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Extending the Sydney Strategic Model to represent toll road and park-and-ride choices

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Abstract

The Sydney Strategic Transport Model (STM) has recently been re-estimated using more recent household travel survey data, a more detailed zoning system, an extended geographic scope and extensions to the model scope. This paper focuses on the two key extensions to the model scope, both of which involved adding additional choice decisions to the mode destination model structure.

First, the choice to travel by tolled or untolled routes was modelled as a nest beneath car driver, with separate alternatives for tolled and untolled routes. Separate assignments were made to provide the level of service for these two alternatives, and these are discussed in the paper. A key finding from the runs was that long-distance travellers were much more likely to choose to use toll roads, even for purposes like commute where willingness to pay was segmented by income.

Second, park-and-ride was modelled by explicitly representing different access mode options to train (park-and-ride, kiss-and-ride, other), and for car access choice of station. The paper will report on specific adjustments that were made to the model in order that the observed variation in observed access mode shares with distance to stations was replicated in base year model predictions.

The paper discusses the estimation of model structure. The following choices are simultaneously represented in the nesting structure:

- main mode
- public transport mode
- train transport access mode
- train station
- destination
- toll road

1. Introduction

Sydney has been maintaining a strategic transport model capability since the early 1970s, when a model named ‘SATS’ was developed, and major model updates took place in 1986 and in 1994/95.

A key stage in the history of the current STM was the commissioning, in 1996, of Hague Consulting Group and Institute of Transport Studies to undertake a review of the Sydney Strategic Model (STM). This review set out a staged development plan for a new model.

At the same time, a new data collection strategy was adopted. In 1971, 1981 and 1991, large one-off household interviews had been collected, with at least 12,000 households interviewed in each. In 1997, a continuous Household Travel Survey (HTS) programme was instigated, with around 3,500 households surveyed per year.

Between 1999 and 2000, the first stage of the development of the new STM began, with the estimation of frequency, mode and destination choice models for home-work travel, as well as models of licence and car ownership. The models were developed at the level of decision makers, either individuals or households, and incorporated a high level of segmentation to reflect differences in sensitivities across the Sydney population. The models were estimated from a combination of 1991 and 1997-1998 data, and the base year was 1996 (see Milthorpe et al, 2000).

The second stage of model development was undertaken between 2000 and 2002, and developed frequency, mode and destination choice models for six more home-based travel purposes, as well as two non-home-based travel purposes. The models were estimated from a combination of 1991 and 1997-2000 data, and the base year was again 1996.

By 2009, the base year was 13 years old, and the model parameters were based on choice data aged 10 years and older. Therefore, it was decided to re-estimate the models so that the parameters reflect a more recent 2006 base year. At the same time, the geographic extent of the model was extended to include Newcastle to the north, and Wollongong to the south, and more detailed zones were used. As a result, the number of zones approximately tripled in number to 2670. Figure 1 overleaf illustrates the extent of the model area.

The focus of the remainder of this paper is on two extensions to the functionality of the STM, modelling toll roads and park-and-ride. Another paper being presented at this conference describes how car ownership is forecast in the new STM (Tsang *et al.*, 2011).

By 2007 there were eight independent toll roads operating in Sydney (Evans & Peck 2009). Thus, there is a need for the STM to be able to predict demand for new and existing tolled crossings at different toll levels, and assess the impact of toll roads on non-toll roads, and on other modes of travel. To address this need, a toll road choice model was developed. Previously the STM had used a single alternative for car driver which might or might not have included toll road(s).

