Oxfordshire Strategic Model

Demand Model Development Report

September2014

Plan Design Enable

Notice

This document has 55 pages including the cover.

Document history

Job number: 5125364			**Document ref: 5125364 - OSM Demand Model Development Report.docx**			
Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
1	Draft Report	WW	AA	GB	AA	12/09/14

Table of contents

Tables

Figures

1. Introduction

1.1. Background

Oxfordshire County Council has commissioned Atkins to develop a suite of multi-modal strategic models to provide evidence to support robust future assessments for funding bids and scheme prioritisation, particularly in regard to transport scheme assessments that meet the DfT Web Transport Appraisal Guidance (WebTAG). The strategic model will also help develop business cases for future major schemes, route strategies and carry out scenario testing of the transport impacts of new development and mitigation measures.

The Oxfordshire Strategic Model (OSM) is a new, fit-for-purpose transport model that has been developed specifically to assess transport interventions in Oxfordshire. Post-SEP submission, it will be used by the LTB and LEP to provide guidance on detailed scheme design and to produce the value-for-money elements at the three scheme business case stages. Within these three stages, there will be particular emphasis on using model to identify the impact of transport and development in Oxfordshire. The model is fully multi-modal and WebTAG compliant.

Within this background, there needs to be particular emphasis on developing model to identify the impact of transport and development in Oxfordshire. The model needs to be multi-model and WebTAG compliant to underpin specific requirements of the Department for Transport.

The model development programme involves the delivery of the following Work Packages:

- WP1 Data and Survey requirements
- WP2 Main Demand Model Specifications
- WP3 Road Traffic Model (RTM) and Public Transport Model (PTM) Specifications
- WP4 Study Objectives
- WP5 Calibration and Validation of: RTM
- WP6 Calibration and Validation of: PTM
- WP7 Main Demand Model Development
- WP8 Model Forecasting
- WP9 Appraisal Tools

This report covers the WP7 of these deliverables, which details the development of Main Demand Model (MDM) for OSM.

1.2. Key Design Considerations

The key consideration for developing the WebTAG compliant OSM is to provide a robust evidence base for the appraisal of major highway and public transport schemes, as well as the assessment of local development proposals. The major interventions are principally around Bicester, Oxford, and the Science Vale corridor. The model also needs to pay special attention to the A40 corridor between Witney and J8 of the M40, as well as public transport and P&R. Other considerations are that the run time should not exceed an overnight 16 hour period.

The OSM should represent travel conditions robustly on the highway and public transport networks in the core study area and 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.

The function of the MDM is to reflect the impact of cost changes (in generalised minutes form) 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 main mode, time period, destination, and sub-mode choice mechanism. The respective modal matrices are then assigned to their corresponding 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.

1.3. Scope and Contents of this Report

This report consists of six chapters. Following this introductory chapter, chapters contained in this report are as follows:

- Chapter two summaries the development of OSM highway and PT assignment models.
- Chapter three describes the structure of the demand model, and its functional forms.
- Chapter four presents demand modelling sensitivity parameters , segmentation factors derived from survey data, and the Value of Time (VOT) variation with distance for consumer trips.
- Chapter five provides convergence statistics and realism test results; including highway fuel, journey time elasticities and PT fare elasticities by purpose, time period and person type.
- A summary of the model development is presented in Chapter six.

2. Base Year Highway and Public Transport Models

2.1. Introduction

The base year 2013 RTM and PTM were developed with newly-collected data. The RTM data included journey time and traffic count data as well as INRIX mobile phone data for the demand and the PTM data included passenger counts and interviews on bus and rail. Both models were validated against appropriate DfT's DMRB and WebTAG guidance.

2.2. Study Area and Zoning System

The OSM modelled area covers the whole Great Britain. Following the latest WebTAG guidance M3, the area is divided into Fully Modelled Area and External Area. The Fully Modelled Area (FMA) is also subdivided into Area of Detailed Modelling (ADM) and the rest of the Fully Modelled Area. The ADM covers the area bounded by:

- Bicester to the north;
- Wallingford to the east;
- Burford and Witney to the west; and
- Wantage and Didcot to the south.

The rest of the Fully Modelled Area covers the remainder of Oxfordshire County in addition to some hinterland area including Swindon, Reading, High Wycombe and Stratford-upon-Avon etc as shown in Figure 2-1. The External Area covers the rest of Great Britain in a skeletal form and connects the ADM via the rest of FMA.

