Oxfordshire Strategic Model (OSM)

ATKINS

WP 2 - Main Demand Model Specification

Oxfordshire County Council

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Plan Design Enable

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Table of contents

Chapter pages

1. Introduction **5**
Background 5
Modelling Suite 5
Key Design Considerations 6
Report Structure 7

2. Demand Model System **9**
Introduction 9
Model Standards 9
Temporal Scope 9
Segmentation 10
Generalised Cost Formulation 11
Demand Model Structure 12
Modelling Park and Ride 14
Cost Damping 16
PA-Based Modelling 17
Details of the PA Formulation 17
Final Comments 18
Modelling the Off-Peak Period 18
Conversion Peak Period to Peak Hour 19
Demand and Supply Model Outputs 19

3. Model Parameters and Factors **20**
Value of Time (VOT) Variation with Distance 20
Factors Derived from Survey Data 20
Fixed Returning Proportions 21
Base Year Bus and Rail Fares 22
Base Year Parking Charges 23

4. Demand Model Validation **24**
Introduction 24
Convergence between Supply-Demand 24
Realism Tests 25

Appendix A - Demand Model Formulation

Appendix B - Demand Model Variable Notations

Tables

Table 2.1 - Demand Model Segmentation 10
Table 2.2 - Demand Model Overview 13
Table 2.3 - Returning Time Period Specification 18
Table 3.1 - From-home / To-home Factors 21
Table 3.2a - Highway Fixed Returning Proportions 21
Table 3.3b - PT Fixed Returning Proportions 22
Table 4.1 - Notation Used in PA Formulation 31

Figures

Figure 1.1 –Modelling Suite 8
Figure 2.1 - Demand Model Choice Structure 13

1. Introduction

Background

1.1. The County Council, Local Transport Board (LTB) and Local Enterprise Partnership (LEP) are currently working together to identify, appraise and prioritise potential transport interventions that could form part of Oxfordshire's Strategic Economic Plan (SEP) up to 2021.

1.2. A number of schemes have recently been identified as priorities by the LTB. There is a need to produce a fit for purpose transport model that can be used, post-SEP submission, by the LTB and LEP to provide guidance on the detailed scheme design and to produce the value for money elements at the three scheme business case stages.

1.3. Within these three stages, there needs to be particular emphasis on using the model to identify the impacts of transport and development in Oxfordshire. The model needs to be multi-model and developed in line with WebTAG guidance to underpin specific requirements of the Department for Transport.

1.4. The model development involves the delivery of the following Work Packages:

- WP 1 Data and Survey requirements
- WP 2 Main Demand Model Specification
- WP 3 Road Traffic Model (RTM) and Public Transport Model (PTM) Specifications
- WP 4 Study Objectives
- WP 5 Calibration and Validation of: RTM
- WP 6 Calibration and Validation of: PTM
- WP 7 MDM Development
- WP 8 Model Forecasting
- WP 9 Appraisal Tools

1.5. This report covers the second element of the deliverables, WP2 giving the specification for developing the MDM. It relates closely to WP3 on the specification of the RTM and PTM.

Modelling Suite

1.6. The modelling suite will consist of:

- a Highway Assignment Model (RTM) representing vehicle-based movements across the area for the morning peak hour (08:00 – 09:00), an average inter-peak hour (10:00 – 16:00) and an evening peak hour (17:00 – 18:00) of an average weekday;
- a Public Transport Assignment Model (PTM) representing bus and rail-based movements across the same area and time periods; and
- a five-stage multi-modal incremental Demand Model (MDM) that estimates frequency choice, main mode choice, time period choice, destination choice, and sub mode choice in response to changes in generalised costs across the 24-hour period of an average weekday.

1.7. The interaction between the different models within the modelling suite is shown in Figure 1.1. The specifications for the RTM and PTM are covered in another report (WP3).

1.8. The MDM is a 24-hour weekday demand model, compliant with WebTAG. It is an incremental demand model which reflects the change in travel pattern in response to changes in costs, measured in generalised minutes.

Key Design Considerations

1.9. The key considerations for developing the WebTAG compliant Oxfordshire Strategic Model (OSM) are to provide an evidence base for the appraisal of major highway and public transport schemes. The major interventions are principally around Bicester, Oxford, and the Science Vale corridor. The model needs to pay special attention to the A40 corridor between Whitney and J8 of the M40, as well as public transport and P&R. Other considerations required by Oxfordshire County Council (OCC) for the model are that the run time should not exceed an overnight 16 hour period.

1.10. The principal objective of the OSM is to appropriately represent travel conditions on the highway and public transport networks for the appraisal of various schemes. The OSM should provide:

- changes in the travel cost between the base year and forecast years for input to the MDM;
- changes in traffic flows for input to the environmental appraisal of a scheme; and
- changes in travel costs for input to the economic appraisal.

1.11. The potential interventions for appraisal will relate to major highway improvements, large traffic management schemes, or large scale complex public transport schemes. The OSM should have the following capabilities:

- reflecting the impact of changes in land use policies, economic conditions and interventions on travel demand;
- testing for scenario development using less detailed modelling; and
- testing of schemes using more detailed modelling to be put forward for inclusion in funding programmes.

1.12. The function of the MDM is to reflect the impact of (generalised) cost changes due to land use changes or development or network interventions, on the changes in travel patterns. Once the model is calibrated and validated in the base year 2013, changes in cost of travel between the base and forecast years are fed into the MDM from RTM and PTM, to produce forecast trip matrices by mode, time period, destination, and sub-mode choice. The respective modal matrices are then assigned to their respective networks using RTM or PTM. Note that the MDM involves an iterative process between supply and demand which will be terminated when certain pre-defined convergence criteria are satisfied or a maximum of demand loops is reached.

1.13. The process of forecasting thus involves the following steps:

a) Base year synthetic matrices for car and public transport are built using gravity modelling, as described in the WP3 report;

b) The synthetic matrices are modified using partial (observed) matrices and are subjected to some form of matrix estimation to produce the base year 'validated' matrices (again see WP3);

c) A Reference Case forecast is first produced by applying NTEM (TEMPRO) growth factors to the base year validated matrices for car available and non car available separately. These forecasts by definition imply no change in travel cost from base year. The LGV and HGV growth is based on the Road Transport Forecasts 2013 forecast from DfT, and the demand is assumed to be fixed during demand model runs.

d) Do-minimum forecasts are produced by inputting the Reference Case matrices and the do-minimum network into the MDM as explained in 1.12.

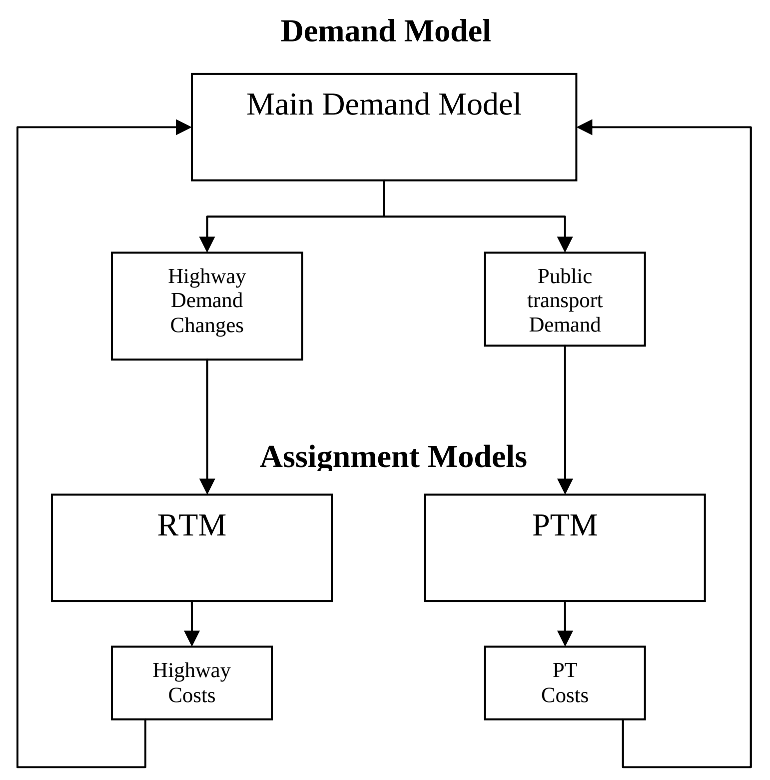
e) To produce do-something forecasts, steps 'd' is repeated but on the do-something network.