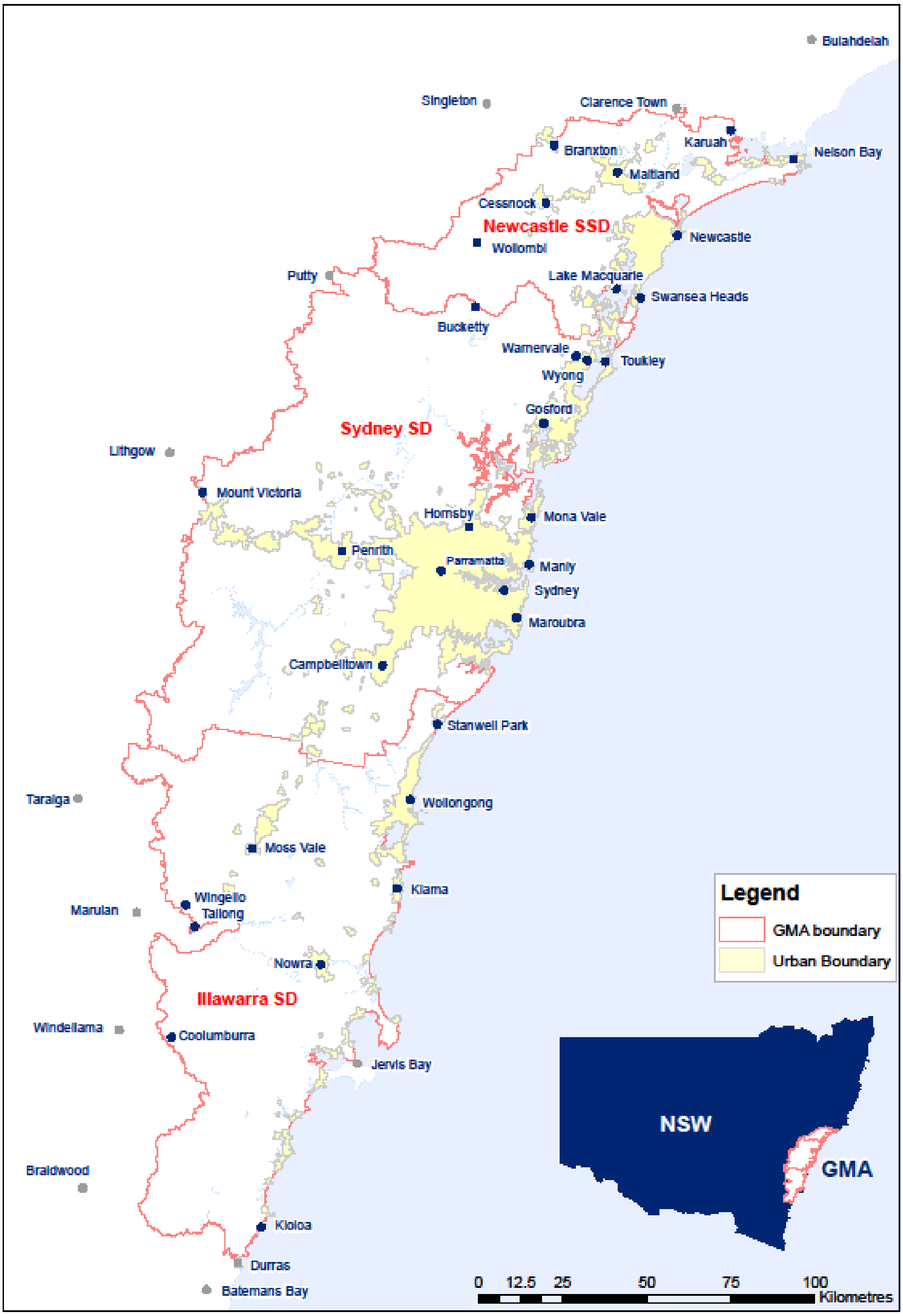
The version of the STM developed between 1999 and 2002 modelled train using an Emme network that represented access and egress to train by walk and bus. However, access to rail stations by car, including park-and-ride, is important, particularly in more suburban areas. Furthermore, there is a need to predict demand for new train services, such as the North West Rail Link, and in order to predict demand accurately account needs to be taken of passengers who access train services by car. Therefore, a new treatment of train access mode and station choice was developed.

The addition of toll road, train access mode and train station choices into the model resulted in a complex choice structure. The paper discusses lessons from the estimations of the choice structures, and summarises the choice structures for the most important journey purposes.

Previous models of toll choice have been presented in the literature. Olszewski and Xie (2005), Deghani *et al.* (2007) and Yan *et al.* (2002) present model systems. However, the present model differs from those in that a full set of traveller responses is included in the model (including, for example, destination choice), while the choice of the toll road is modelled stochastically rather than deterministically as part of the assignment. The modelling of park-and-ride does not appear to have been covered in this way in the literature; the paper by Li *et al.* (2007) presents coverage of some of the elements we report here, but not in the context of a strategic model and our own work (Cohn *et al.*, 1996, and Fox, 2009) seems to give the only comparable models.

The remainder of this paper is structured as follows. Section 2 of the paper discusses how toll road choice was added into the model structure, and summarises the key findings from the toll road choice models. Section 3 describes the models of train access mode and station choice, describing how the modelling approach builds on recent work in the UK, and setting out the key results from the access mode and station choice components. Section 4 describes the structural tests that were undertaken, and presents a figure summarising the key model structure. Finally, Section 5 presents a summary and sets out recommendations for further work.

Figure 1: Model study area



Note: prior to the extension in geographical coverage in this work, the STM study area covered the Sydney SD only.

2. Toll road choice

2.1 Modelling approach

The issue of choice between tolled and untolled highways has been studied in Australia, Europe and the US for some time. The issue for travellers is whether to pay the toll, in return for which they could expect improved travel time and perhaps improved reliability, ride comfort, way-finding and possibly other benefits. For modellers, the facilities of large-scale assignments mean that tolls and travel times can be predicted reasonably accurately but that other aspects of the choice usually cannot be modelled at all and at best a constant can be used to summarise them.

When the choice of tolled roads is modelled in an assignment, the use of a constant is unwelcome. A further problem when modelling this choice in an assignment is that the toll has to be converted to time units using a single value of time (for each user group) which means that the choice becomes ‘lumpy’, i.e. there is a tendency for all travellers to use the toll road or all not to use it. In the Sydney context assignments with a single user group, applying a value of time about twice the usual average value, can give reasonable results. The increased value of time can be seen as compensating for the omission of other variables favouring the choice of the toll road, but the choice of the precise value of time to be used is arbitrary and could be context-specific. Moreover, the ‘lumpy’ choice is undesirable.

Therefore the option adopted for the STM was to model the choice of toll roads as a probabilistic choice. The advantages of this approach are that it gives a smoothly varying choice fraction while also allowing a constant (toll road ‘bonus’) to be incorporated in the model, as well as allowing variation in cost sensitivity with income, distance and journey purpose. The disadvantages with this approach are that it requires separate user types to be defined in the assignment for those choosing and not choosing the toll road and that the sensitivity of the choice has to be calibrated (along with the constant). However, in the context of the Sydney STM, the assignments could be carried out reasonably conveniently, and furthermore the HTS data that formed the choice dataset for model estimation provided information on the choice of toll road.

