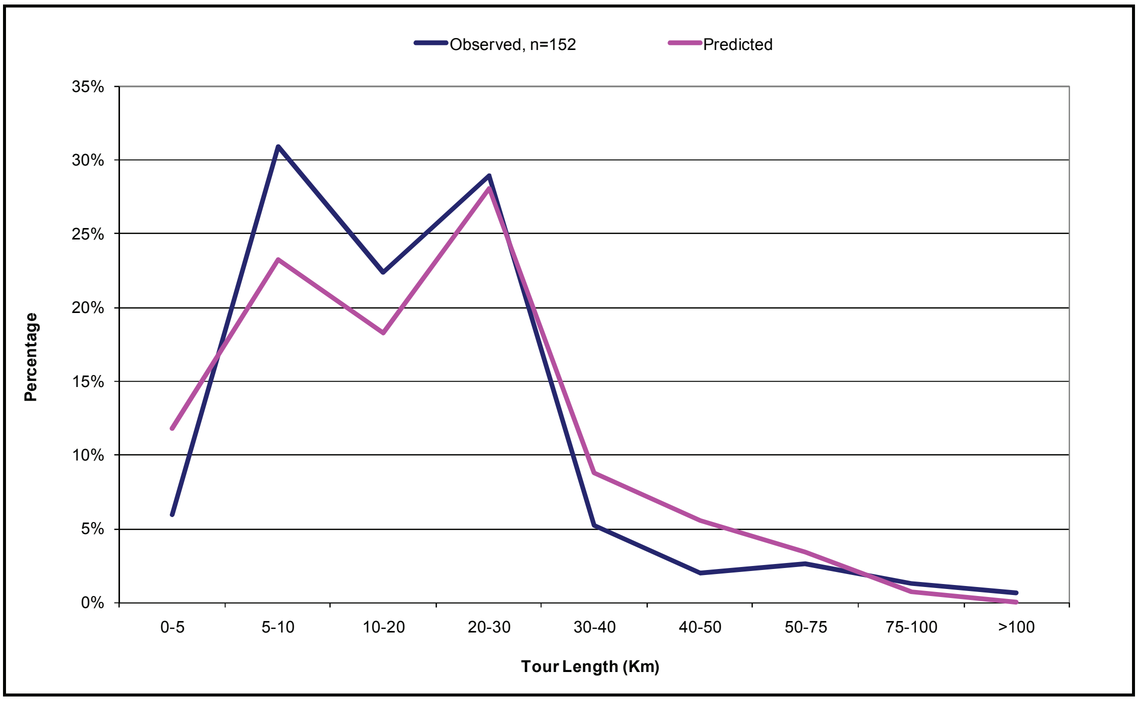
Train, Access Mode Shares by Distance, Before Modification