Report Structure

1.14. This report consists of five chapters. Following this introductory chapter:

- Chapter 2 describes the structure of the demand model and its functional forms;
- Chapter 3 presents parameters used to build the MDM, such as segmentation factors, and Value of Time (VOT) parameters as well as the VOT variation with distance for HBO and NHBO trips;
- Chapter 4 provides convergence statistics and realism test results, including highway fuel cost/journey time elasticities and PT fare elasticities, and derived sensitivity parameters and scale theta parameters; and
- The detailed mathematical formulation of the logit choice models and the PA derivation are included in Appendices A and B respectively.

Figure 1.1 –Modelling Suite



2. Demand Model System

Introduction

2.1. The demand model will be developed to appraise a wide range of transport scenarios and strategies that could be implemented in the County. The strategies could cover highway improvements, demand management and parking charges as well as bus rapid transit, rail, park and ride, and traffic management schemes. The scenarios would allow for a change in demographics as well as specific developments.

2.2. The demand model uses a Production – Attraction (PA) formulation as recommended in WebTAG Unit 3.10.2. It also includes variation of the value of time (VOT) with trip length for non-work trips for reasons explained later.

2.3. External to external movements are considered as fixed movements along with goods vehicle movements, and therefore these are not modelled in the demand model. The zoning follows the same zoning system used for RTM and PTM.

Model Standards

2.4. The design of the demand model closely follows the latest DfT WebTAG guidance[1]. In particular, the development of the demand model is in compliance with:

- WebTAG Units 3.10.1 to 3.10.4 - Variable Demand Modelling;
- WebTAG Unit 3.11 - Modelling of Public Transport Schemes; and
- WebTAG Unit 3.12.2c - Design, Modelling and Appraisal of Road Pricing Schemes.

Temporal Scope

2.5. The demand model is a 24-hour demand model representing four time periods: the morning peak (AM), the inter-peak (IP), the evening peak (PM) and the off-peak (OP) period, starting from 07:00 and concluding at 07:00 the following day.

2.6. The relationships between the various peak periods and peak hours are defined as follows:

- AM peak period: 07:00 - 10:00;
- AM peak hour (for assignment modelling only): 08:00 - 09:00;
- Inter-peak period: 10:00 - 16:00;
- Inter-peak hour (for assignment modelling only): 1/6th of 10:00 - 16:00;
- PM peak period: 16:00 - 19:00;
- PM peak hour (for assignment modelling only): 17:00 - 18:00; and
- Off Peak period: 19:00 - 07:00 (but without assignment).

Note that the AM and PM peak hours are not the average of AM and PM peak period hours.

2.7. The definition of the modelled time periods has been informed by the discussion in WebTAG Unit 3.10.2, paras 1.8.8 - 1.8.16, with time period choice (within the demand model) undertaken at the peak period level whilst a specific AM peak hour, inter-peak (IP) hour and PM peak hour is used in the assignment.

[1] WebTAG2 will become definitive in January 2014

Segmentation

2.8. Travel demand in the MDM is segmented by car availability and journey purpose as described below:

By person type

- Car available (CA); and
- Non-car available (NCA).

By household income

- Income Low (IL): less than £20,000;
- Income Medium (IM): £20,000 to £40,000; and
- Income High (IH): greater than £40,000.

By journey purpose

- Home based work (HBW);
- Home based other (HBO);
- Non-home based other (NHBO);
- Home based employer's business (HBEB); and
- Non-home based employer's business (NHBEB).

2.9. It is noted that the assignment models do have a separate purpose for education, HBED but in the MDM, that purpose is combined with HBW due to a variety of reasons such as lack of sensitivity choice parameter (lambda or Theta) for HBED in WebTAG, and no separate VOT and VOC values for HBED. Table 2.1 shows the segmentation proposed for the MDM. There are 16 demand segments including the income segments which are reserved for future user charging development, data for which will be collected at the 3 new RSI sites as well as from NTS[2]. Note that the work trips (i.e. HBEB and NHBEB) and NCA trips are not segmented by income band.

Table 2.1 - Demand Model Segmentation

Supply Purpose	Trip Purpose	Car Available (CA)			Non Car Available (NCA)
		<£20,000	£20,000 to £40,000	> £40,000	
Commuting	HBW	8	9	10	15
Other	HBO	0	1	2	11
	NHBO	3	4	5	12
Work	HBEB	7			14
	NHBEB	6			13

Note: the numbers shown above refer to the segment ID used within the demand model.

Within the RTM

2.10. The base year RTM matrices will be built to six purposes (HBW, HBEB, HBED, HBO, NHBEB and NHBO) but when interacting with the MDM, HBED will be combined with HBW to form the five purposes that the MDM operates on. The goods vehicle movements for LGV and HGV are not considered within the MDM. As suggested by WebTAG Unit 3.10.1, para 1.2.5, their forecast year trip matrices are assumed not to change in response to cost changes, only re-routing effects will be taken into account in the RTM.

[2] As explained in the WP3 report

Within the PTM

2.11. Within the EMME-based PTM, no distinction is made between journeys undertaken for different purposes, household income bands or car availability. Instead, the overall public transport demand is allocated (by logit-based choice mechanisms) to the various PT sub-modes, where available:

- Rail; and
- Bus / BRT.

Generalised Cost Formulation

Private Car

2.12. WebTAG Unit 3.10.2 defines the generalised cost (in minutes) for private car person trips and includes elements relating to:

- fuel cost;
- in-vehicle time;
- parking costs;
- tolls or other user charges;
- access/egress time; and
- vehicle occupancies.

2.13. The demand model follows the WebTAG formula for the definition of generalised costs for cars: Gcar , measured in units of time-minutes:

$$G_{car} = V_{wk}*A + T + D*VOC/(occ*VOT) + PC/(occ*VOT)$$

where:

- V_{wk} is the weight applied to walking time (assumed 0 currently);
- **A** is the total walk time to/from the car (minutes);
- **T** is the journey time spent in the car (minutes);
- **D** is the motorised journey length (kilometres);
- **VOC** is the vehicle operating cost (pence per km): including the fuel and non-fuel operating cost for the work purposes but only the fuel operating cost for non-work purposes;
- **occ** is the occupancy (i.e. the number of people in the car) who are assumed to share the cost;
- **VOT** is the appropriate Value of Time per person (pence per minute); and
- **PC** is the parking cost and tolls (if and when incurred), in monetary units (pence).

2.14. WebTAG Unit 3.5.6 provides guidance for calculating Values of Time and vehicle operating costs for general scheme appraisal and assessment whilst WebTAG Unit 3.12.2 Annex A provides guidance on segmentation and values of time by income group for road pricing models. Values of vehicle operating costs (VOC), values of time (VOT) and occupancy (occ) will be derived from WebTAG Unit 3.5.6[3] as outlined in Chapter 3.

[3] WebTAG 3.5.6d will become definitive in January 2014. The current official released version is October 2012

Public Transport

2.15. WebTAG Unit 3.10.2 defines the generalised cost for public transport users and includes elements relating to:

- fares;
- in-vehicle time;
- walking time to and from the service;
- waiting times; and
- interchange penalty.

2.16. The WebTAG formula for PT generalist cost GPT, measured in units of time (minutes) is given as:

$$G_{PT} = V_{wk}{*}A + V_{wt}{*}W + T + F/VOT + I$$

where:

- V_{wk} (=2) is the weight applied to time spent walking;
- **A** is the total walking time to and from the service;
- V_{wt} (=2.5) is the weight applied to time spent waiting;
- **W** is the total waiting time for all services used on the journey;
- **T** is the total in-vehicle time;
- **F is total fare;**
- **VOT** is the appropriate Value of Time, in pence per minute; and
- **I** (=10 minutes) is the interchange penalty if the journey involves transferring from one service to another, subject to calibration.

2.17. The above weights 2 and 2.5 are within the recommended ranges of values provided in WebTAG Unit 3.10.2, subject to calibration.

Park and Ride

2.18. The generalised cost for P&R will be the sum of the car component between production zone and P&R site, and the public transport element from the P&R to the attraction. The costs for car and public transport will be in line with the above, and will include any parking charges at the P&R site, additional to the bus fare.

Demand Model Structure

2.19. The demand model has a hierarchical logit choice structure as shown in Figure 2.1. Compliant with WebTAG, an incremental demand modelling approach is adopted which responds to changes from the base year generalised costs, measured in generalised minutes.