The toll road choice is represented as a sub-mode choice for car driver between toll and no toll alternatives. The utilities of the toll and no toll options are defined as follows, noting that the model parameters estimated are specific to a particular journey purpose and the cost parameters specific to an income group:

$$\begin{aligned} U(Toll) = {} & \beta_{TollBonus} + \beta_{TT} TT_{Toll} + \beta_{Cost}(CC_{Toll} + Toll) \\ & + \beta_{LogCost} \log(CC_{Toll} + Toll) \end{aligned} \tag{2.1}$$

$$U(NoToll) = \beta_{TT} TT_{NoToll} + \beta_{Cost} CC_{NoToll} + \beta_{LogCost} \log(CC_{NoToll}) \tag{2.2}$$

where: $\beta_{TollBonus}$ is the toll road bonus term

β_{TT} is the sensitivity to travel time

TT_{Toll} and TT_{NoToll} are the travel times by toll and no toll alternatives

β_{Cost} and $\beta_{LogCost}$ are the sensitivities to cost represented in linear and log forms

CC_{Toll} and CC_{NoToll} are the car costs for toll and no toll alternatives

(fuel, other vehicle operating costs and parking costs at the destination)

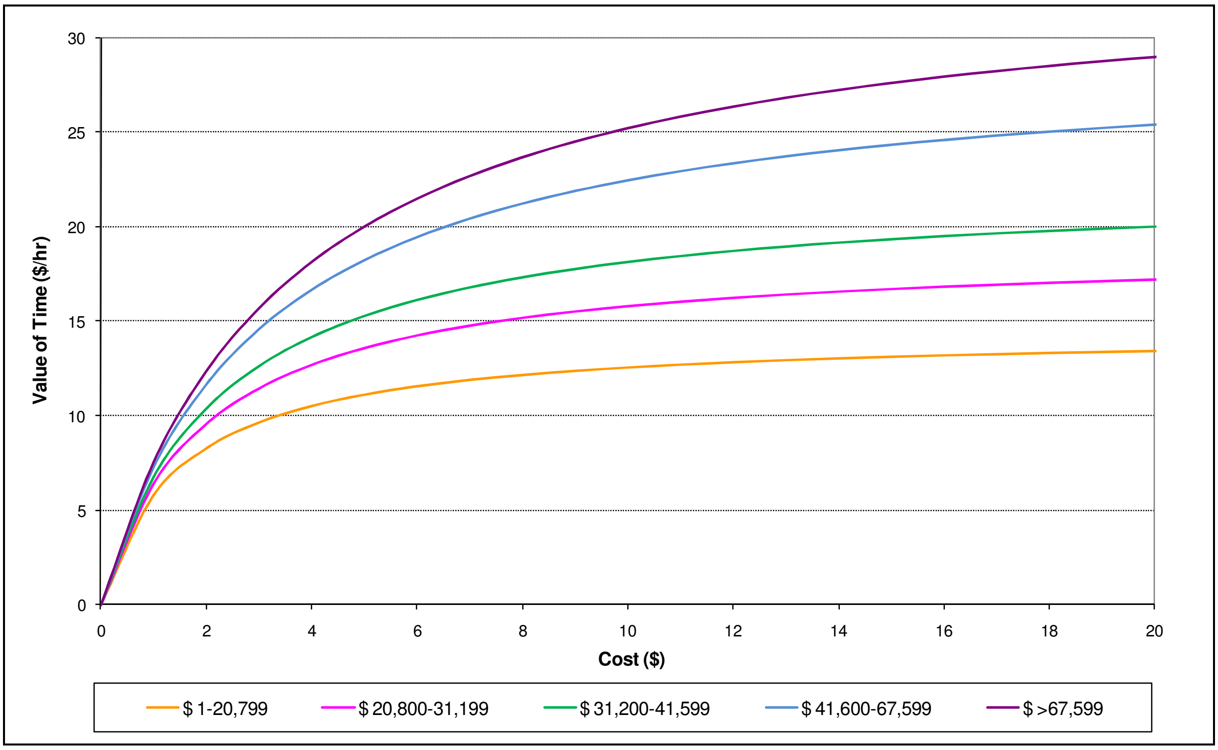
Toll is the toll cost

Representing cost in both linear and log forms means that the value of time varies with the cost of the journey, with higher values of time for more expensive (typically longer) journeys.

A full discussion the advantages of combined linear and log cost terms in terms of fit to the data and model elasticity is given in Fox *et al.* (2009).

For the commute and home-business models, the linear cost terms are also segmented by income band. Thus, for these two purposes, values of time vary both with income band and with the cost of the journey. Figure 2 plots the implied value of time for car for the commute model, noting that as per Equations (2.1) and (2.2) time enters the utility function in a linear form.

Figure 2: Commute values of car time



It is noted that for many origin-destination (OD) pairs, there is no toll road alternative, and so the toll alternative is unavailable. Thus, the toll road constant is estimated from the set of origin-destination pairs where both toll and no toll alternatives are available.

2.2 Representation in assignment

In order to estimate the probabilistic toll road choice model, it is necessary to generate two sets of assignments, one for the toll road alternatives, and the other for the no toll alternatives. The challenge for the toll assignment is to determine an appropriate value of time (VOT). If the value is too low, for some OD 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 unrealistically small amounts of time for a relatively high cost.