Train, Access Mode Shares by Distance, After Modification

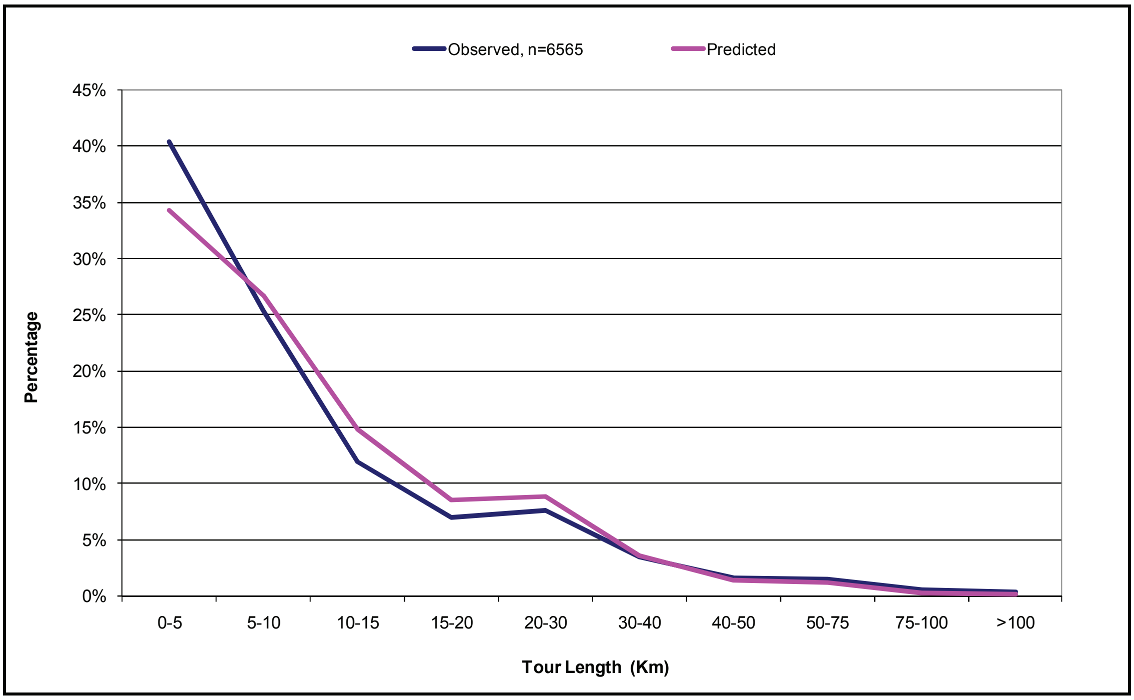


Bus

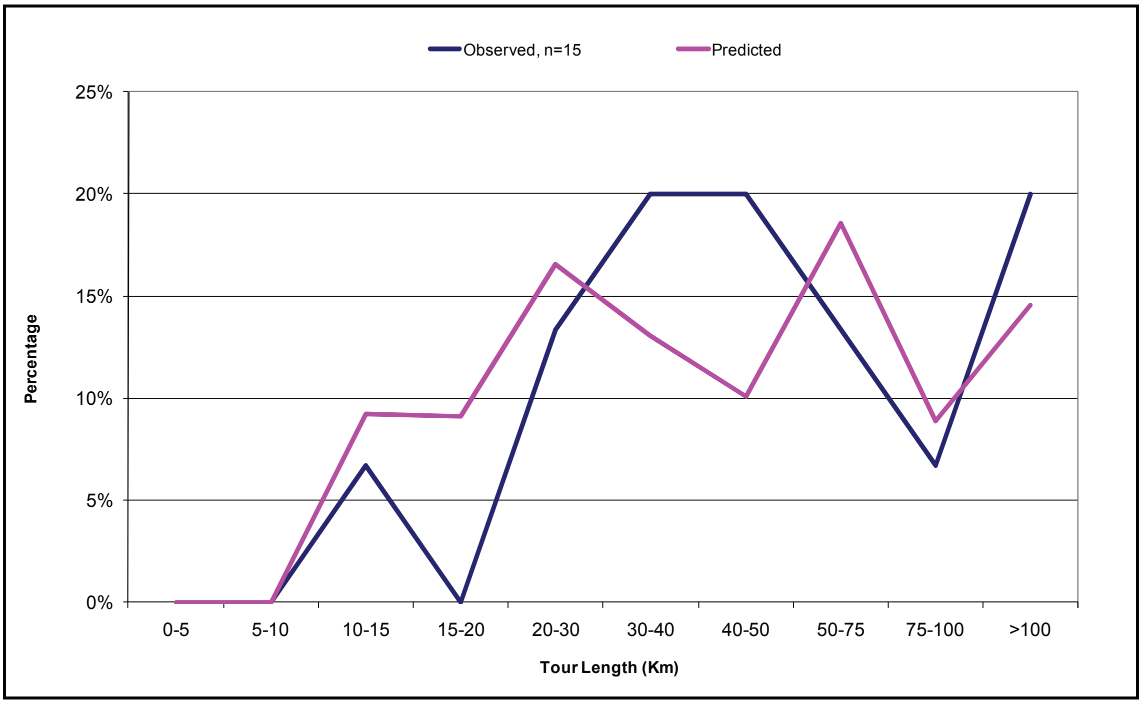


Shopping

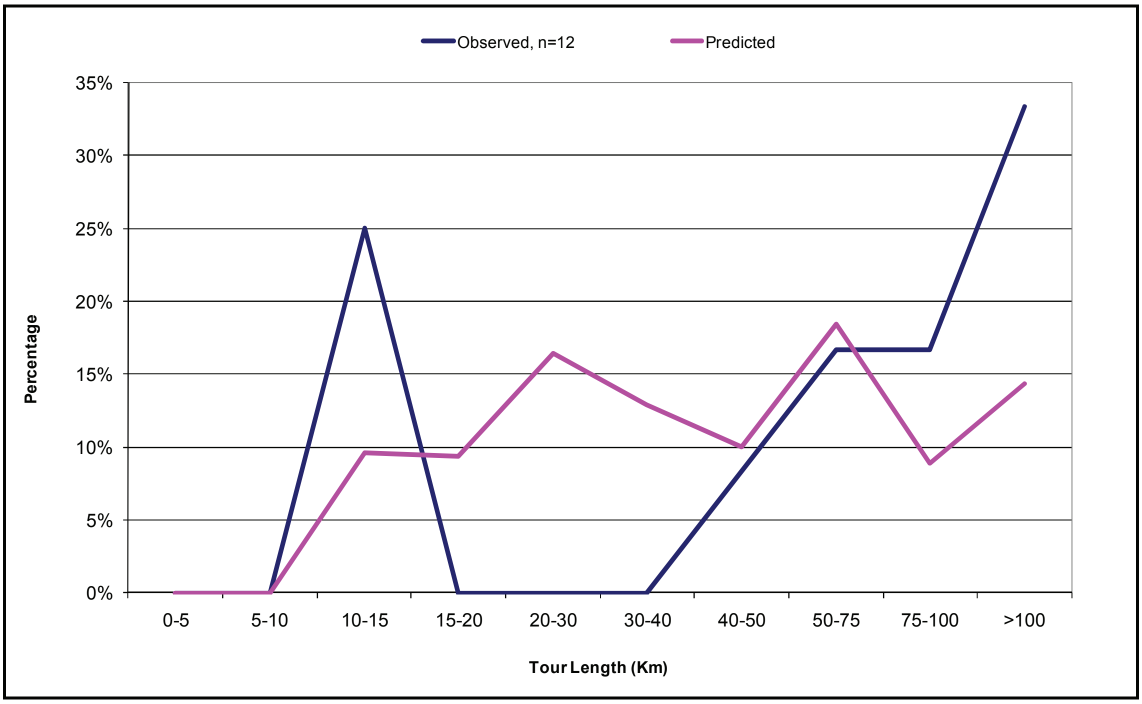
Car modes (car driver, car passenger, taxi)