Based on the TEMPRO and 2011 UK Census geographic zone boundaries, a new zoning system was developed for OSM, which serves as a common basis for all highway, public transport and demand model components. In total, there are 704 zones covering the whole Great Britain, among which there are 555 zones within Oxfordshire county boundary, as shown in Figure 2-2.

The summary of OSM zones by area is shown in Table 2-1. In particular, all five existing P&R sites and major car parks in Oxford are given specific zones. Meanwhile, two separate zones are assigned to Heathrow and Gatwick airport, and Greater London is split into 5 individual zones. It is also estimated that a total of approximately 120 dummy zones will be added later to allow for future development proposal testing.

Figure 2-1 Area of Detailed Modelling and Fully Modelled Area for OSM

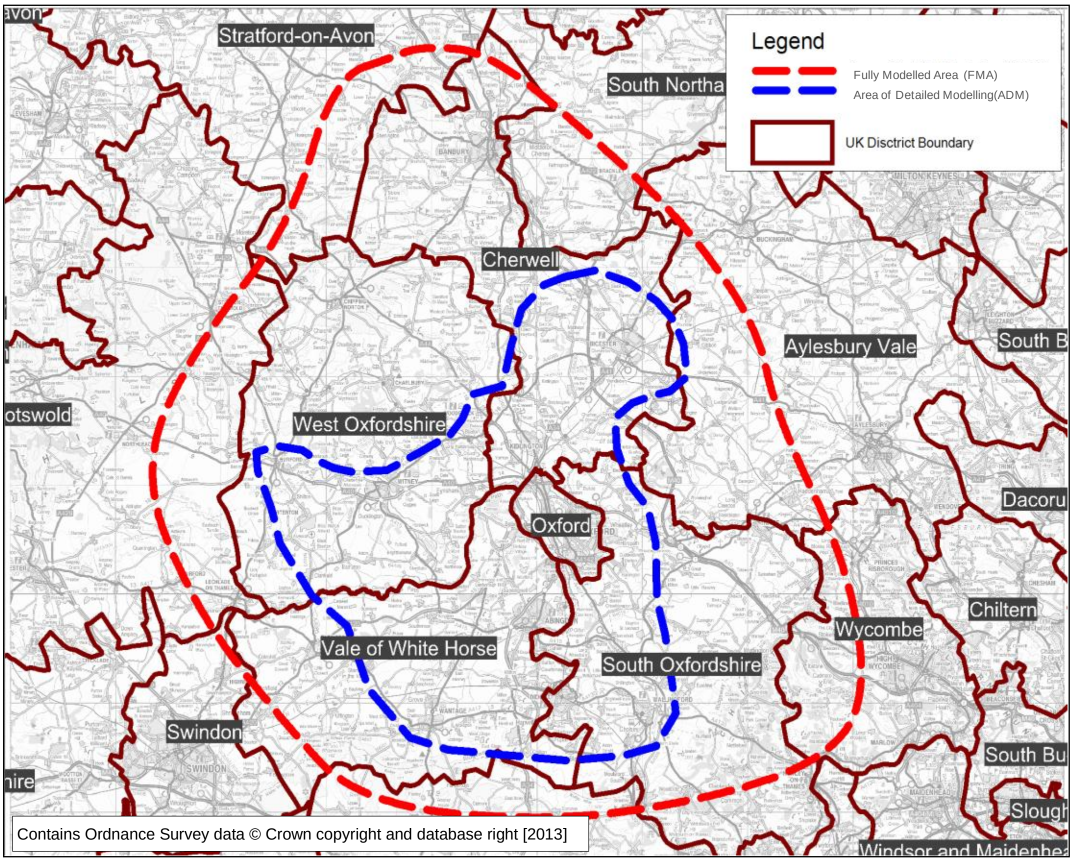
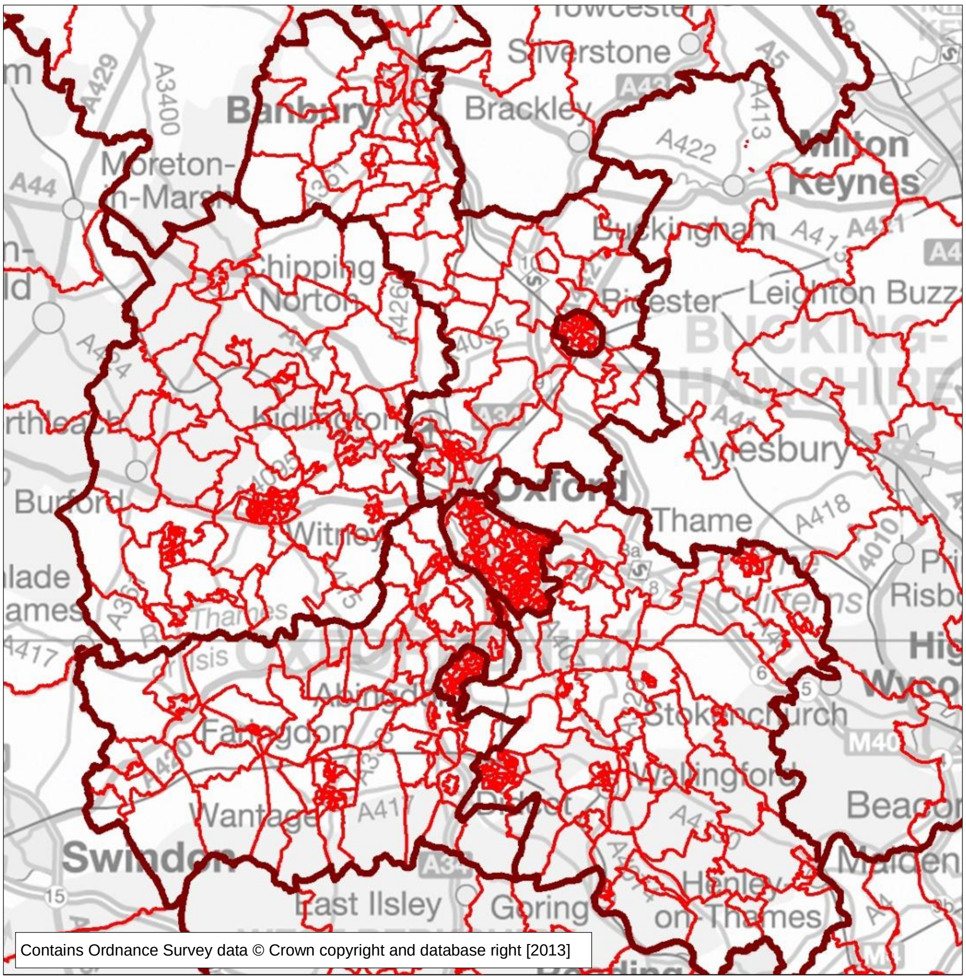