The starting point for the toll road assignments was a VOT of $30/hr, a value used by the New South Wales Roads and Traffic Authority (RTA) for highway assignment when using the STM road network. This value is already relatively high compared to guidance values of $11.55/hour (RTA, 2007), because RTA's experience was that high VOTs are required to get appropriate levels of demand assigned to toll road links. Table 1 shows the impact of different VOT values on toll road usage for a toll-user user class, relative to a single class assignment with sensitivity to time only.

Table 1: Toll road usage

VOT ($/hr)	Toll Road Usage	Loss of demand relative to time only
Single class assignment (sensitive to time only)	11.1 %	-
30	7.1 %	35.7 %
60	7.8 %	29.6 %
90	8.6 %	22.6 %
180	9.5 %	14.0 %
240	9.9 %	10.6 %
1,000,000	11.1 %	0.0 %

It can be seen that at a VOT of $30/hr, 36 % of demand is ‘lost’ relative to the single class assignment with no sensitivity to costs, and even at $90/hr 23 % of demand is lost. By lost we mean that as the VOT increases, demand that was previously being assigned to paths including toll roads is now assigned to routes that do not include toll routes. With an extremely high VOT of 1,000,000 $/hr, the results of the single class assignment are reproduced, so by definition the loss of demand is zero. The VOT finally used was $180/hr, which gives a balance between losing demand relative to the single class assignment, and using a VOT so high that individuals will pay a toll for a marginal time saving.

A complication when the toll road skims came to be used in the choice model was that due to multi-routing, there were instances were a toll path was selected by the assignment but used by a low percentage of the traffic. A minimum toll threshold value was used to overcome this issue.

2.3 Model results

The expectation at the outset of this work was that a positive toll road constant would be obtained, i.e. that the time savings provided by toll roads would not fully account for the cost, and that an additional positive constant would be required to explain observed levels of toll road usage. However, when test runs were made for the commute model, significant negative toll ‘bonus’ constants were identified.

Following a number of further tests, it became apparent that the negative toll road constant was associated with OD pairs that are rarely chosen, often short distance OD pairs, whereas toll roads were much more likely to be chosen for long distance tours. This result is illustrated in Table 2, which shows tour distances (i.e. outward and return legs combined).

Table 2: Toll road mean tour distances (km)

Purpose	Toll available and chosen	Toll available but not chosen	No toll alternative available
Commute	66.1	51.4	26.6
Business	90.2	70.0	32.4

It can be seen from Table 2 that when toll is chosen, the mean tour distances are significantly higher than when no toll is chosen. Considering cases where toll is available but not chosen, it can be seen that the mean distances are lower than when it is chosen. Thus, toll is available but not chosen for a proportion of shorter distance OD pairs.

Given the strong relationship between toll road usage and journey distance, model formulations were adopted with a distance term added to the toll constant. These terms give a significant positive effect with distance, so that the net effect is negative for short tours, and positive for long tours.

The sensitivity of toll road choice relative to the other choice decisions represented in the mode-destination model structure is discussed in Section 4.

3. Train access mode and station choice

3.1 Modelling approach

The version of the STM developed between 1999 and 2002 modelled access to train using the Emme software, which represents access by walk and bus modes. However, access to rail stations by car, including park-and-ride (P&R), is important, particularly in more suburban areas. Furthermore, there is a need to predict demand for new train services, such as the North West Rail Line. In order to predict demand accurately account needs to be taken of passengers who access train services by car, particularly in areas where access by bus or walk is difficult. Therefore, a new treatment of train access mode and station choice was developed.

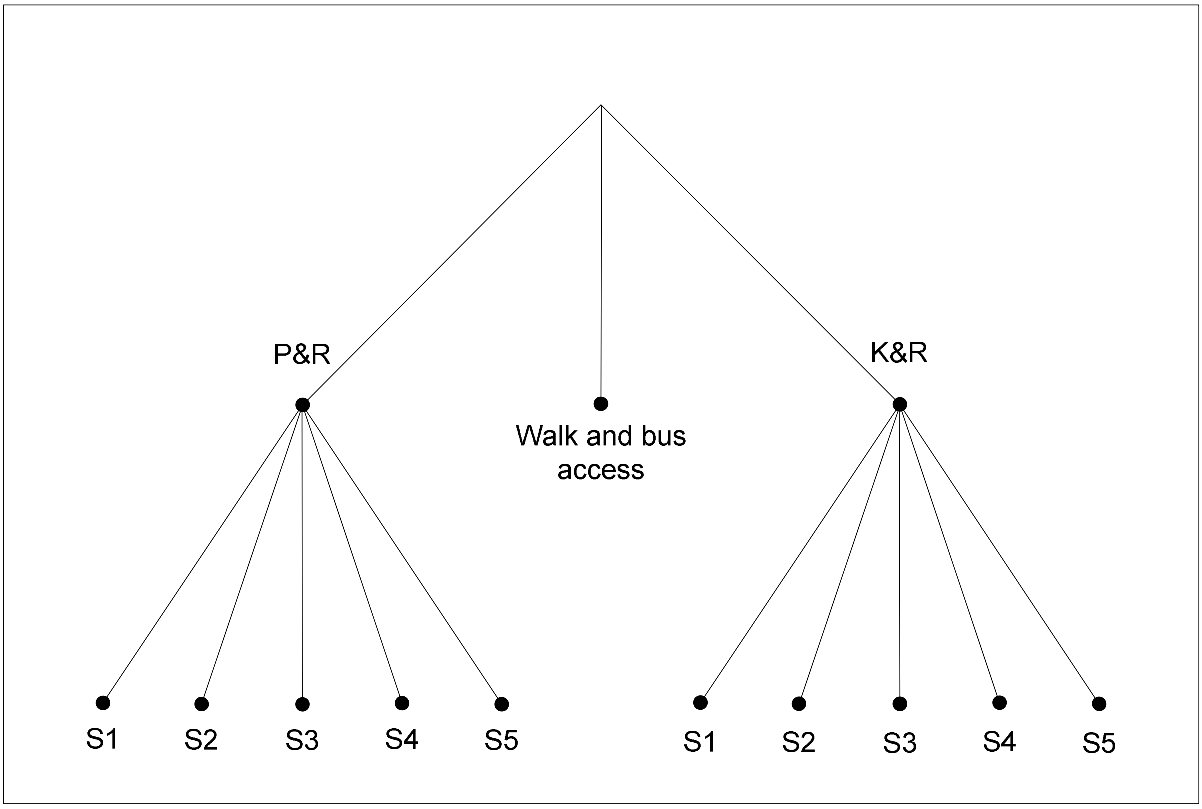
At this stage it is useful to define P&R as when a car is driven to the station, the car is parked, and then the occupants travel onwards by train. Kiss-and-ride (K&R) is then defined as when a car drops one or more passengers at the station, and then drives away. An ‘other access’ category can then be used to include access by walk and bus.