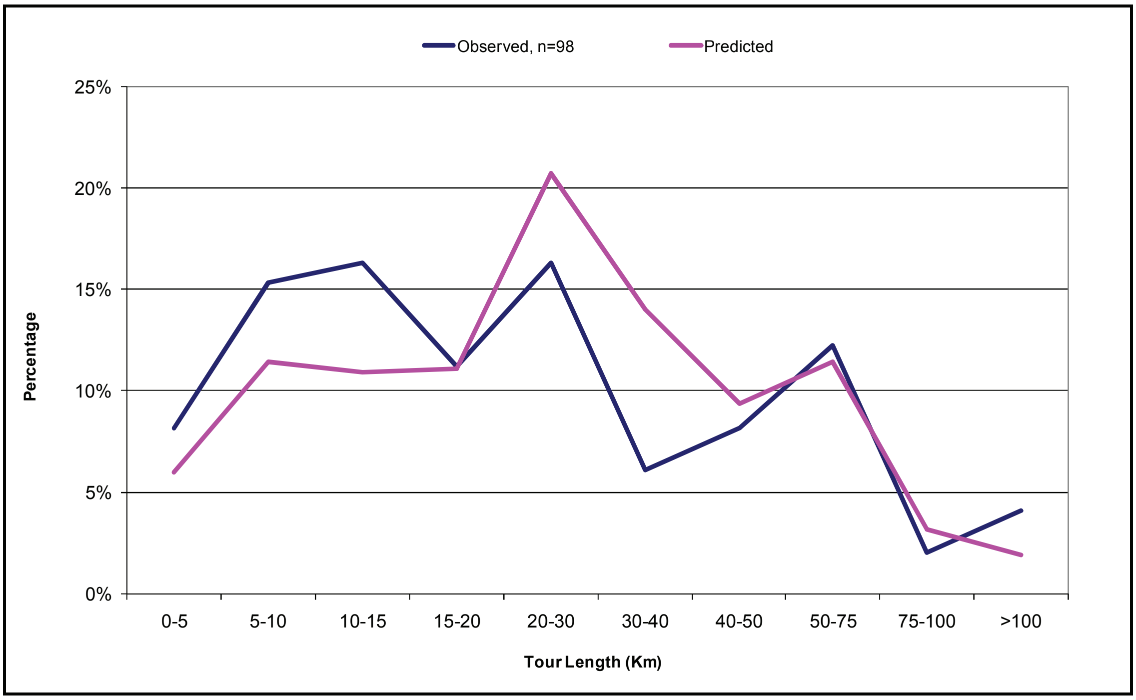
Train, Park-and-Ride Access



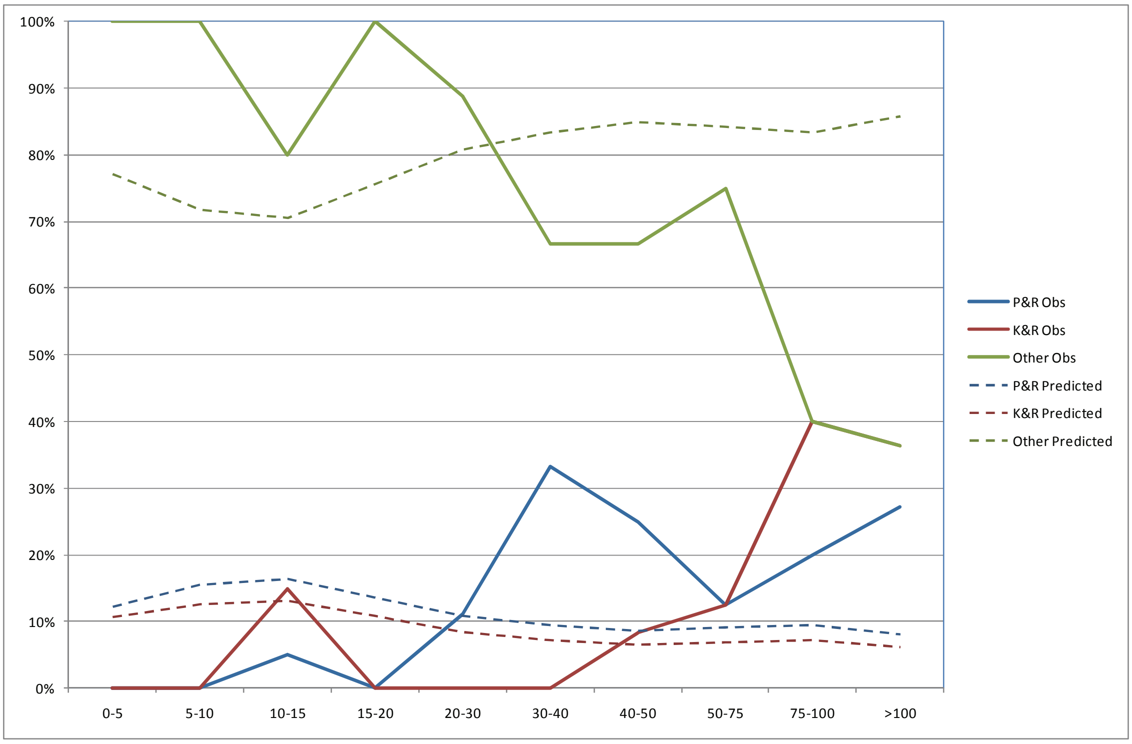
Train, Kiss-and-Ride Access