Table 2-1 OSM Zones by area

Area	No. of Zones
Oxford	130
Didcot / Wallingford / Wantage	42
Bicester	26
Abingdon	30
Witney	25
Banbury	7
Rest of Oxfordshire	293
Hinterland	115
Rest of UK	36
Total	**704**

Figure 2-2 OSM zones in Oxfordshire



2.3. OSM Sector System

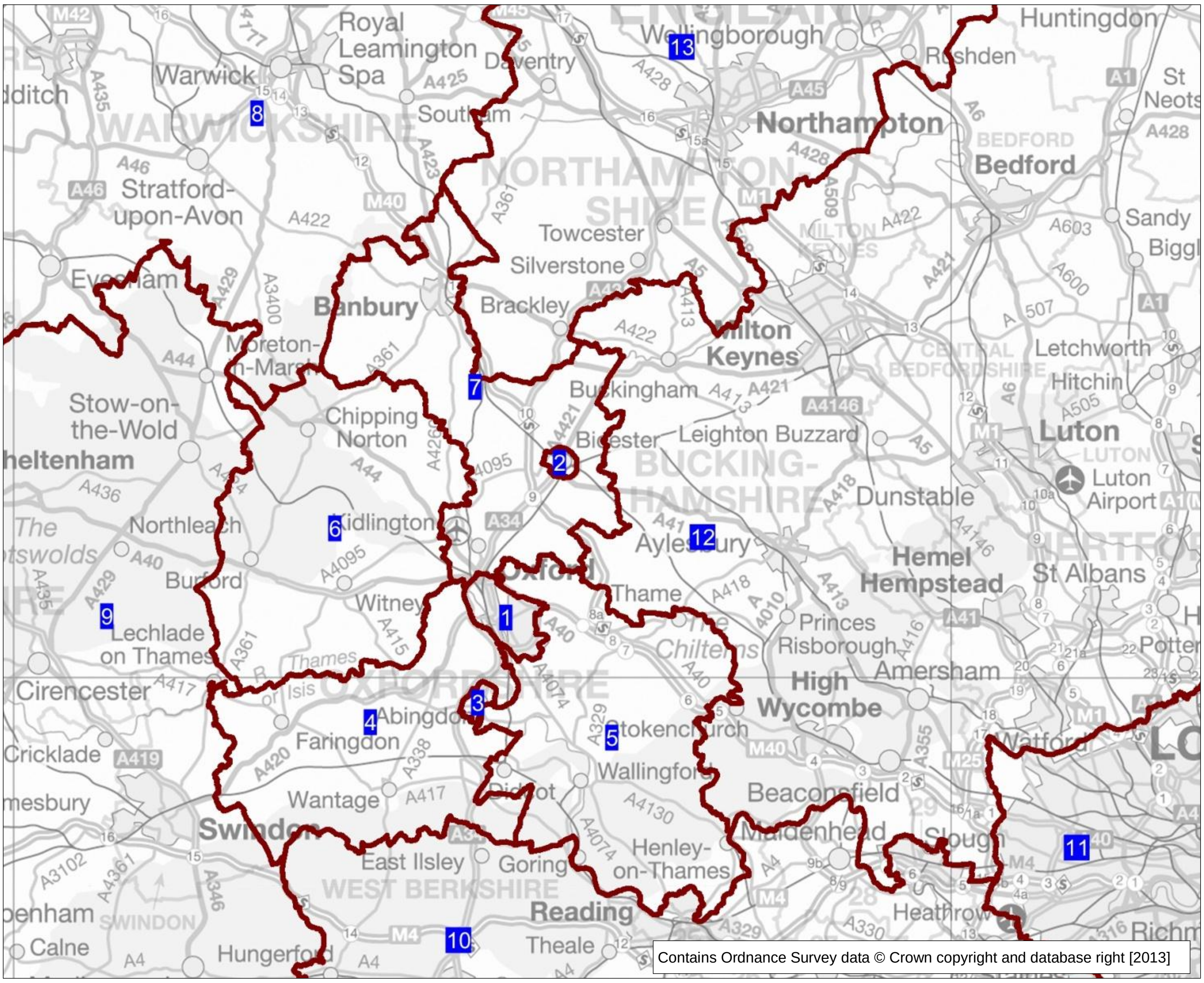
During the OSM highway assignment model development stage, a 13-sector system was developed to facilitate matrix manipulations at an aggregated level. The sectors are generally compatible with NTEM (TEMPRO) and UK district boundary. The size of the sectors decreases from the external sectors, to hinterland sectors, and to the sectors in the core study area in Oxfordshire. The 13-sector system can also further be aggregated into a 4-sector and 2-sector system, as shown in Table 2-2.

- Figure 2-2 shows the location of 13 sectors for OSM.

Table 2-2 OSM Sector Systems

13 Sector	Sector Description	4 sectors	2 sectors
1	Oxford	1	1
2	Bicester	2	1
3	Abingdon	3	1
4	Wantage/Grove and rest of Vale of White Horse	3	1
5	Didcot & rest of South Oxfordshire	3	1
6	Witney& rest of West Oxfordshire	3	1
7	Kidlington, Banbury & rest of Cherwell	3	1
8	West Midlands & Wales	4	2
9	Gloucestershire & Wiltshire& rest of SW region	4	2
10	Rest of SE Region	4	2
11	Greater London	4	2
12	Milton Keynes, Buckinghamshire & East of England	4	2
13	EM, Northern Regions and Scotland	4	2

Figure 2-3 OSM 13 Sector Map



2.4. Highway Assignment Model

Assignment Model User Classes

The OSM base year highway assignment model includes 3 vehicle types, i.e. car, light good vehicles (LGV) and heavy goods vehicles (HGV). The matrix estimation (ME) was carried out on the car matrix at all purpose level, along with LGV and HGV matrices. The car matrix was further split into 2 classes by trip purpose after ME process, as follows;

- Employer Business (Work);
- Commute and Other (Non-Work)

No purpose split was applied to LGV and HGV matrices. This brings the total modelled user classes to 4.