The basis for the modelling approach adopted was RAND Europe’s experience from the PROMISE model for Netherlands Railways (Cohn *et al.* (1996)), and the PRISM model for the West Midlands region of the UK (Fox (2005)). The PRISM model was developed to assess policy in a region of around 5 million inhabitants, similar to the STM study area, and P&R was high on the policy agenda when the model was developed. The approach used in the STM follows the PRISM approach and represents two linked choices:

- access mode to train: P&R, K&R and other; and
- for car access (P&R and K&R), choice of access station.

The model structure is illustrated in Figure 3. For the P&R and K&R alternatives, there are five possible station choice alternatives labelled S1 to S5.

Figure 3: Access mode and station choice structure



To represent the choice between different station alternatives, the level of service associated with both the car access and the train legs is represented. The five stations selected are the 'best' options, given the level of service for both the car access and train legs. So S1 might be a nearby station with a stopping service to the destination, and S2 might be a more distant station with an express service to the destination.

An iterative process has to be used to determine the five best station alternatives, where results from an earlier model are used to determine the most attractive stations, which then form the choice set for the estimation of the next model.

The model then predicts the choice between these station alternatives given the different levels of service associated with each station option. Level of service for the walk and bus access option is taken directly from Emme, and so station choice is not represented in the choice model structure for this access mode, rather the Emme route choice algorithm determines the most appropriate access station or stations.

By explicitly modelling the choice of access station, it is possible to represent the impact of car access legs on congestion on the highway network. Representing P&R and K&R separately also enables predictions to be made of the number of cars parking at each station, as the number of P&R tours gives the number of cars (after accounting for mean car occupancy).

3.2. Model results

Rather than present detailed parameter results this section presents some key findings for commute and business travel, where the P&R and K&R access shares are higher than for education, shopping and other travel, and so there is more data available for model estimation.

Analysis was undertaken to assess the correspondence between the 5 most attractive stations identified by the model and the stations actually chosen. Table 3 presents the results obtained for commute travel, with station rank 1 corresponding to the most attractive station identified by the model.

Table 3: Analysis of selected commute P&R and K&R stations

Station Rank	Percentage of cases where station rank is chosen	
	P&R	K&R
1	51.9 %	55.9 %
2	19.7 %	18.6 %
3	7.8 %	5.6 %
4	6.0 %	5.6 %
5	2.9 %	1.9 %
Total predicted	88.3 %	87.6 %

It can be seen that for both P&R and K&R, the chosen station is in one of the five stations identified for 88% of cases. Furthermore, for more than half of cases the chosen station corresponds to rank 1. Overall, it was concluded that the approach was working correctly in identifying the station alternatives.

The models estimate the sensitivity of travellers to car access time for the car access leg of P&R and K&R tours. Table 4 presents these parameters scaled relative to in-vehicle time for train and bus, with the t-ratios of the relative valuations (expressed relative to a value of zero) presented in brackets.

Table 4: Car access time parameter multipliers

Purpose	Rail time	Bus time
Commute	3.24 (6.6)	1.80 (8.0)
Business	3.98 (2.9)	2.39 (3.3)

The results demonstrate that car access time is valued more than three times as highly as rail in-vehicle time, and around twice as highly as bus time. This means that individuals will tend to minimise their car access legs relative to their train legs.

3.3. Access mode shares with distance

While the station choice models were able to identify the most attractive stations successfully, comparison of observed and predicted tour length distributions by train access mode revealed a consistent pattern of under-predicting tour lengths for P&R and K&R, and over-predicting tour lengths for the other access alternative. As a result, the observed pattern of higher P&R and K&R usage for longer tours was not being adequately predicted by the models.

A number of changes were made to the models to improve the predictions. First, K&R and P&R were set to be unavailable for shorter tours (under 10 km in length) based on analysis of the observed data. Second, a number of origin specific effects were added for regions where car access to train was higher, in particular for tours originating in Gosford-Wyong to the north of Sydney. Third, constants were added for some purposes to reflect the lower likelihood of using other access for the longest train tours. Finally, distance terms were added to car access modes for some purposes to reflect the predicted mean tour length for car access tours.