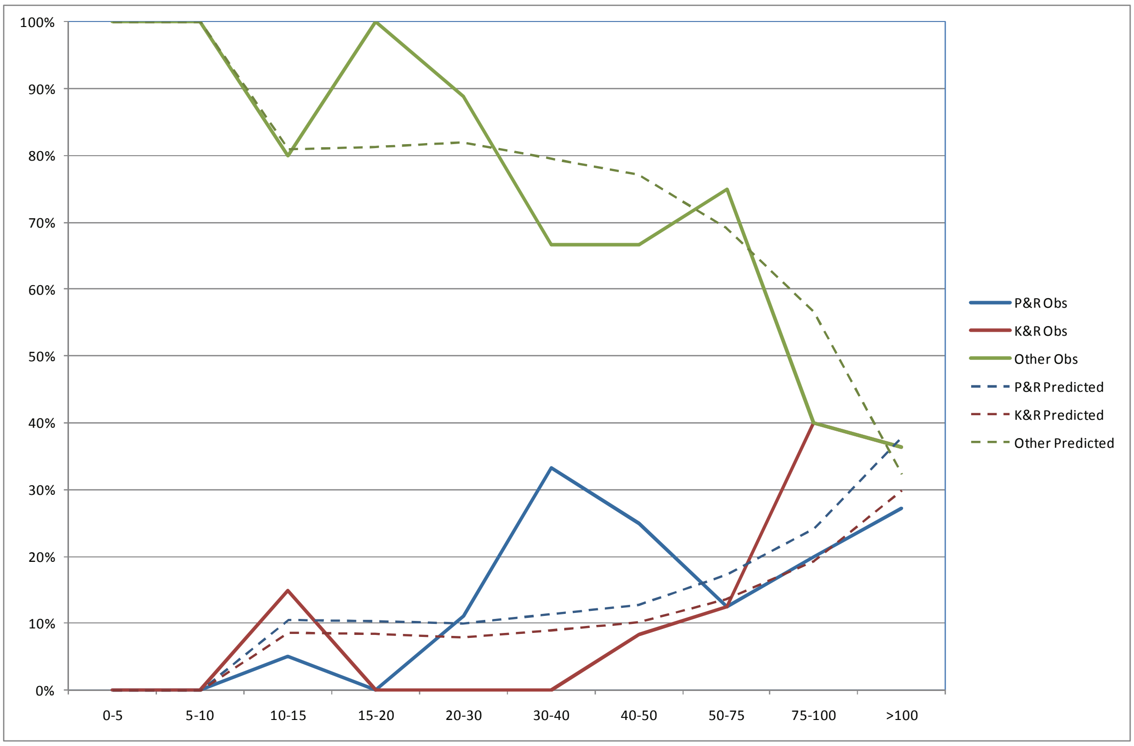
Train, Other Access



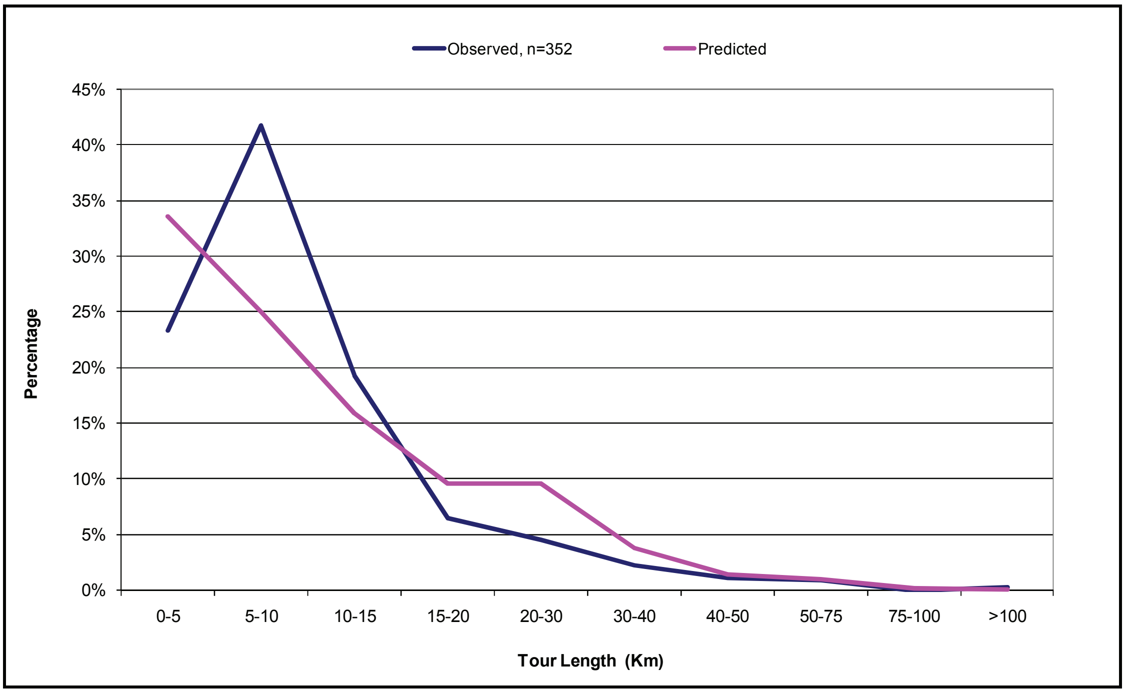
Train, Access Mode Shares by Distance, Before Modification