2.20. The P&R sub-mode[4] is a highway sub mode which means that P&R generally extracts more patronage from cars. The P&R extraction from bus-all-the-way is modelled implicitly by the main mode choice, up and down the demand model hierarchical tree via the destination choice and the time period choice as shown in Figure 2.1.

2.21. An overview of the model stages, functional forms (e.g. OD/PA and Car-Available / Non-Car Available) and time periods is listed in Table 2.2 for each of the six stages in the demand modelling. Note that Frequency choice is included as the model does not allow for slow modes such as walking and cycling. The Brief did originally

[4] This is principally the bus based P&R, the rail based P&R is assumed to be a rail trip with car access, since the predominant component of the trip is by rail

require some representation of slow modes (walk & cycle). In lieu of demand data for those modes, we are proposing this is covered within the ‘frequency’ response in line with WebTAG recommendations.

2.1. The frequency modelling (stage 1) is undertaken for HBO and NHBO trips only, as trips of these purposes are typically more elastic to changes in costs. As suggested by WebTAG Unit 3.10.3 para 1.11.9, no frequency response is included for commuting or employer's business trips.

2.2. The main mode choice (stage 2) between car and PT operates for the Car Available (CA) person type only. The MDM operates at the 24-hour level until the time period choice (stage 3) is undertaken. For destination choice modelling (stage 4), the demand model considers all four time periods AM/IP/PM/OP for all person types in parallel. The resulting PA matrices are converted into OD matrices after the sub-mode choice (stage 5) and before the individual highway and PT assignments (stage 6) are undertaken.

2.3. The full model formulation is given in Appendix A.

Figure 2.1 - Demand Model Choice Structure

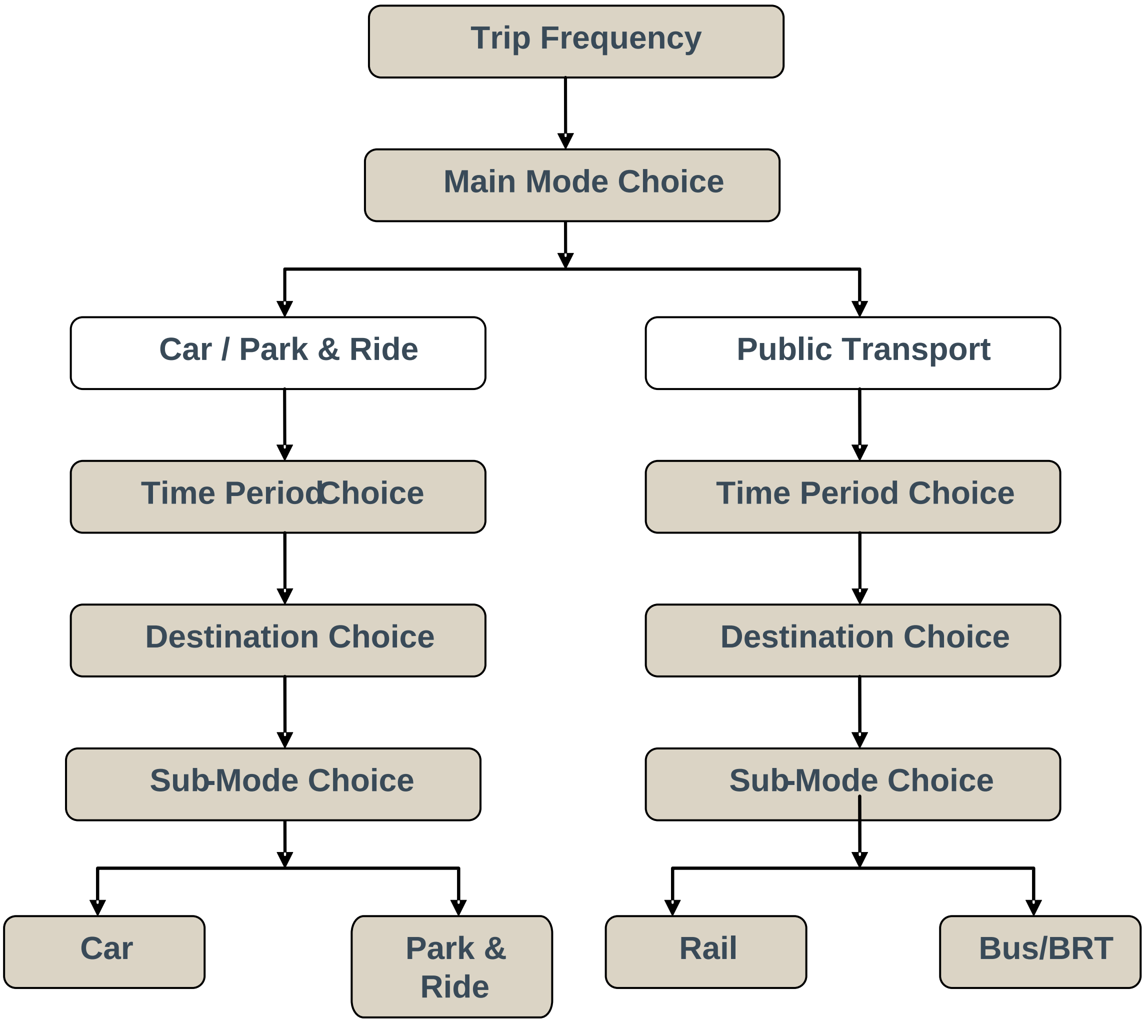


Table 2.2 - Demand Model Overview

Stage	Model	Temporal Scope	Form	Person Type
1	Frequency Modelling	24-hour	PA Production End	All (CA & NCA)

2	Main Mode Choice	24-hour	PA Production End	CA
3	Time Period Choice	Translate 24-hour to AM (3hr), IP (6hr), PM (3hr) and OP (12hr) periods	PA Trip Ends	CA & NCA
4	Destination Choice	3hr (AM), 6hr (IP), PM (3hr) and OP (12hr)	Translate PA Trip Ends to PA matrices	All (CA & NCA)
5	Sub-Mode Choice	3hr (AM), 6hr (IP), PM (3hr) and OP (12hr)	PA matrices	All (CA & NCA)
6	Assignment[5]	1-hour	OD matrices	All (CA & NCA)

Modelling Park and Ride

2.4. Modelling park and ride (P&R, a highway sub-mode) raises a number of issues as it requires linking the highway and public transport elements of the model. This section sets out the modelling methodologies to be implemented in the demand model.

2.5. WebTAG Unit 3.10.7 advises that for models where evidence from a local estimation is not available, the positioning of park-and-ride choice as a sub-mode of either car or public transport may be based on the following:

- where park-and-ride is dominated by relatively short car legs in order to gain access to a substantial public transport leg, then positioning as a sub-mode of public transport is likely to be the more appropriate; and
- where the park-and-ride site is located so as to attract relatively long car trips to change mode on the edge of the urban area, and where public transport mode share is low for the movements of interest, then treatment as a sub-mode of car is likely to be the more appropriate.

2.6. Within the Oxfordshire County, the park and ride sites are located in a position to intercept relatively long car journeys on the edge of the urban area. As such, park-and-ride choice is a sub-mode of car in the demand model. There are four key stages in the P&R modelling approach:

- derivation of park and ride generalised costs;
- estimation of park and ride demand in the demand model;
- site allocation of park and ride demand to competing sites; and
- assignment of highway and PT legs of park and ride trips to the networks.

2.7. P&R sites are defined in the model as individual zones. The P&R modelling is undertaken via a definition of catchment areas for each P&R zone. This restriction on P&R movements on home locations[6] reflects what is likely in reality where convenient sites are used (e.g. travellers from the north of a city are most likely to use a site on the north side of the city).

Deriving Park and Ride Generalised Costs

2.8. The highway and PT network models are used to define the generalised cost for a park and ride journey between zone to zone pairs. P&R sites are defined in the model as individual zones. In the base year there are five existing bus P&R zones as listed below:

- Thornhill;

[5] Clearly not part of the MDM but left for completeness
[6] Though some might have attraction limitations, such as that only some P&R sites serves the hospital

- Redbridge;
- Seacourt;
- Peartree; and
- Water Eaton.

2.9. A number of P&R zones are reserved for potential future applications. It is possible to define different park and ride sites for those identified as “proposed” providing the new zone is appropriately located in the highway and PT networks.

2.10. The highway network model (SATURN) is used to determine travel times and costs from production zones to each park and ride site (zone). The PT network model (EMME) is used to determine travel times and costs from the park and ride zones to each attraction zone.