Figure 4 and Figure 5 present the car access mode shares for commute travel before and after these changes, demonstrating the significant improvement achieved in the fit to the observed data. The following information is plotted in Figures 4 and 5:

- observed access mode shares by mode, shown by the solid lines, with blue, red and green lines indicating the access mode shares for P&R, K&R and other access modes respectively
- predicted access mode shares by mode, shown by the dashed lines, with the same colours used to indicate the three access modes.

Figure 4: Commute train access mode shares with distance, before improvement

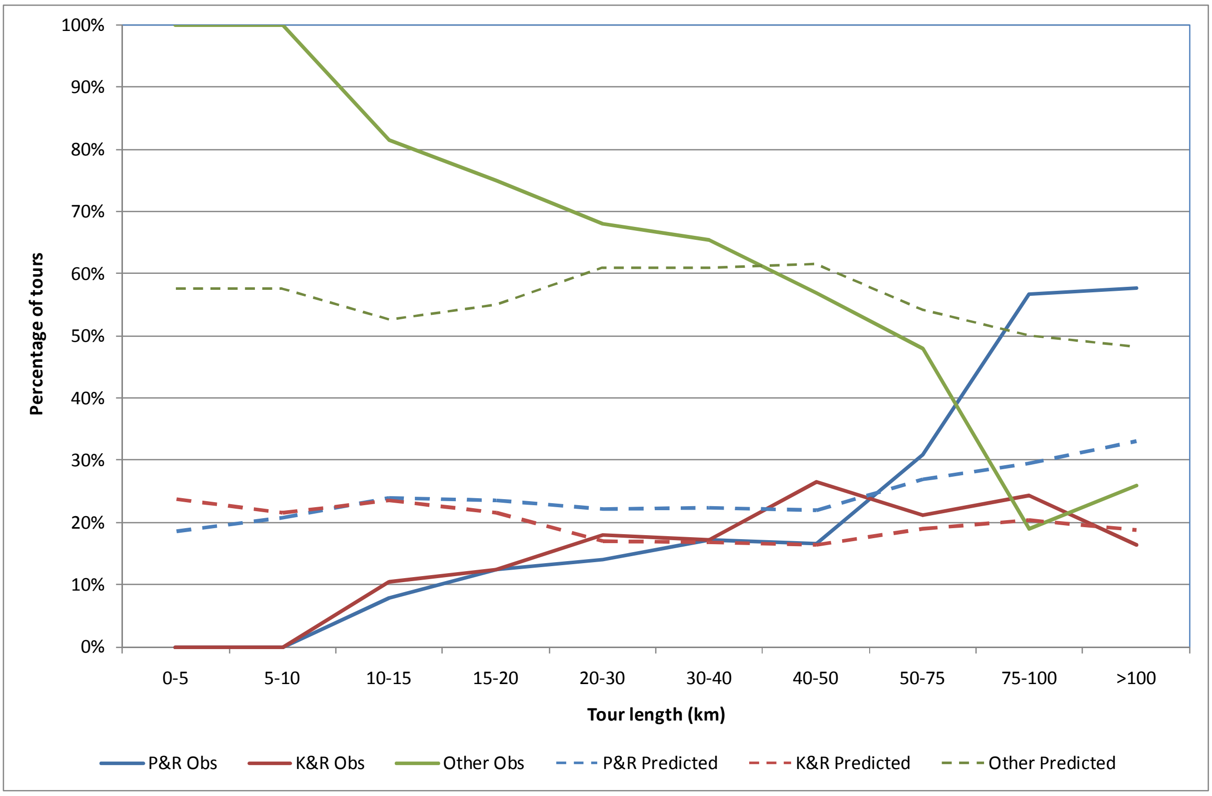
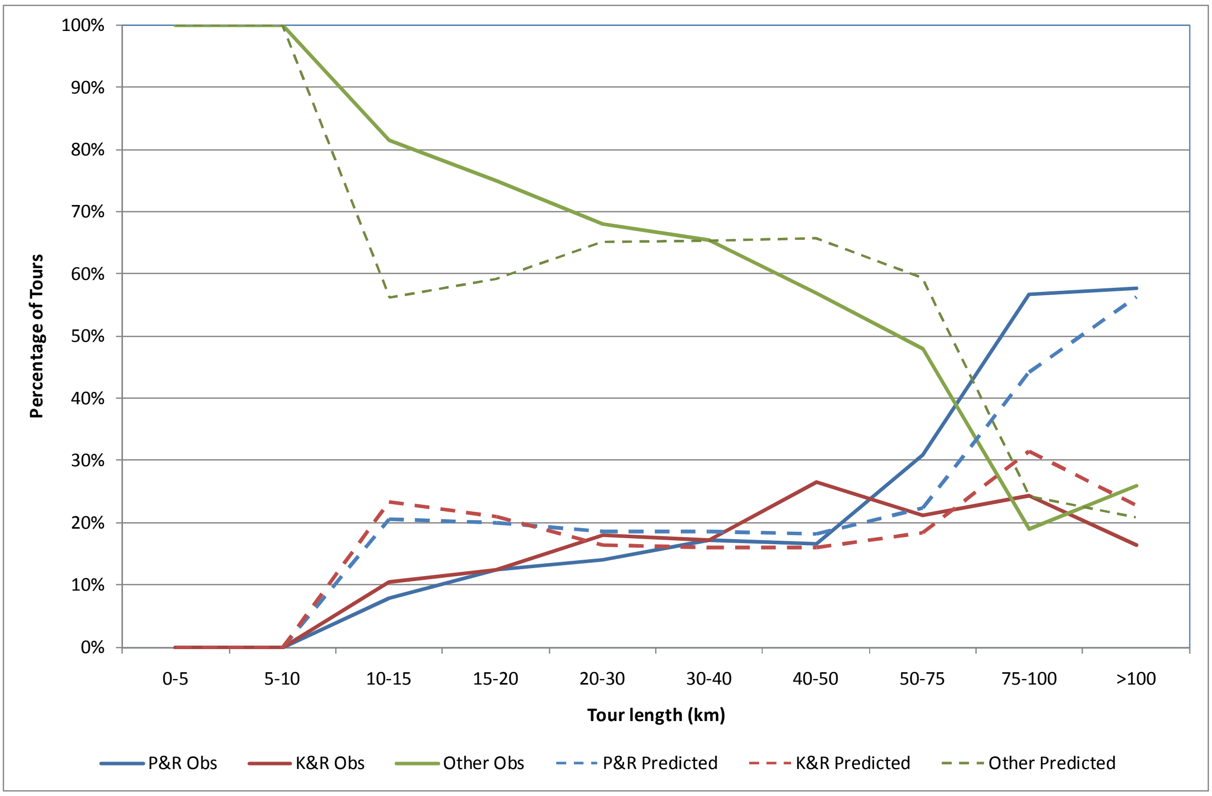