Train, Access Mode Shares by Distance, After Modification

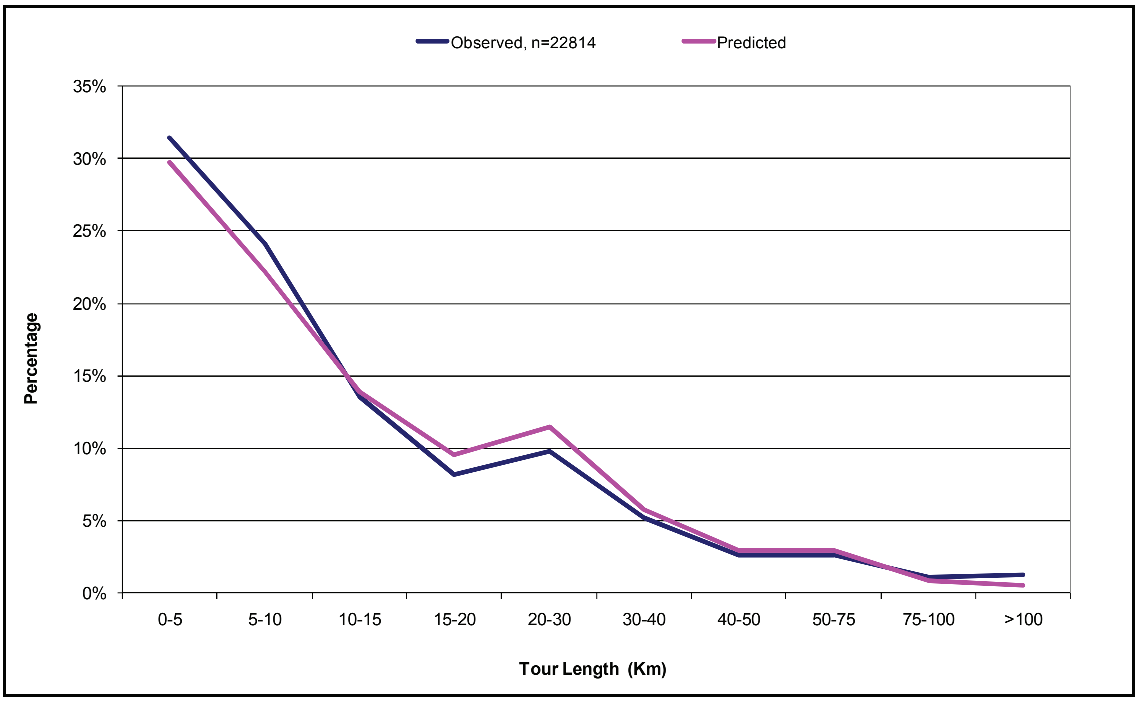


Bus

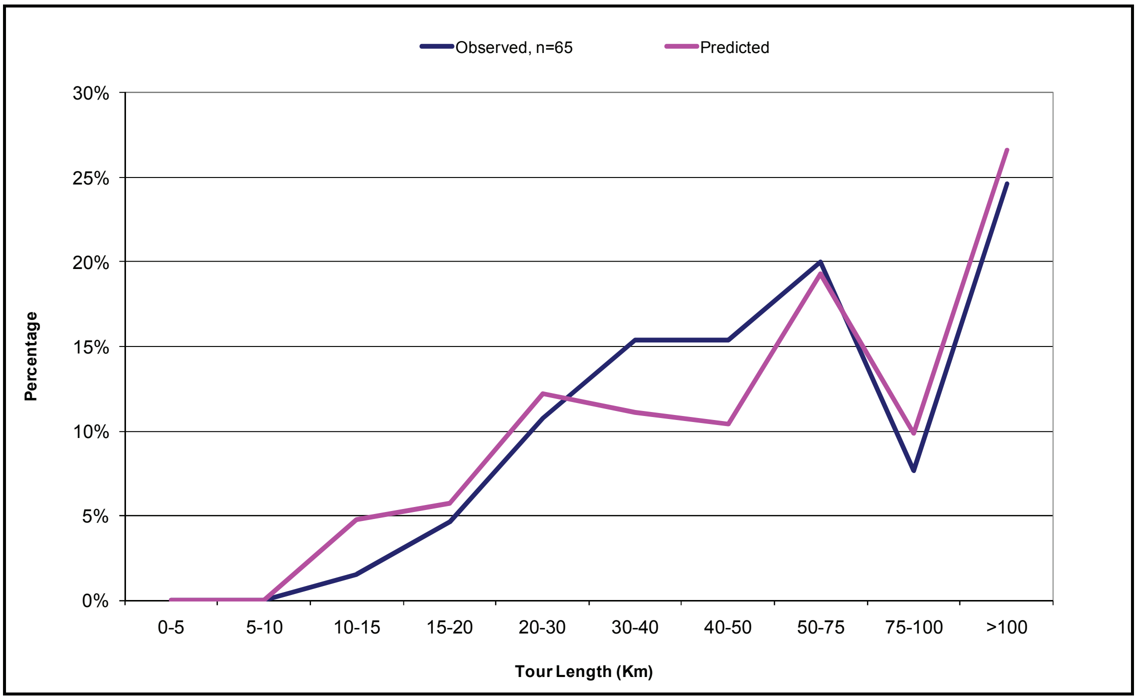


Other Travel

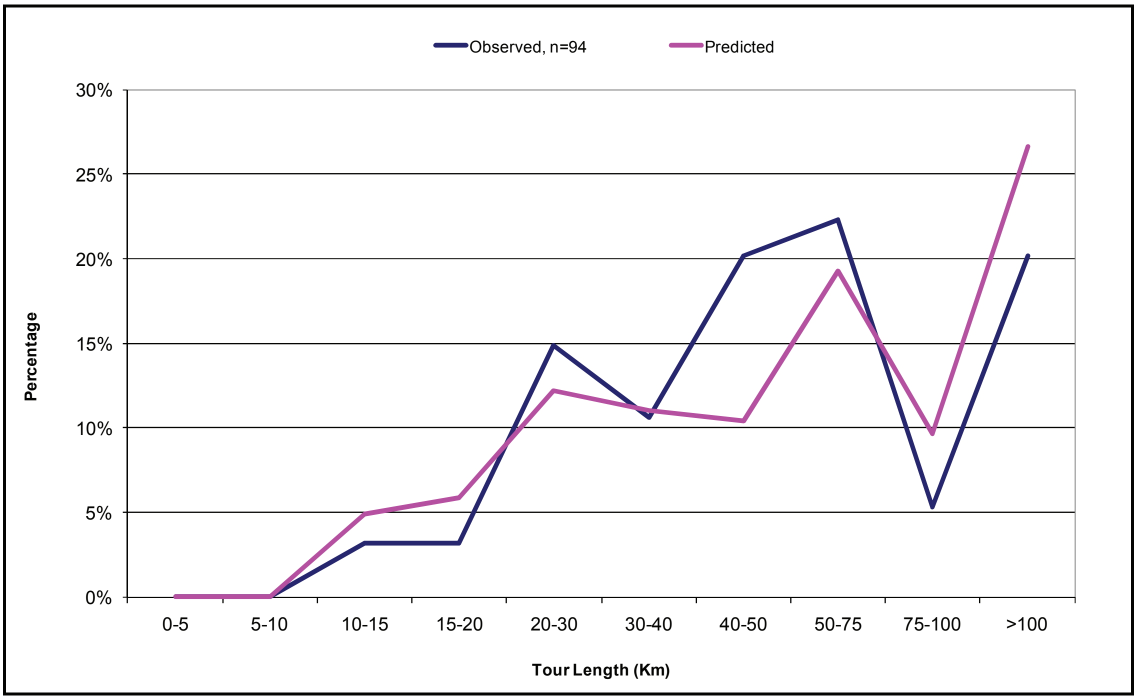
Car modes (car driver, car passenger, taxi)