2.11. The park and ride generalised cost for a given production to attraction zone movement is determined by taking the minimum combination of highway plus PT generalised costs also taking into account a parking charge, PT fare and a ‘site specific constant’, representing non generalised cost factors that influence the use of one site over another. The constants become calibration parameters to match modelled and observed patronage at the different P&R sites.

2.12. In model application only those sites considered active are used in the process (i.e. even though additional zones are defined for possible future sites they are only used if a site is assumed in place in a given forecast model run).

2.13. It is noted that this process is undertaken to derive park and ride generalised costs for all car-available demand segments by purpose, income group (if modelled), and modelled time period.

Application in the Demand Model

2.14. The park and ride generalised costs are passed to the demand model. As shown in Figure 2.1, park and ride appears in the bottom of the car nest of the main mode choice, and is not treated as a PT sub-mode. The model has a typical binary logit structure with the following to note:

- The main demand model uses the minimum generalised cost (between a production and attraction zone pair through a P&R site) to determine overall park and ride demand for all sites; and
- The scaling parameter λ_{sub} used at this level is set slightly higher than (or equal to) the destination sensitivity choice parameter λ_{dist}, and is typically about 0.1 (in generalised minutes). There is no current guidance on lambda values of sub mode choice -- sensitivity tests may be needed.

2.15. The demand model structure passes composite costs up from the lower levels to higher levels, so park and ride generalised costs have an influence on destination choice, time period choice and main mode choice.

Assignment of Highway and PT networks

2.16. The subsequent output from the site choice module consists of separate car-leg highway matrices and PT-leg bus matrices. These car-leg and bus-leg demands are person PA trips which are then added into the relevant car and public transport PA matrices, before converting to highway vehicle OD trips and PT person OD trips for assignment. The PA to OD factors will be derived from the 3 new RSI data for each of the appropriate demand model segments (i.e. income, purpose and period), as well as any older RSI data if that data is still found valid.

Cost Damping

2.17. There is some evidence that the sensitivity of demand responses to changes in generalised cost reduces with increasing trip length. This can be overcome by applying cost damping. Two forms of cost damping will be considered in the demand model:

- damping generalised cost by a function of distance; and
- varying non-working time with distance.

Damping Generalised Cost by a Function of Distance

2.18. The cost damping function is applied to the change in generalised costs for all the demand segments operating at this lowest level of the hierarchy. The form of the damping function adopted is from WebTAG Unit 3.10.2, paras 1.11.5 - 1.11.10:

$$g' = (d / k)^{-\alpha}.(t + c/v)$$

where:

- g' is the damped generalised cost;
- t, c are the trip time and money cost respectively;
- v is the VOT;
- d is the trip length; and
- α and k are parameters

2.19. The α and k will initially be set at the commonly used parameters suggested in para 1.11.10 of WebTAG 3.10.2. A minimum cut-off distance d' is also set, below which no damping is applied to prevent short distance trips becoming unduly sensitive to cost changes. The proposed starting values for the parameters to be used are:

- α = 0.5;
- k = 30; and
- d' = 30 km.

Varying Non-Working Time with Distance

2.20. Variation in non-working time with distance is introduced in the way suggested in WebTAG Unit 3.10.2. The expression for the VOT variation by distance for non-work trips is:

$$v_d = v \cdot \left(\frac{\max(d, d_c)}{d_0} \right)^{\eta_c}$$

where:

- v is the average value of time;
- v_d is the value of time which varies with distance
- d is the trip length;
- d_0 is a calibrated parameter value to ensure that the average value of time is consistent with that derived from WebTAG
- ηc is the distance elasticity (0.421 for commuting, 0.315 for other); and

- dc is a calibrated parameter value designed to prevent short-distance trips, particularly intra-zonal trips, becoming unduly sensitive to cost changes (dc was set at 4km).

2.21. Evaluation of the above formula gives rise to a matrix of VOTs by distance for non-work trips. The trip length d is taken from a matrix of the minimum distance on an uncongested network between each zone pair, skimmed from the base year inter-peak highway network after assignment.

PA-Based Modelling

2.22. The introduction of PA-based modelling for a 24hr day with the explicit consideration of time period choice is complex, particularly when (as shown in Figure 2.1), time period choice is undertaken after main mode choice but before destination choice. The key technical challenge, with the demand model, is how the demand and costs arising from the return leg of a home-based trip may be estimated when the timing of the return leg is dependent on the outward journey. In other words, if an outward home-based trip retimed from the morning peak period to the corresponding inter-peak period in response to the introduction of a morning peak road pricing, when would the corresponding return leg be undertaken? The issue does not arise with NHB trips which only have a single leg.

2.23. Within the demand model, the key issue is to determine the appropriate travel demand and associated costs of return-legs of home based trips in a coherent and consistent manner given that the return-leg journeys are constrained by the nature of their outward journeys. Whilst WebTAG recommends that this functional form should be adopted, it does not provide guidance on how it may be implemented.

2.24. The fundamental assumption underpinning the formulation is the use of fixed return proportions whereby for outward trips leaving home within each time period, the proportions of trips returning in subsequent time periods remain fixed by purpose over the base year and future forecast years. In other words, if AM tolls are applied and certain trips shifted to the IP period (for example), the return leg of these transferred outward trips would have the same return patterns as those already established in the base inter-peak period for the same demand segment.

2.25. Accordingly, for the PA formulation, only the outward from-home trips in each time period are explicit variables within the demand model. The return-leg demand is calculated from the initial outward-leg demand factored by the associated return proportions. The return proportions are derived from the information supplied by DfT and further details are provided in Chapter 3.

2.26. The following paragraphs describe the fixed-return proportion method for modelling PA-based time period choice. The two key assumptions underpinning the formulation are that:

- the return proportions are fixed between base and forecasting year; and
- the time of a day choice assumes that trips departing over the course of the day will all return before the commencement of the following AM Peak period the next day. In other words, for each outbound from-home trip, there would be an equivalent trip returning home during the day and the sum of outward journeys equals to the sum of return journeys over the day.

Details of the PA Formulation

Time Period Specification

2.27. We denote the modelled time period as (t), outward from-home time period as (s), and return to-home time period as (r), respectively.

2.28. The four time periods (t) in a 24-hour day in the demand model are:

- t=am: 07:00 – 10:00;
- t=ip: 10:00 – 16:00;
- t=pm: 16:00 – 19:00; and
- t=op: 19:00 – 07:00.

2.29. For a given time period t, the outward from-home time period (s) is the same as t:

- s = t for t $\in$ {am, ip, pm, op}.

2.30. For each time period t (or s), there are multiple corresponding return time periods (r) as defined below:

- r $\in$ {am, ip, pm, op}, if t = am;
- r $\in$ {ip, pm, op}, if t = ip;
- r $\in$ {pm, op}, if t = pm; and
- r $\in$ {op} if t = op.

2.31. The above relationship is illustrated in Table 2.3 where symbol √ indicates available returning time periods for each outward time period.

Table 2.3 - Returning Time Period Specification

		Return To-Home time period (r)			
		AM	**IP**	**PM**	**OP**
Outward From-Home Period (s)	AM	√	√	√	√
	IP		√	√	√
	PM			√	√
	OP				√

Final Comments

2.32. The demand model calculates the outward estimates of the PA demand directly by the Incremental Hierarchical Logit (IHL) technique. The return-leg demand is implicitly considered via the outward journeys in the following way:

- Return OD costs are incorporated in formulae (4) and (6) above, i.e. the PA costs are taken as the average OD costs between the outward and return journeys;
- Return-leg trips were calculated by formula (10) from their relevant outward legs using fixed return proportions. Therefore, any reduction of AM trips resulting from say, the introduction of AM tolls, would have been mapped onto the corresponding return legs.

Modelling the Off-Peak Period

2.33. The off-peak (OP) time period (i.e. 19:00 – 07:00) is modelled within the demand model. A representation of the off-peak costs and demand is needed for the PA-based modelling as defined by the formulae (4) to (11) presented earlier in this chapter.

2.34. WebTAG does not provide any guidance on how the OP period should be represented. Accordingly, a number of assumptions are made to enable off-peak demand and costs to be estimated for use in the model, reflecting both the limited data available and insignificance of scheme benefits within this period usually. The assumptions to be adopted are:

- OP car users travel at free-flow conditions in the base year;

- the change in OP costs will be equal to the change in Inter-Peak costs in the same forecasting year; and
- the use of nominal OP base demands was assumed, consisting of 5% of the corresponding IP base demands.