Figure 5: Commute train access mode shares with distance, after improvement



4. Model structure

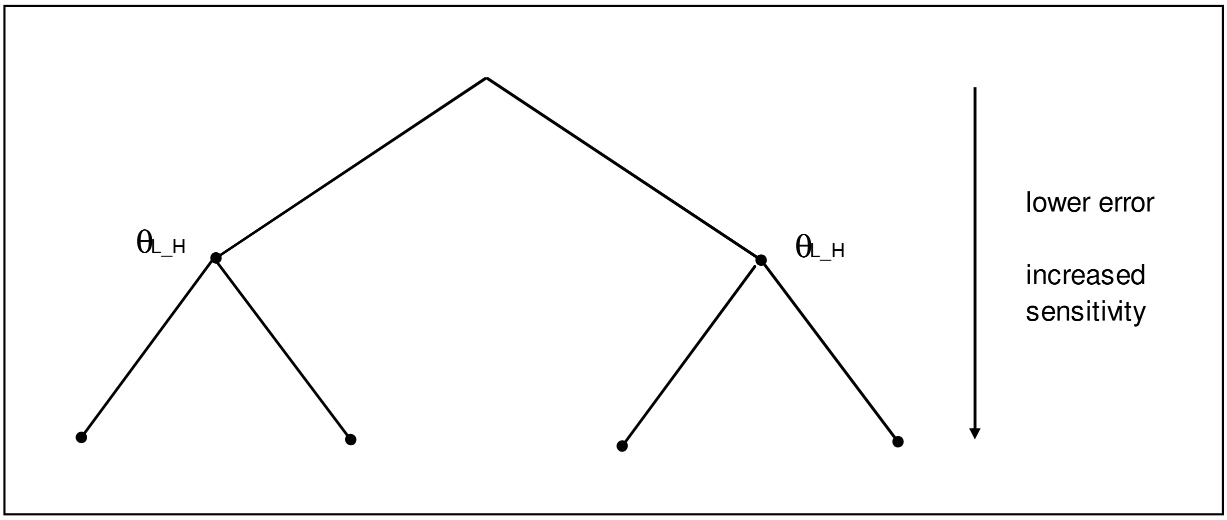
In this section, the tests to identify the final mode-destination model structures are described. The section starts by describing the approach used to estimate the model structures, highlighting the strategy adopted to deal with the high number of candidate structures for testing. The section goes on to summarise the results from the structural tests, presenting the most important model structure, and discusses some of the issues encountered with identifying the structures given the high number of choice decisions represented.

4.1 Modelling approach

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 which 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 6.

Figure 6: Nesting 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:

$$\theta_{L\_H} = \frac{\sigma_L}{\sigma_H} \tag{4.1}$$

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

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

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; and

- 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.

4.2 Model results

Sets of structural tests were run for the seven home-based purposes, and two non-home-based purposes, represented in the current STM. Up to six choice decisions are represented for each travel purpose:

- main mode
- public transport mode
- train transport access mode
- train station
- destination
- toll road

The large number of model zones (2690) combined the number of structural parameters we were seeking to estimate and the number of model alternatives represented led to substantial run times, with some runs taking a number of days to complete. For example, the commute model has 18 mode, access mode, station and toll alternatives and 2690 destinations, resulting in 48,420 alternatives in total.