Modelled Time Periods

Based on the analysis of counts data (from RSI and MCC[1] surveys) within Oxfordshire, a single hour in each of the three peak periods was specifically modelled, as follows:

- Morning peak (AM) assignment peak hour of 08:00 to 09:00;
- Inter-peak (IP) assignment covering an average hour between 10:00 to 16:00; and
- Evening peak (PM) assignment peak hour of 17:00 to18:00.

For the model to adequately represent network performance in congested urban conditions additional traffic load is needed on the queues at the start of the modelled hour. The PASSQ option in SATURN enables this feature and requires information about queuing from the previous hour to be passed onto the model hour.

The PASSQ option was only used for the morning and evening peak models and based on factoring the prior matrix to represent the previous model hour (07:00-08:00) and (16:00-17:00) respectively.

2.5. Public Assignment Model

Network

The PTM was developed by EMME software which contains bus and rail mode. The zone system and network definitions for the highway, public transport and demand models are shared. The highway network is SATURN based and this was converted to an EMME based PT model as the skeleton network. Bus services from major operators such as Stagecoach and Oxford Bus were then coded as the equivalent bus lines for the public transport network. The rail network, covering the main line between London Paddington and Reading, including the branch lines and part of London Tube network, was added to the EMME bus network to create an integrated PT network.

Modes and Vehicles

The modes and vehicle types included in the PT assignment model include car, transit (for bus and rail mode) and auxiliary transit (for walk). The existing P&R demand and services in Oxford, were also specifically validated against P&R car park and bus on-board counts. The default speed for each vehicle type was rarely used in the public transport assignment, as journey times were calculated from the SATURN highway travel times to simulate on-line running. Default speeds are available, however, for bus only sections such as bus lanes and other priority infrastructure, where the speed was checked against timetable data to ensure appropriate assumptions are made. Rail speeds for each segment were based on timetable information, taking account of non-stop services.

Time period and user class

The PT modelled time periods are identical to the RTM as described in section 2.4. Both bus and rail demand matrices were initially split as 5 purposes, namely, home based work (HBW), home based

[1] Manual Classified Count

employer business (HBEB), home based other(HBO), non-home based employer business(NHBEB) and non-home based other (NHBO). They are subsequently merged as one single bus and one single rail matrix for PT assignment.

Model Calibration and Validation

The calibration and validation of the PT assignment model was undertaken separately for the bus and rail modes. Online timetable information system was used to validate the journey times within the PT model. Electronic Ticketing (ETM) data; boarding and alighting surveys at key bus stops and rail stations; and bus occupancy counts at screenlines were also used for comparison against modelled flows.

The PTM was first calibrated by adjusting the bus matrix so that modelled and observed counts are in parity across screenlines. The P&R bus passengers were checked and validated against existing P&R car park arrival and departure counts. The model was then validated for each of the three time periods against best practice and in line with the Department for Transport guidance (WebTAG)

3. Demand Model System

3.1. Introduction

The OSM was developed from Atkins' G-BATS3 demand model which has been tried and tested in the appraisal of a wide range of transport options. This includes schemes such as highway improvements, demand management and parking charges as well as bus rapid transit, rail, park and ride, and traffic management schemes. The demand model was converted from the software platform of EMME version 3 to EMME version 4[2], taking the new features of the software improvements especially the change from traditional macro language to Python scripts combined with EMME newly-introduced Modeller tools.

The demand model represents travel choices across a typical 24-hour weekday period explicitly representing an AM peak period (07:00 – 10:00), an Inter-Peak period (10:00 – 16:00), a PM Peak period (16:00 – 19:00), and an off-Peak period (19:00 – 07:00).

The demand model is a variable demand model in an incremental hierarchical form, pivoting off the base year, and estimating the change in choice between travel alternatives (frequency, modes, time periods, and destinations) depending on the change in generalised costs or disutility.

The demand model works in conjunction with RTM and PTM (elements of the multi modal model) whereby generalised costs from the assignment models are input into the demand model to produce new forecast matrices. This process is repeated until the demand model has suitability converged.

The demand model uses a Production – Attraction (PA) formulation as recommended in WebTAG Unit M2. It also includes variation of the Value of Time (VOT) with trip length for non-Work trips.