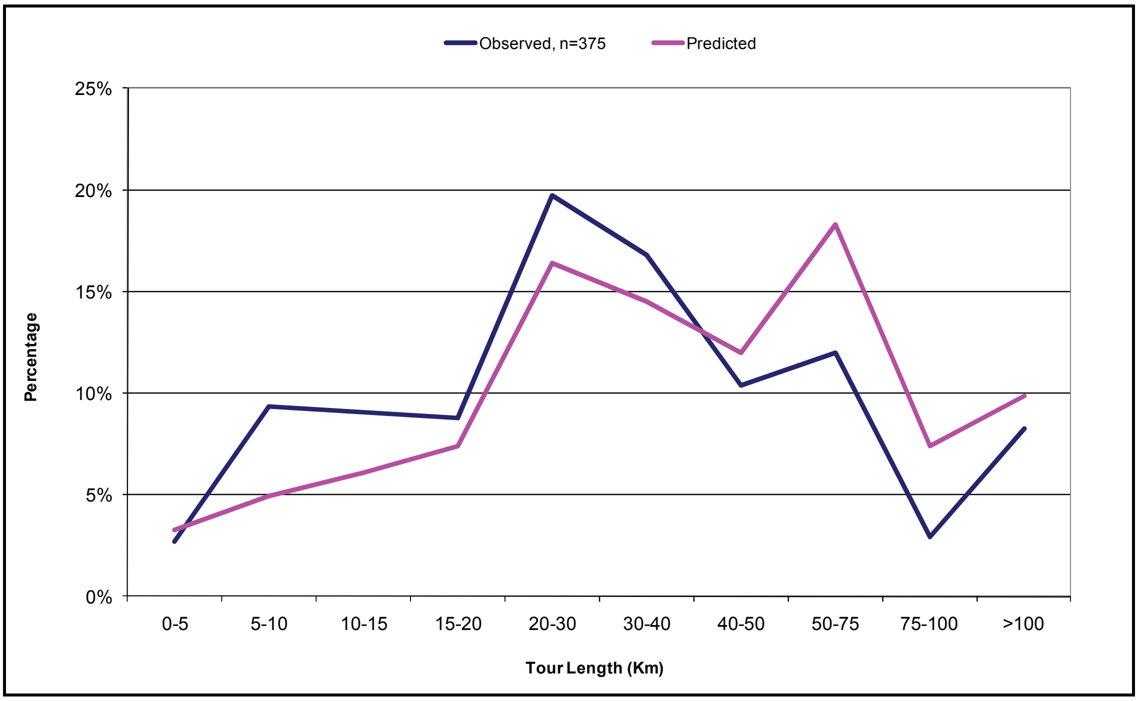
Train, Park-and-Ride Access



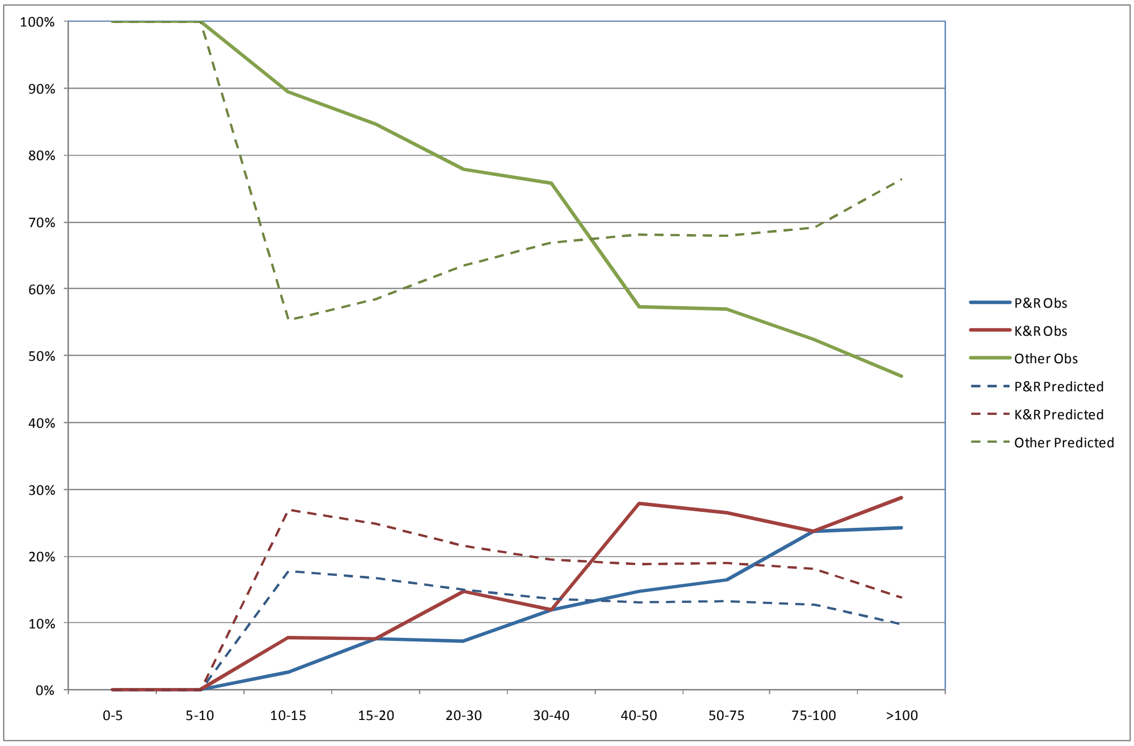
Train, Kiss-and-Ride Access