2.35. These assumptions ensure that the switch to the OP period from any of the AM, IP, and PM is always limited and restrictive. For example, the change of OP outward demand is very small in response to the introduction of AM peak tolling (if any). In other words, the introduction of tolling would shift outbound demand to the inter peak period (10:00 -16:00) rather than the off peak period (19:00 to 07:00). The practical limitations of the software and the impact on model runtimes is also an important consideration in this decision.

Conversion Peak Period to Peak Hour

2.36. As stated in the WP3 report, demand has to be converted from peak period (used in the MDM) to peak hour ready for assignment. To achieve this, traffic counts are used for highway trips, and bus and rail passenger survey count data is utilised for public transport trips.

Demand and Supply Model Outputs

2.37. The output from the demand model after the sub-mode choice (stage 5) includes two sets of updated matrices for use in the highway and PT assignments namely:

- Highway AM peak hour OD matrices (08:00 – 09:00), Inter-Peak average hour matrices (10:00 – 16:00), and PM peak hour OD matrices (17:00 – 18:00), segmented by car user class in vehicles and converted to the zoning system; and
- Bus/BRT and Rail AM peak hour OD matrices (08:00 – 09:00), Inter-Peak average hour matrices (10:00 – 16:00), and PM peak hour OD matrices (17:00 – 18:00), aggregated over person types and journey purposes.

2.38. The output from the PT and Highway assignment models is a set of cost skim matrices, produced by the assignment models to feedback into the demand model, namely:

- Highway matrices: skimmed time, distance, and toll matrices; and
- Bus/BRT and rail matrices: skimmed in-vehicle time, wait time, penalties, and number of interchanges.

2.39. Both highway and public transport skims are converted from OD format into the equivalent PA format within the demand model consistent with the conversion of PA demand matrices into OD matrices.

3. Model Parameters and Factors

3.1. This chapter presents parameters and factors that are needed to develop the MDM:

- VOTs and the introduction of VOT variation with distance;
- Vehicle Operating Costs are calculated using TAG 3.5.6 (October 2012) and defined separately for fuel and non fuel, the latter only considered in work time;
- factors derived from the new RSI survey data and old data if proved to be valid, including segmentation factors, PA pseudo-tour factors, occupancies and others; and
- bus and rail fares
- parking costs.

Value of Time (VOT) Variation with Distance

3.2. VOT will be derived from WebTAG Unit 3.5.6[7] by purpose and by income group. The five purposes in the MDM will be combined into three:

- Commuting (HBW)
- Other (HBO+NHBO)
- Work (HBEB+NHBEB)

3.3. The average VOT for non-working purpose will be varied by distance to implement cost damping as given in section 2.19 as a function of the distance for the i-j cell in the matrix. It is noteworthy that the variation of VOT with distance is applied only to the demand model, and not to the assignment models.

Factors Derived from Survey Data

3.4. The development of the demand model involves the derivation of local factors, such as demand segmentation factors, PA returning factors, and car occupancy factors. One of the principal data sources for the demand model will be the three new RSI survey data (and existing 2007 RSI data if found to be still valid), supplemented by other data sources such as the NTEM dataset and the National Travel Survey (NTS) where necessary. The 2013 RSI surveys were undertaken to collect up-to-date travel patterns to strengthen existing demand matrices, with 2 sites in Oxford and 1 site in Abingdon.

3.5. The following factors will be derived from the RSI survey data:

- Purpose splitting factors on a sector-sector level and by time period;
- Car occupancy factors by purpose, and time period. Note that no distinction was made between home-based and non home-based trips within a purpose;
- From-home / to-home factors by purpose and time period. An example of these factors is given in Table 3.2. These base year values are assumed to remain constant across all the forecast years;

[7] Though these values are under review. WebTAG 3.5.6 does not give VOT by CA/NCA. The MDM will assume VOT for NCA is half of the corresponding CA

Table 3.1 - From-home / To-home Factors

Demand Segment	AM	IP	PM
HBW	0.96 / 0.04	0.55 / 0.45	0.12 / 0.88
HBO	0.86 / 0.14	0.65 / 0.35	0.55 / 0.45
HBEB	0.97 / 0.03	0.54 / 0.46	0.22 / 0.78

- Factors to convert demand from the peak hour to peak period (or inverse for the reverse), derived from the RSI and PT surveys. These factors will be derived by purpose and time period for car, and by time period and all purposed combined for bus and rail;
- Local household survey data is not available and the car availability person type factors will need to be derived for the public transport segmentation using other data sources such as PT surveys and NTS. The Car-available (CA) and non-Car available (NCA) splitting factors for rail and bus users will need to be estimated by time period.

Fixed Returning Proportions

3.6. Table 3.2 a and b present an example of the returning proportions that will be used in the demand model for the three HB purposes. The DfT supplies national tour information derived from NTS datasets from which returning proportions will be derived. The national average values will be subsequently adjusted to reflect the travel demand in the County.

Table 3.2a - Highway Fixed Returning Proportions

	HBW	HBO	HBEB
AM Outward			
AM Return	0.03	0.27	0.07
IP Return	0.24	0.56	0.38
PM Return	0.65	0.15	0.44
OP Return	0.08	0.01	0.11
Total	*1.00*	*1.00*	*1.00*
IP Outward			
IP Return	0.26	0.72	0.50
PM Return	0.51	0.24	0.38
OP Return	0.23	0.04	0.12
Total	*1.00*	*1.00*	*1.00*
PM Outward			
PM Return	0.46	0.58	0.40
OP Return	0.54	0.42	0.60
Total	*1.00*	*1.00*	*1.00*
OP Outward			
OP Return	*1.00*	*1.00*	*1.00*
Total	*1.00*	*1.00*	*1.00*

Table 3.3b - PT Fixed Returning Proportions

	Bus			Rail		
	HBW	**HBO**	**HBEB**	**HBW**	**HBO**	**HBEB**
AM Outward						
AM Return	0.04	0.22	0.12	0.04	0.25	0.09
IP Return	0.35	0.59	0.38	0.13	0.62	0.35
PM Return	0.54	0.18	0.31	0.75	0.12	0.42
OP Return	0.08	0.01	0.19	0.08	0.01	0.15
Total	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
IP Outward						
IP Return	0.30	0.72	0.64	0.25	0.79	0.56
PM Return	0.44	0.25	0.21	0.53	0.17	0.31
OP Return	0.26	0.03	0.15	0.22	0.04	0.13
Total	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
PM Outward						
PM Return	0.46	0.59	0.40	0.47	0.58	0.40
OP Return	0.54	0.41	0.60	0.53	0.42	0.60
Total	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
OP Outward						
OP Return	1.00	1.00	1.00	1.00	1.00	1.00
Total	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*

Base Year Bus and Rail Fares

3.7. Public transport fares are excluded from the PTM assignment module and are incorporated into PT generalised cost calculations within the demand model. Crowding for public transport is not modelled.

3.8. The bus fares matrix will be derived from published fare data. A distance based bus fare system is compiled from the bus ETM data and fare charts obtained from major bus operators such as Stagecoach, Oxford Bus Company and Thames Travel. When deriving the bus fare system, the journey purpose and time period should be considered:

- Bus passengers on employer business and infrequent bus users generally purchase single or return tickets, and their patronage is generally low;
- Bus passenger commuters generally purchase return tickets or seasonal travel cards, most starting journeys in AM or PM peak period ;
- Most concessionary users are for “Other” purpose such as shopping and recreation etc., and those normally use bus in Inter peak period. The users on “Other” purpose are generally formed by a mixture of single, return tickets and seasonal travel cards.

3.9. Rail fares are calculated based on the function of skimmed rail OD distances and any connecting bus interchanges:

- AM / PM fare = (a+ b *Distance_km) + c* number of bus boardings
- IP fare = (d+ e *Distance_km) + f* number of bus boardings

Where a to f are calibration factors.

Base Year Parking Charges

3.10. Parking charges (where they exist) will increase generalised cost for car and can impact both on destination and mode choice. These charges will be included to the generalised cost at the relevant P&R zones wherever applicable. For other zones, such as the Oxford city centre and Didcot, Abingdon, Banbury and Bicester centres, we will review the parking use and tariff and compare to total (car) trip ends so that we can estimate an average parking fee for all trips into these centres. Note that we will not be distinguishing between paid and unpaid parking, but will be distinguishing between land uses that attract a charge (the centres listed above) and those that do not (elsewhere). This weighted average parking charge is added to the generalised cost for those zones in the RTM so that a more realistic destination and mode choice forecasts can be obtained.