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 model was developed in a modular fashion to enable subsequent adaptation in response to further updates and refinement. The design of the demand model closely follows the latest DfT WebTAG guidance including:

- Unit M2 variable demand modelling;
- Unit M3-1 highway assignment modelling;
- Unit M3-2 public transport assignment modelling; and
- Unit M5-1 modelling parking and Park-and-ride.

3.2. Temporal Scope

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 AM and PM peak periods rather the peak hour proportions calculated from related data source.

[2] The version used is EMME 4.0.8 release.

The definition of the modelled time periods is based on TAG Unit M2 with macro 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.

3.3. Demand Segmentation

Within the Demand Model

Travel demands in the demand model were segmented by car availability and journey purpose as described below:

By person type

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

By household income

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

Income bands are referenced from WebTAG Data Book and also consistent with National Travel Survey (NTS). The income bands by time period for car, bus and rail were derived from NTS for households[3] in Oxfordshire, as shown in Table 3-1.

Table 3-1 Income band splits for MDM

Mode	Income band	AM			IP			PM		
		HBO	NHBO	HBW	HBO	NHBO	HBW	HBO	NHBO	HBW
Car	Income Low (IL)	25%	18%	10%	25%	18%	10%	25%	18%	10%
	Income Medium (IM)	30%	31%	32%	30%	31%	32%	30%	31%	32%
	Income High (IH)	45%	51%	58%	45%	51%	58%	45%	51%	58%
	Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Bus	Income Low (IL)	50%	34%	12%	same as Bus AM			same as Bus AM		
	Income Medium (IM)	25%	30%	38%						
	Income High (IH)	25%	36%	50%						
	Total	**100%**	**100%**	**100%**						
Rail	Income Low (IL)	48%	25%	10%	same as Rail AM			same as Rail AM		
	Income Medium (IM)	27%	30%	35%						
	Income High (IH)	25%	45%	55%						
	Total	**100%**	**100%**	**100%**						

Table 3-2 gives the segmentation undertaken within the MDM. Overall, there are 16 demand segments including income segmentation (reserved for future development). Note that the work trips

3 NTS data from 2002 to 2010 were combined in order to increase the sample size. Bus and rail income bands were not split by time period due to low sample rate.

(i.e. HBEB and NHBEB) and NCA trips are not segmented by income band which are in line with WebTAG guidance[4].

Table 3-2 Demand Model Segment Number

Supply Purpose	Demand Purpose	Car Available (CA)			Non Car Available (CA)
		<£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 Highway Assignment Model

The OSM demand model segmentation was undertaken in a more aggregated form than that adopted for the demand models to reduce the model runtimes. There are four highway demand segments aggregated from the demand segments:

- Car Non Work (demand segments 0-5, and 8-10);
- Car Work (demand segments 6 and 7);
- Lights LGV; and
- Heavies (HGV).

The goods vehicle movements for LGV and HGV are not considered inside the demand model. As suggested by WebTAG, their demand assessment is undertaken using assumptions based on fixed exogenous growth.

Within the Public Transport Assignment Model

Within the EMME-based Public Transport assignment models, no distinction is made between journeys undertaken for different purposes, household income bands or car availability, due to the restrictions in the software. The model assigns a combined single user class instead. Furthermore, as crowding is not specifically modelled in the PT assignment model the PT routing choice and subsequent journey time skim are generally independent of bus and rail demand. The overall public transport demand is allocated (by logit-based choice mechanisms) to the various PT sub-modes, where available.

For rail and bus, skimmed EMME assignment costs including walk time, wait time, in-vehicle time and interchange are incorporated into the demand model via the WebTAG formula as described in the following section.

3.4. Generalised Cost Formulation

Private Car

TAG Unit M2 Chapter 3 defines the generalised cost for private car person trips and includes elements relating to:

- Operating costs (including fuel cost);
- in-vehicle time;

4 WebTAG requires income segmentation for CA users only when testing road user charging (RUC) schemes. There is no requirement for the segmentation of business travellers or NCA travellers, as for the former, the charge would be paid by employers and the latter is captive to public transport and therefore no impacts exist on RUC schemes.

- parking costs;
- access/egress time; and
- tolls or other user charges.