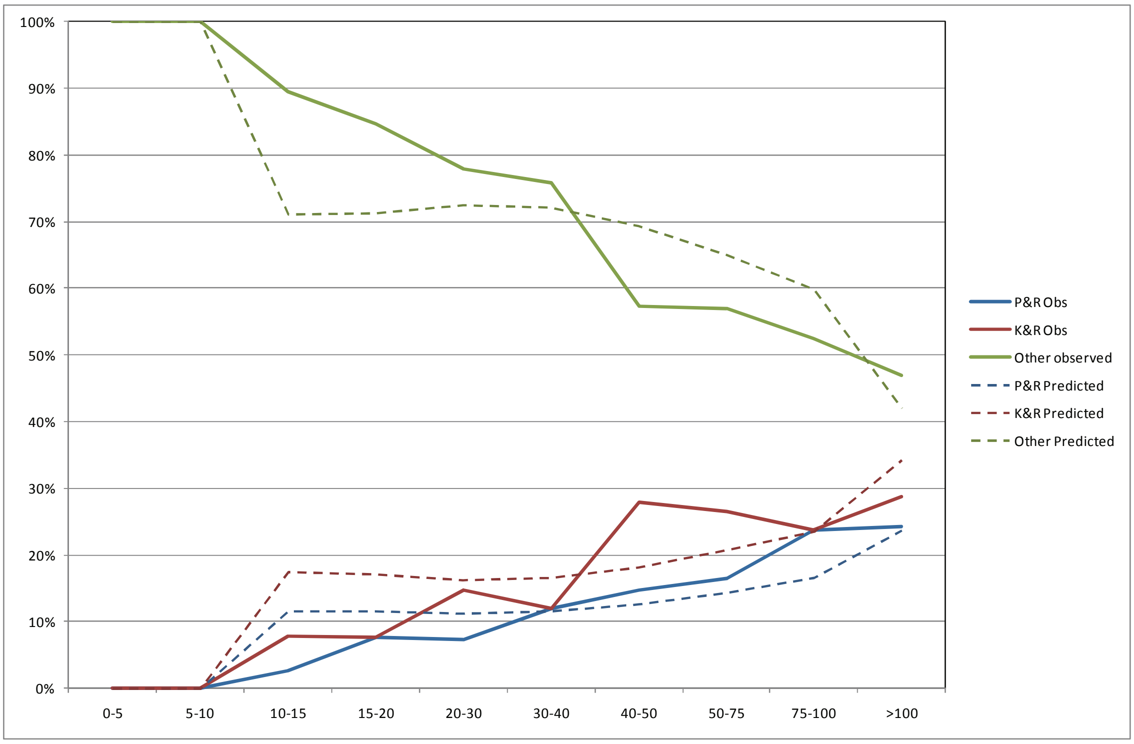
Train, Other Access



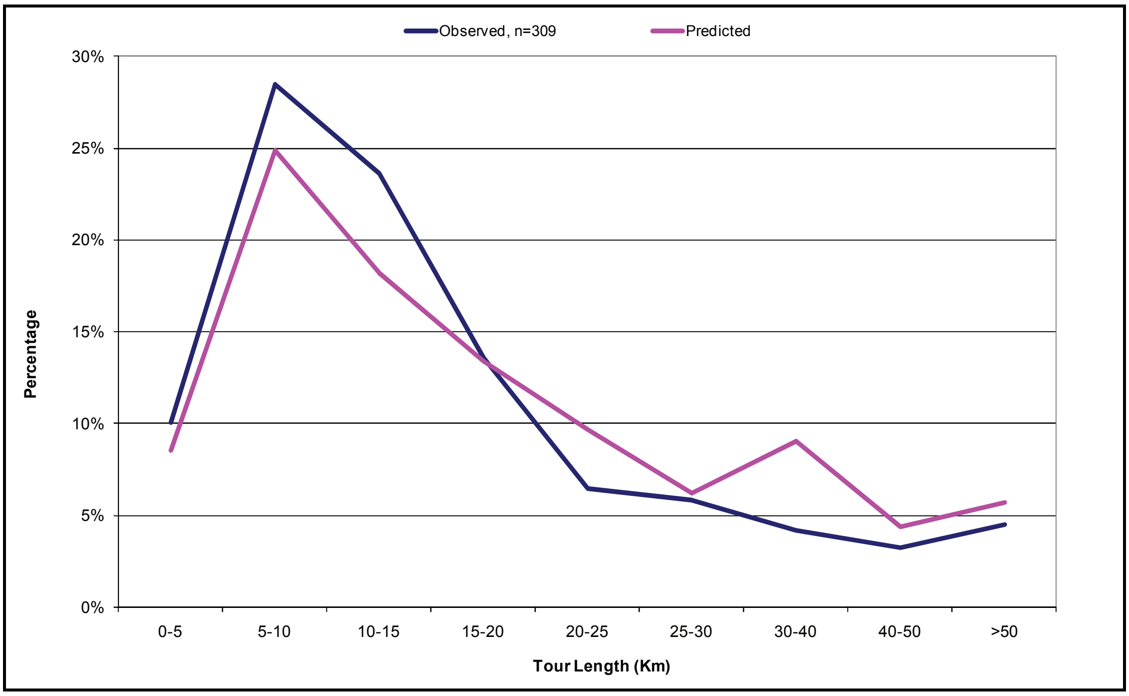
Train, Access Mode Shares by Distance, Before Modification