3.11. If such data is not available, then parking charges will not be included in the MDM. Because the MDM is incremental, this implies that if the tariffs do not change in real terms between base and forecast years, then there is no impact on future travel patterns. If there are increases in parking tariffs, then these increases can be added to the generalised cost for those zones that contain significant and paid parking. Note that if this approach is adopted, the same conditions will apply in that we will not be distinguishing between paid and unpaid parking, but will be distinguishing between land uses that attract a charge (the centres listed above) and those that do not (elsewhere).

4. Demand Model Validation

Introduction

4.1. The validity of the MDM will be assessed by realism tests undertaken rigorously. The main purpose of the realism tests is to demonstrate that the chosen model parameters (either locally calibrated or adopted from the nationally recommended parameters) replicate long-term elasticities derived from empirical observations and/or best practice.

4.2. The target elasticities for the realism tests, as defined by WebTAG Unit 3.10.4, are:

- Car fuel cost - recommended elasticity between -0.1 to -0.4, with an overall target value of -0.25 to -0.35 across all segments;
- Car journey time - recommended elasticity less than -2.00; and
- PT fare - recommended elasticity between -0.2 to -0.9.

4.3. WebTAG recommends the use of locally calibrated demand parameters if they can be estimated from Revealed Preference and Stated Preference data. If these are not available, as is the case with Oxfordshire Strategic Model, WebTAG recommends the use of illustrative sensitivity parameters provided in WebTAG Unit 3.10.3. In either case, the robustness of the MDM validation needs to be demonstrated through the application of a set of realism tests.

4.4. This chapter presents how the MDM elasticities will be derived from the realism tests, by using the sensitivity parameters and structure parameters presented in Chapter 3, together with the introduction of VOT variation with distance for non-Work trips.

Convergence between Supply-Demand

4.5. The five-stage demand model employs an iterative method to achieve convergence between the assignment models (i.e. SATURN highway and EMME PT) and the EMME-coded MDM. Convergence is achieved by passing costs from the RTM, PTM assignment models to the MDM and subsequently passing trips from the five-stage MDM back to the assignment models. The process is terminated once the convergence criterion had been met.

4.6. Two convergence algorithms are implemented to create a stable converged solution between the demand and supply responses. The convergence algorithms are:

- the method of successive average (MSA); and
- the average method which simply used the mean value between previous results and the current new estimates.

4.7. Previous testing work undertaken identified that the simple average method provided a more stable (and quicker) solution and this will be adopted for the modelling system.

4.8. The recommended criterion by WebTAG Unit 3.10.4, for measuring convergence between demand and supply models, is the demand/supply Gap over all segments as defined by:

$$\frac{\sum_{ijctm} C(X_{ijctm})\left|D(C(X_{ijctm})) - X_{ijctm}\right|}{\sum_{ijctm} C(X_{ijctm}) X_{ijctm}} * 100$$

where:

- X_{ijctm} is the current flow vector or matrix from the model
- $C(X_{ijctm})$ is the generalised cost vector or matrix obtained by assigning that matrix
- $D(C(X_{ijctm}))$ is the flow vector or matrix output by the demand model, using the costs $C(X_{ijctm})$ as input
- *ijctm* represents origin i, destination j, demand segment/user class c, time period t and mode m.

4.9. It is important to achieve a high level of supply-demand convergence. WebTAG suggests that the convergence level, measured by %GAP, should be lower than 0.2% (or, if that cannot be achieved, a more relaxed criterion related to the projected benefits of a scheme).

Realism Tests

4.10. The realism tests will identify a set of sensitivity parameters which are the most appropriate for the OSM (with respect to the demand hierarchy form presented in Figure 2.2). The initial demand response parameters will be the illustrative parameters in WebTAG and these will be altered in an iterative process of tuning until Realism testing is satisfied.

4.11. The arc elasticity formulation recommended by WebTAG was used for the realism testing for a 10% increase in cost:

4.12.

$$e = \frac{\log(T^1) - \log(T^0)}{\log(C^1) - \log(C^0)} = \frac{\log(T^1) - \log(T^0)}{\log(1.1)},$$

where the superscripts 0 and 1 indicate values before and after the change in cost respectively, and for:

- Car fuel cost elasticity: T represents the car-kms travelled whilst C represents fuel costs;
- PT fare elasticity: T represents PT trips and C represents fares.

4.13. The realism tests will be undertaken assuming:

- a 10% increase in fuel prices for the car fuel cost elasticity test; and
- a 10% increase in bus and rail fares for the public transport fare elasticity test.

4.14. The car fuel elasticity can be estimated on a network wide basis or at the matrix level. The elasticity will be presented by purpose work/non-work and by time period. The results will distinguish between the various network areas (i.e. simulation, buffer link and buffer centroid connectors). The elasticity values will be estimated by direct calculation using SATURN output network statistics. Alternatively, the matrix-based vehicle-km fuel cost elasticities are estimated by time period, by ‘super’ sector (e,g Internal to Internal plus Internal to External), and by purpose (i.e. HBW / HBO / NHBO / Work). It is noted that the MDM does not consider the impact on external to external trips.

4.15. Fare elasticities derived from PT realism tests should reflect WebTAG values between -0.2 and -0.9. Matrix-based PT fare elasticities will be presented for “I to I&E” movements only, (as with the case exhibited for car fuel cost elasticities). The PT fare elasticities are evaluated as the change in the total number of public transport trips (including all PT sub modes) with respect to the 10% increase of bus and rail fare. The results will be presented by purpose. No concession fare is considered in the MDM.

4.16. As noted previously, since PT assignments are modelled with the EMME software which is not capable of incorporating stage-based bus and rail fare in route choice modelling (this applies to most PT modelling software). Therefore, the PT fare is considered in the MDM only and may have influence in the fare elasticity patterns presented.

4.17. In addition, WebTAG 3.10.4 also requires a car journey time elasticity test, which examines the change in car trips in response to the change in journey time. WebTAG suggests the elasticity should be less than -2.00 both by a single demand model run and a matrix-based calculation using times from the networks, for each trip purpose in each modelling time period.

Incremental Logit-based

The choice modelling for various demand responses follows an incremental approach as recommended by WebTAG, pivoted off the base year. The logit-based formulation is described below for each of the five demand modelling stages.

The demand model is implemented in terms of utilities and composite utilities consistent with the WebTAG hierarchical logit (HL) formulation (WebTAG Unit 310.3, Appendix 4). The formulae given below are specified in terms of the WebTAG HL tree structure, i.e. using lambda parameters for the lower level sub-mode choice and destination choice but using theta parameters for the upper level time period choice, main mode choice and the trip frequency modelling.

Frequency Modelling

The demand model does not explicitly model 'slow' modes (i.e. walking and cycling) and WebTAG suggests that it may be logical to consider some form of frequency modelling within the demand model to allow for that (WebTAG Unit 3.10.3, paras 1.7.17 -1.7.18).

WebTAG does not provide illustrative parameters for frequency other than noting its position within the demand model structure. The theta values for the frequency parameters are set during the realism tests and adjusted, through an iterative process, in order to achieve the target elasticities.

The formula for the frequency modelling is as follows

$$T_{ipc} = T^0_{ipc} * e^{\theta_{freq} \Delta U_{ipc}}$$

where:

- i : production end zone; p: purpose; c: person type such as CA, NCA, or income segment;
- T^0_{ipc} : base year number of zonal trip productions over i.p.c;
- T_{ipc} : output number of zonal trip productions over i.p.c;
- θ_{freq} : frequency choice structure (or scale) parameter by purpose; and
- $\Delta U_{ipc} = \ln(\sum_m T^0_{ipcm} e^{\theta_m \Delta C_{ipcm}} / T^0_{ipc})$: utility U logsum of lower level main mode choice, where m is the main mode (car / PT), where C is generalised cost in minutes

WebTAG recommends that frequency modelling is undertaken for the more responsive discretionary trip purposes: HBO and NHBO only.

Main Mode Choice

WebTAG (Unit 3.10.2) suggests that in the absence of local data to estimate the demand model structure, the main mode choice between cars and public transport for car available travellers should be placed just below the frequency modelling in the choice hierarchy, whilst the time period choice should be placed at a level similar to main mode choice.