The demand model follows the WebTAG formula for the definition of generalised costs for cars: G_{car}, measured in units of time in minutes:

$$G_{car} = V_{walk} * t_{walk} + t_{ride} + d * VOC/(occ * VOT) + C_{park}/(occ * VOT)$$

Where:

- V_{walk} is the weight applied to walking time (assumed 0 currently);
- t_{walk} is the total walk time to/from the car (minutes);
- t_{ride} 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) in 2010 price: 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 by person (pence per minute) in 2010 price; and
- **Cpark** is the parking cost and tolls (if and when incurred), in monetary units (pence).

The evaluation of vehicle operating costs (**VOC), values of time (VOT)** and occupancy (**occ)** is undertaken by following the WebTAG TAG Book (a replacement of previous release of TAG Unit 3.5.6), which provides guidance for estimating Values of Time and vehicle operating costs for general scheme appraisal and assessment..

Public Transport

TAG Unit M2 section 3 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.

The WebTAG formula for PT generalised cost G_{PT}, measured in units of time (minutes) is given as:

$$G_{PT} = V_{walk} * t_{walk} + V_{wait} * t_{wait} + t_{ride} + C_{fare}/VOT + C_{interchange}$$

Where:

- V_{walk} is the weight applied to time spent walking;
- t_{walk} is the total walking time to and from the service;
- Vwait is the weight applied to time spent waiting;
- t_{wait} is the total waiting time for all services used on the journey;
- t_{ride} is the total in-vehicle time;
- C_{fare} is total fare in pence;
- VOT is the appropriate Value of Time (pence per minute in 2010 price); and
- $C_{interchange}$ (=10 minutes) is the interchange penalty if the journey involves transferring from one service to another.

The walking time weight V_{walk} and waiting time weight V_{wait} are 2.0 and 2.5 for both bus and rail mode which are in line with the recommended WebTAG range.

It is difficult to derive an appropriate bus fare system within Oxfordshire due to the prevailing concessionary fare passengers and a variety of seasonal ticket fares, as well as various bus service operators within the county. Moreover, since the PT demand segments, as described in previous sections, do not specifically include concessionary fare passengers it is important that the bus fare matrices are derived to represent the average fare paid by all bus passengers, including concessionary fare and seasonal ticket users.

A distance based bus fare system was then derived from the bus ETM data and fare charts received from major bus operator Oxford Bus & Stagecoach covering bus service route X13, 4, X32, 26, 16 and X90. These routes, combined with local and long service between major cities and towns, represent a typical fare purchase and usage across the key study area. The distance bands were assumed as 0-2 km, 2-5 km, 5-10 km, 10-15 km, 15-20 km, 20-25 km, 25-50 km and >50 km, taking account of bus service coverage and model geographic location. Note that to keep simplicity it was also assumed that any bus trip with travel distance longer than 50 km was kept as a fixed fare charge of £4.5 in 2013 price base[5].

On the other hand, the time period and journey purpose for bus passengers were also considered, due to the following considerations:

- Bus passengers with employer business purpose and infrequent bus users and therefore generally purchase single or return tickets, and their patronage is generally much lower than commuting and other trip purpose. Table 3-3 shows the bus patronages by time period, derived from 2013 bus passenger interview surveys.
- Bus passengers for commuting generally purchase return tickets or seasonal travel cards, most starting their journeys in AM or PM peak period;
- Most concessionary users are for “Other” purpose such as shopping and recreation etc., which normally board buses during Inter peak period. For the rest passengers with “Other” trip purpose, the tickets are generally formed by a mixture of single, return tickets and seasonal travel cards.

Table 3-3 Bus patronage by purposes

Time Periods	EB	Commuting	Other	Total
AM (08:00-09:00)	1.4%	46.7%	51.9%	100%
Av. IP (10:00-16:00)	2.0%	23.2%	74.8%	100%
PM (17:00-18:00)	1.6%	43.2%	55.2%	100%

The final distance-based bus fare systems by journey purpose are shown in Appendix Table A-1, A-2 and A-3 for AM peak hour (08:00-09:00), average inter peak hour (10:00-16:00) and PM peak hour (17:00-18:00) respectively, which was derived from the average of fare purchase and bus usage across the routes analysed. From the tables it can be found that:

- The fare unit prices for employer business passengers is higher than commuting and “other” purpose since the former are formed by occasional bus users who are most likely to purchase single or return tickets;
- Bus passengers with “other” purpose have a lower average fare than commuting and employer business users since they include a large proportion of concessionary passes and discount ticket holders. Meanwhile the average fare in Inter peak is lower than AM and PM peak for passengers with “other” purpose due to the higher percentage of concession and discount ticket usage.