Train, Access Mode Shares by Distance, After Modification

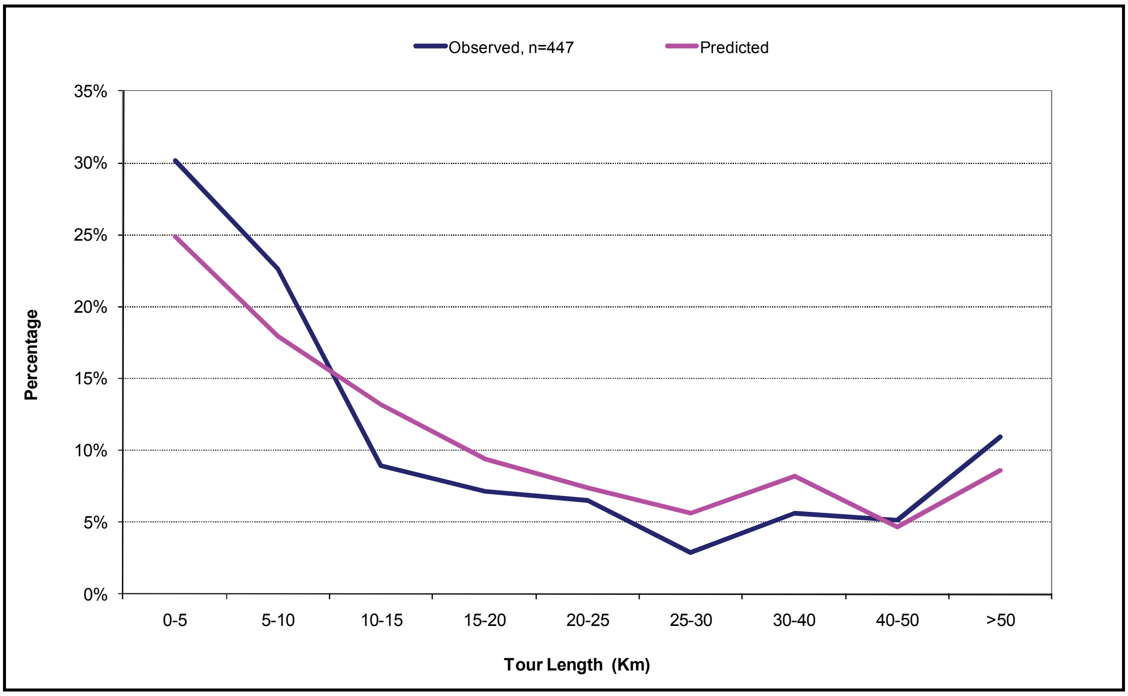


Bus

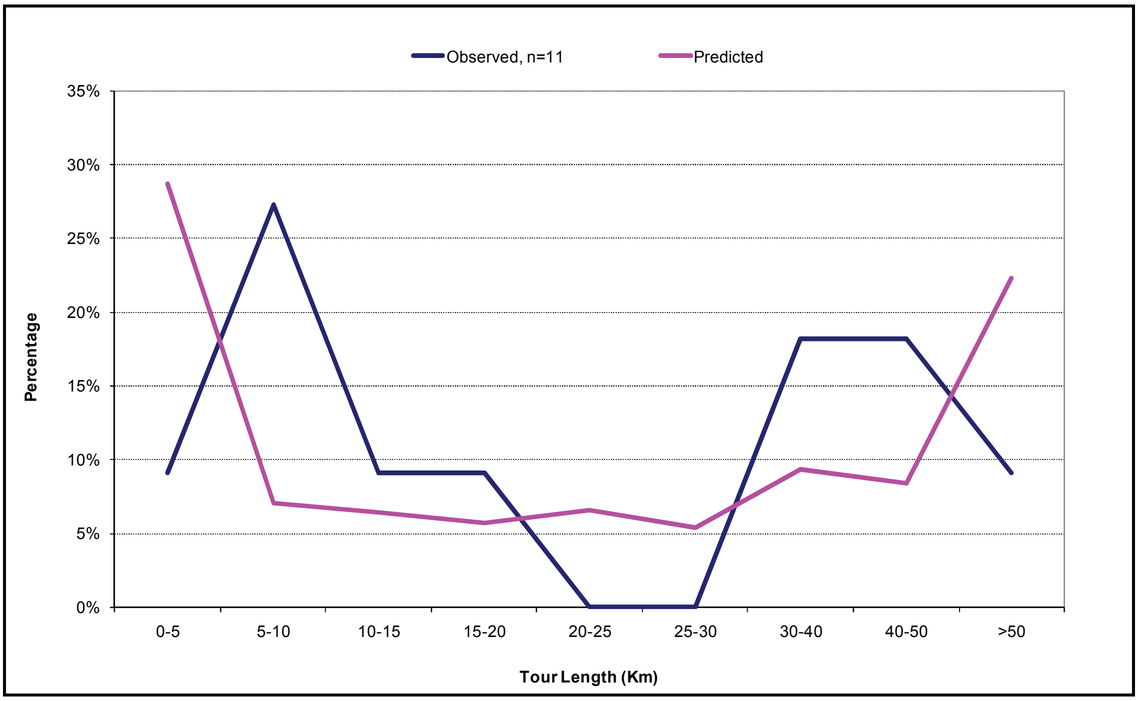


Work-Based Business

Car modes (car driver, car passenger, taxi)

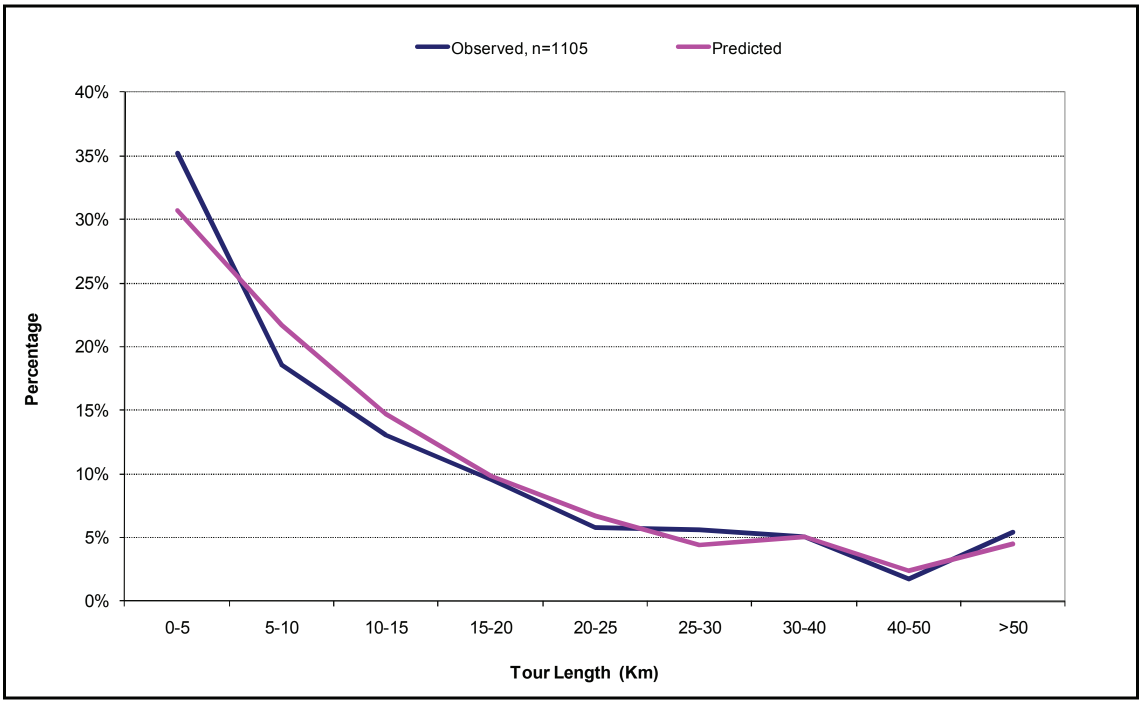


Public transport modes (train, bus)



Non-Home-Based Business Detour

Car modes (car driver, car passenger, taxi)



Public transport modes (train, bus)