The formula for the main mode choice is as follows:

$$T_{ipcm} = T_{ipc} \frac{T^0_{ipcm} e^{\theta_m \Delta U_{ipcm}}}{\sum_k T^0_{ipck} e^{\theta_m \Delta U_{ipck}}}$$

where:

- i: production end zone; p: purpose; c: person type; m: main mode (car or PT); k: used for summation over main modes car and PT;

T_{ipcm} : output zonal production trip ends over i.p.c.m;

- T^0_{ipcm} : reference zonal production trip ends over i.p.c.m;
- θ_m : main mode choice structure (or scale) parameter by purpose
- T_{ipc} : forecast zonal production trip ends over i.p.c output from the above frequency stage;
- $\Delta U_{ipcm} = \ln(\sum_t T^0_{ipcmt} e^{\theta_t \Delta U_{ipcmt}} / T^0_{ipcm})$: logsum of lower level time period choice, where t is time period.

Time Period Choice

WebTAG (Unit 3.10.2) suggests that time period choice parameter values should be similar in magnitude to main mode choice parameter values. The scale parameters used for the time period choice are set to the same value as used in main mode choice. This means that in mathematical terms, they are modelled simultaneously in a multinomial form, but will be subject to calibration.

The formula for the time period choice between the four weekday periods (i.e. AM, IP, PM and OP period) is as follows:

$$T_{ipcmt} = T_{ipcm} \frac{T^0_{ipcmt} e^{\theta_t \Delta U_{ipcmt}}}{\sum_k T^0_{ipcmk} e^{\theta_t \Delta U_{ipcmk}}}$$

where:

- t: time period; k: used for summation over time periods AM, IP, PM and OP;
- T^0_{ipcmt} : reference zonal production trip ends over i.p.c.m.t;
- T_{ipcm} : input zonal production trip ends over i.p.c.m from the above mode choice stage;
- θ_t : time period choice tree structure scale parameter;
- $\Delta U_{ipcmt} = \ln(\sum_j T^0_{ijpcmt} e^{\lambda_{dist} \Delta U_{ijpcmt}} / T^0_{ipcmt})$: logsum of lower level summed over all attractions j, singly constrained destination choice for HBO, NHBO, NHBEB, and HBEB purposes; and
- $\Delta U_{ipcmt} = \ln(\sum_j B_{jp} T^0_{ijpcmt} e^{\lambda_{dist} \Delta U_{ijpcmt}} / T^0_{ipcmt})$: logsum of lower level, doubly constrained destination choice for HBW purpose only.

However, the estimation of the logsum ΔU_{ipcmt} for the doubly constrained distribution is not as straightforward - further details are provided below.

Destination Choice

WebTAG (Unit 3.10.2) recommends that destination choice should be modelled as singly (origin/production) constrained distribution for trips with HBO, NHBO, NHBEB or HBEB purposes. In contrast, WebTAG recommends that the destination choice for HBW should be modelled as doubly (i.e. origin-and-destination) constrained distribution. To meet this requirement, a rectangular Furnessing procedure will be used to undertake the HBW distribution modelling.

The formula for the singly constrained destination choice is:

$$T_{ijpcmt} = T_{ipcmt} \frac{T^0_{ijpcmt} e^{\lambda_{dist} \Delta U_{ijpcmt}}}{\sum_k T^0_{ikpcmt} e^{\lambda_{dist} \Delta U_{ikpcmt}}}$$

where:

- j : attraction end; k: numeration of all destinations;
- T^0_{ijpcmt} : reference PA matrix over p.c.m.t;
- T_{ipcmt} : input zonal production trip ends over i.p.c.m.t from the above time period choice;
- λ_{dist} : destination choice sensitivity parameter[8];
- T_{ijpcmt} : output PA matrix over p.c.m.t; and
- $\Delta U_{ijpcmt} = \ln(\sum_s T^0_{ijpcmts} e^{\lambda_{sub} \Delta C_{ijpcmts}} / T^0_{ijpcmt})$: logsum of lower level sub-mode choice, summed over all sub-modes S.

All distribution models, irrespective of whether they are singly or doubly constrained, satisfy the following row constraints:

$$T_{ipcmt} = \sum_j T_{ijpcmt}.$$

For doubly constrained distribution, another set of column constraints is also introduced:

$$\sum_{imtc} T_{ijpcmt} = \sum_{imtc} T^0_{ijpcmt}.$$

The Furnessing procedure guarantees that the above two sets of constraints are always satisfied. In other words, each zone attracts a fixed amount of (total) trips for each person type within a purpose.

The formula for the doubly constrained distribution is

$$T_{ijpcmt} = T_{ipcmt} \frac{B_{jp} T^0_{ijpcmt} e^{\lambda_{dist} \Delta U_{ijpcmt}}}{\sum_k B_{kp} T^0_{ikpcmt} e^{\lambda_{dist} \Delta U_{ikpcmt}}}$$

where:

- j : attraction end; k: used for summation over all destinations;
- T^0_{ijpcmt} : reference PA matrix over p.c.m.t;
- T_{ipcmt} : input zonal production trip ends over i.p.c.m.t;
- λ_{dest}: destination choice sensitivity parameter;
- B_{jp} : attraction balance factors for purpose p and destination j, estimated via the rectangular Furnessing procedure (across all main modes);
- T_{ijpcmt} : output PA matrix over p.c.m.t;
- $\Delta U_{ijpcmt} = \ln(\sum_s T^0_{ijpcmts} e^{\lambda_{sub} \Delta U_{ijpcmts}} / T^0_{ijpcmt})$: logsum of sub mode choice

Note that the attraction balance factors were estimated via inner loops between this distribution stage and the above time period choice and main mode choice. This was necessary because

[8] Although with sub-mode choice, this should also strictly be theta

the trip ends from the above two stages were a function of the logsum (or B_{jp}) of this doubly constrained stage, which in turn, was a function of the Furnessing procedure for B_{jp}, dependent on the resulting forecast trip ends from the above two stages.

The initial values for the inner loops are:

$T_{ipcmt} = \sum_j T^0_{ijpcmt}$, $\alpha_{ipcmt} = 1,$ and B_{jp} =1,

where α_{ipcmt} are the row balance factors to ensure doubly constrained distribution satisfied.

Note that within the inner loops, before the logsum is evaluated, the attraction balance factors are normalised such that $\sum_j B_{jp} = N,$ where N = number of zones with non-zero attractions.

Sub-Mode Choice

After destination choice, the sub-mode choices are undertaken for highway and public transport users independently.

Park and Ride (P&R) users appeared in the single nest of sub-mode choices (as previously shown in Figure 2.1), to facilitate the sub-mode switching in forecast years between highway and P&R only.

The formula for the sub mode choice is:

$$T_{ijpcmts} = T_{ijpcmt} \frac{T^0_{ijpcmts} e^{\lambda_{sub} \Delta U_{ijpcmts}}}{\sum_k T^0_{ijpcmts} e^{\lambda_{sub} \Delta U_{ijpcmts}}}$$

where:

- s: sub-mode, k: used for summation over highway sub-modes car and P&R, or PT sub-modes rail and bus;
- $T^0_{ijpcmts}$: reference PA matrix over p.c.m.t;
- T_{ijpcmt} : input PA matrix over p.c.m.t from the above destination choice;
- λ_{sub} : sub-mode choice sensitivity parameter;
- $T_{ijpcmts}$: output PA matrix over p.c.m.t.s;
- $\Delta U_{ijpcmts} = \lambda_{sub}(C_{ijpcmtsb} - C^0_{ijpcmtsb})$: the change in Utility U as a function of the generalised costs (in minutes) at the lowest level of the hierarchy.

WebTAG does not provide explicit values to be used for the sub-mode choice scale parameter lambda. Similar models developed by Atkins have used a value around -0.1. The demand model will adopt the same value of -0.1 for both highway and PT sub mode choice, subject to calibration.

Note that the bottom level $\Delta U_{ijpcmts}$ is subject to damping to overcome the oversensitivity for long distance trips. This arises because the elasticity of logit formulation scales with the disutility - longer distance trips exhibit larger generalised cost differences producing unrealistically high elasticities, if these costs are not scaled. More details of the cost damping functions used are given in section 2.69?.

APPENDIX B **Demand Model Variable Notations**

We use “p.c.m” or “pcm” to represent segmentation used in the demand model with combination of purpose (p), person type (c) (household income band and CA/NCA), and mode (m). This is consistent with the formulae presented in Appendix A for Incremental Hierarchical Logit (IHL) formulation.

Table 4.1 provides the notations of variables used for the PA specification (which is arranged according to the appearance of variables in the following text).