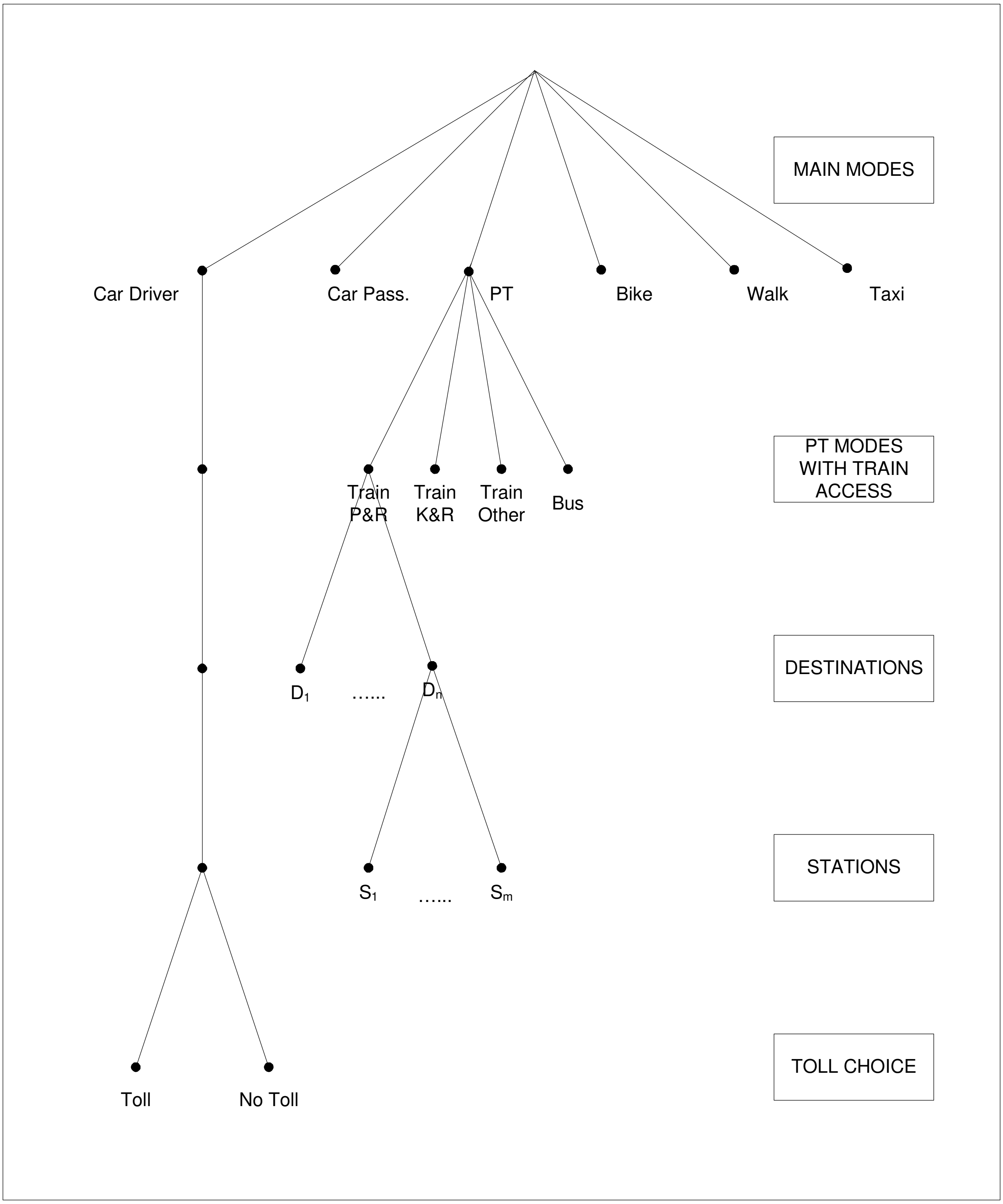
A key finding from the runs was that, for purposes with all six choices represented, it was not possible to estimate the five structural parameters that are necessary to fully define a model structure. However, when by constraining parameters that were close to a value of one to unity, up to two structure parameters could be identified per purpose. Commute, home-business, home-shopping and home-other travel account for the majority of trips and kilometres in the STM, and can be described by a common estimation structure, illustrated in Figure 7 overleaf. However, as discussed above some of the structural parameters are constrained to one in this structure.

Key findings from the structural tests for these four purposes were that:

- destination choice is more sensitive (lower in the structure) than main mode choice;
- the only purpose where a significant public transport nest parameter was estimated was other travel; and
- toll road choice is the most sensitive choice, with significant toll nests parameters estimated for commute and business travel (where there is more choice data).

Once the model structures had been finalised for each travel purpose, the models were validated by examining key parameter ratios, the implied values of time, elasticities to cost and travel time changes, and fit to the observed trip length distributions. The models validated well against observed data, and comparison value of time and elasticity values, and are therefore ready to be used to test policy once they have been implemented in the forecasting system.

Figure 7: Model structure, commute, home-business, home-shopping and home-other travel



5. Summary and recommendations for further work

The mode-destination model specifications identified during the 1999-2002 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.

Two key extensions to the mode-destination structure have been ensure that the STM is able to predict demand for existing and planned toll road facilities, and to better predict access to, and demand for, existing and planned train services. These improvements have been made while maintaining the policy functionality of the existing model, and moving to a more detailed zoning system.

Further work is recommended on strategies for estimating complex multi-level structures. A sequential estimation strategy may be a better approach, with the structure determined by estimating different parts of the model in stages, and only estimating the final structure simultaneously at the very end of the process.

The new mode-destination models have validated well at the estimation stage, both against observed data and in comparison with guidance values for value of time and elasticity. The new STM will be applied for the first time over the coming months, and given the extensions in model scope a useful exercise will be to validate the base year predictions of the toll road and park-and-ride components of the model against observed data.

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