Table 4.1 - Notation Used in PA Formulation

Notation	Description	Source Data
$Pout^{0}_{IJpcmt}$	Given time period t, reference outward from-home trip proportion by p.c.m for origin sector I and destination sector J. These factors are used only once in creating base PA trips[9].	RSI data[10]
$\Pr et^{0}_{pcmsr}$	Given time period s, fixed to-home proportion for trips returned in time period r by p.c.m. These factors are only segmented by p.c.m – not enough data is available to populate all ij pairs in a matrix form.	RSI data and NTS data
$T^{(RSI)}_{IJpcms}$	The total of from-home trips from RSI by p.c.m in time period s from origin sector I to destination sector J (directional from-home).	RSI data
$T^{(RSI)}_{IJpcmt}$	The total of from-home and to-home trips from RSI by *p.c.m* in time period *t* from origin sector *i* to destination sector *j* (non directional).	RSI data
$T^{(OD)0}_{ijpcmt}$	Reference OD assignment matrices from origin *i* to destination j in time period *t* by *p.c.m* (non directional).	Calibrated/ validated base assignment matrices
$T^{(OD)0}_{ijpcms}$	Reference outward OD trips from origin *i* to destination *j* in time period *s* by *p.c.m* (directional from-home).	
$T^{(PA)0}_{ijpcmt}$	Reference production-attraction (PA) trips from production zone i to attraction zone *j* in time period *t* by *p.c.m*.	
$C^{(PA)0}_{ijpcmt}$	Reference production-attraction (PA) costs from production zone *i* to attraction zone *j* in time period t by *p.c.m*.	
$C^{(OD)0}_{ijpcms}$	Skimmed base OD generalised costs of travel for outward trips in time period s from origin *i* to destination *j* by *p.c.m* (directional from-home).	
$C^{(OD)0}_{ijpcmtr}$	Given time period *t*, skimmed base OD generalised costs of travel for trips returning home in time period r from origin *i* to destination *j* by *p.c.m* (directional to-home)	
$T^{(PA)0}_{ijpcm24}$	Reference 24hr PA trips from production zone *i* to attraction zone *j* by *p.c.m.*	Fixed
$C^{(PA)}_{ijpcmt}$	PA costs of travel for time period *t* converted from relevant OD outward and return costs from production zone *i* to attraction zone *j* by *p.c.m.*	
$C^{(OD)}_{ijpcms}$	Skimmed OD generalised costs of travel for outward trips in time period s from origin *i* to destination *j* by *p.c.m* (directional from-home).	
$C^{(OD)}_{ijpcmtr}$	Given time period *t*, skimmed OD generalised costs of travel for trips returning home in time period r from origin *i* to destination *j* by *p.c.m* (directional to-home)	
$\Delta C^{(PA)}_{ijpcmt}$	The change of PA costs from the forecast year over the base year from production zone *i* to attraction zone *j* in time period *t* by *p.c.m.*	WebTAG

[9] For details, see WP3 on creating base year matrices
[10] Whether the three new RSI’s or the old RSI’s that are found to be usable.

Notation	Description	Source Data
CC	Composite costs (logsums) over IHL	WebTAG
λ, θ	A series of IHL sensitivity parameters and scale parameters over FMTD stages.	Subject to realism tests
$T^{(PA)}_{ijpcmt}$	Latest production-attraction (PA) trips from production zone *i* to attraction zone *j* in time period *t* by *p.c.m*.	Output directly from the demand model
$T^{(OD)}_{ijpcms}$	Estimated OD outward trips from origin *i* to destination *j* in time period *s* by *p.c.m* (directional from-home).	
$T^{(OD)}_{ijpcmtr}$	Given time period *t*, estimated OD return trips that happen in time period *r* from origin *i* to destination *j* by *p.c.m* (directional to-home).	
$T^{(OD)}_{ijpcmt}$	Given time period *t*, the latest total OD trips estimated in the current demand/supply loop from origin *i* to destination *j* in time period *t* by *p.c.m* (non directional).	Send to the assignment stage

Create Outward and Return Proportion

For a given time period t, the reference proportion of outward from-home trips over total trips is calculated via RSI data[11], which should only be used once to create reference PA matrices by time period and by all other segmentation:

$$Pout^0_{IJpcmt} = \frac{T^{(RSI)}_{IJpcms}}{T^{(RSI)}_{IJpcmt}} \quad (1)$$

Return reference proportions are assumed fixed over the forecasting years for each time period (s). These factors for the demand model are presented in the next chapter (supplied by DfT and refined locally). For a given time period s, reference proportions for trips returning home in time period r were subject to the following constraint:

$$\sum_r \mathrm{Pret}^0_{pcmsr} = 1 \quad (2)$$

Create Reference PA Costs and Demands

For a given time period t, reference demands and costs are calculated by the following two formulae respectively:

$$T^{(PA)0}_{ijpcmt} = T^{(OD)0}_{ijpcms} = T^{(OD)0}_{ijpcmt} Pout^0_{ijpcmt} \quad (3)$$

$$C^{(PA)0}_{ijpcmt} = (C^{(OD)0}_{ijpcms} + \sum_{r \geq s} (C^{(OD)0}_{ijpcmtr})' \mathrm{Pr}et^0_{pcmsr}) / 2 \quad (4)$$

where $r \geq s$ means that r ranges from the outward from-home time period (s) up to the last time period (op) in a day, and the ()' means a transpose. In other words, the costs defined in (4) are a weighted average of the outward and return legs.

The daily 24-hour reference demand is the sum of the time period PA demands (which account for only half of total OD demands):

$$T^{(PA)0}_{ijpcm24} = \sum_t T^{(PA)0}_{ijpcmt} \quad (5)$$

Convert OD Costs to PA

For each demand/supply loop, the skims from the OD-based assignment by time period (t) were converted to PA costs (for an average single leg) for feeding into the demand model. With the

[11] Whether the three new RSI's or the old RSI's that are found to be usable.

same formulation as given by (4), the PA costs in forecasting considered both outward and return journeys simultaneously as a weighted sum given below:

$$C^{(PA)}_{ijpcmt} = (C^{(OD)}_{ijpcms} + \sum_{r \geq s} (C^{(OD)}_{ijpcmtr})' \Pr et^{0}_{pcmsr}) / 2 , \qquad (6)$$

where $r \geq s$ means that r ranges from the outward from-home time period (s) up to the last time period (op) in a day.

By adding the relevant return costs, say, any AM tolls will be appropriately allocated to to-home trips occurring in the same and subsequent time periods (i.e. IP, PM and OP), and therefore the impact of AM tolls will be distributed across all time periods rather than incorrectly allocated to the AM demand calculation only.

Incremental Demand Modelling

For an IHL-based demand modelling, the change of PA costs at the bottom level of hierarchy are simply defined as:

$$\Delta C^{(PA)}_{ijpcmt} = C^{(PA)}_{ijpcmt} - C^{(PA)0}_{ijpcmt} \qquad (7)$$

Based on $\Delta C^{(PA)}_{ijpcmt}$, the composite costs (i.e. the structured logsums over the various stages of the demand model) are calculated in the standard way, as presented above.

$$CC = f(\Delta C^{(PA)}_{ijpcmt}, T^{(PA)0}_{ijpcmt}, \lambda, \theta) \qquad (8)$$

Based on the CC and others, the demand model calculates a new set of PA outward-leg demands for each demand/supply loop, or simply:

$$T^{(PA)}_{ijpcmt} = f(CC, T^{(PA)0}_{ijpcmt}, \lambda)$$

Convert PA Demands to OD for Assignment

The outward PA demand $T^{(PA)}_{ijpcmt}$ output from the demand model are then converted to the OD form for assignment. The outward from-home OD demands are simply the latest PA demands output from the demand model for the time period:

$$T^{(OD)}_{ijpcms} = T^{(PA)}_{ijpcmt} \qquad (9)$$

Return-leg demands is constrained by relevant outward from-home trips that take place in previous time periods. As indicated above, for example, the PM return demands corresponded to proportions of trips travelling out in the AM period, IP period, and PM period respectively.

For a given time period (t), the formula to calculate to-home demand is given below by applying the fixed return proportions over the latest outward from-home trips:

$$T^{(OD)}_{ijpcmtr} = \sum_{s \leq r} \Pr et^{0}_{pcmsr} (T^{(OD)}_{ijpcms})' , \qquad (10)$$

where $s \leq r$ means that s ranges from the first time period (AM) up to the current time period t.

Finally, the OD assignment demands were simply the sum of from-home and to-home trips:

$$T^{(OD)}_{ijpcmt} = T^{(OD)}_{ijpcms} + T^{(OD)}_{ijpcmtr} \qquad (11)$$

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