The bus fares were initially derived in 2013 price base and then converted to 2010 price using the RPI index, to maintain a consistent price base with VOC and VOT in the generalised cost formula for

[5] This is based on the cost of £180 for the monthly pass for Oxford Tube, and therefore the cost for a one-way trip is the average weekday price of £9 divided by 2, i.e. £4.02 discounted into 2010 price base.

highway and PT demand segments within the demand model. The distance based bus fare system was then applied onto the distance skim (excluding walking distance on both ends) from base year PT assignment model to produce the base year bus fare matrices for the MDM.

A distance based rail fare system was derived following a similar approach to bus. In contrast, a selection of rail station to station pairs was identified which covered short, middle and long rail travel distance range as shown in Table 3-4:

Table 3-4 Selected Rail Station Pairs

Station a	Station b	Distance(KM)
Oxford	Appleford	13
Oxford	Didcot Parkway	16
Didcot Parkway	Reading	28
Oxford	Banbury	37
Oxford	Reading	44
Banbury	Didcot Parkway	53
Birmingham	Banbury	68
Banbury	Reading	81
Bicester North	London Marylebone	88
Oxford	London Paddinton	91
Birmingham	Bicester North	91
Oxford	Worcester Shrub Hill	92

The current ticket price for single, day return, seasonal ticket cost per journey by time period was obtained from the National Rail website[6]. From the website, the seasonal ticket price per journey was also extracted, based on the broad assumption of two daily journeys (i.e. an outward and return journey) with an allowance for annual leave.

The ticket splits by purpose for the whole GB were obtained from NRTS, along with the purpose splits from OSM rail survey data, which were then applied to the rail ticket fares to derive a weighted rail ticket fare by distance for AM, IP and PM peak. The distance bands were split into 0-20km, 20-40 km, 40-60km, 60-90 km ad >90 km.

On the other hand, it was found that unlike bus distance based fare, the rail fare also varied significantly by the geographic location of journey origin and destination. For example, with identical 91km journey distance, the day return ticket in the AM peak for a journey from Oxford to London Paddington costs £58, in contrast to a ticket price of £24.4 for a journey from Birmingham New Street to Bicester North rail station. To take this into account, the distance based rail ticket was treated separately for any rail journey from/to OSM zones 9447, 9448, 9454, 9455 and 9456 in Greater London including Heathrow airport.

The rail fares, derived in 2013 price, were converted in 2010 price by RPI index as shown in Appendix B. The rail fare system was then applied to the distance skim (excluding walking distance on both ends) from base year PT assignment model to produce rail fare matrices for demand model.

Note that the impact of rail or bus crowding is not considered in the current demand modelling system.

[6] http://www.nationalrail.co.uk/

3.5. Demand Model Structure

The MDM has a hierarchical logit choice structure as shown in Figure 3-1. Compliant to WebTAG, an incremental demand modelling approach was adopted which responds to changes from the base generalised costs, measured in generalised minutes.

Sub-mode choice between rail and bus is carried out as a logit formulation. However, further mode choice between bus and bus rapid transit (BRT), when available in future, is undertaken within the PTM, i.e. they are within the same segmentation in the demand model. This is achieved by defining bus and BRT as different modes in EMME, as agreed by DfT in earlier discussions on other projects.

The P&R sub-mode is a highway logit based sub mode which means that P&R can generally extract 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 3-1. In summary as the demand model is incremental the first choice is between car and P&R and significant generalised cost changes are required for choices closer to the top of the hierarchical tree to have an impact whereby a choice of main modes is made (Car/P&R vs. Public Transport)

The primary reason to place P&R as a sub-mode of highway demand (as opposed to public transport demand) was based on the consideration to model the direct impact of P&R schemes on car-all-the-way users. More detailed description on P &R modelling has been given in section 3.7.

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 3-5 for each of the six stages in the demand modelling. Note that:

- Stages 1 to 5 are undertaken within the MDM whilst stage 6 is provided through the separate RTM and PTM.
- In the current demand model structure the slow mode choice (e.g. walking and cycling) is not explicitly modelled as it is assumed the modal transfer mechanism can be largely represented by frequency choice, in accordance with guidance.

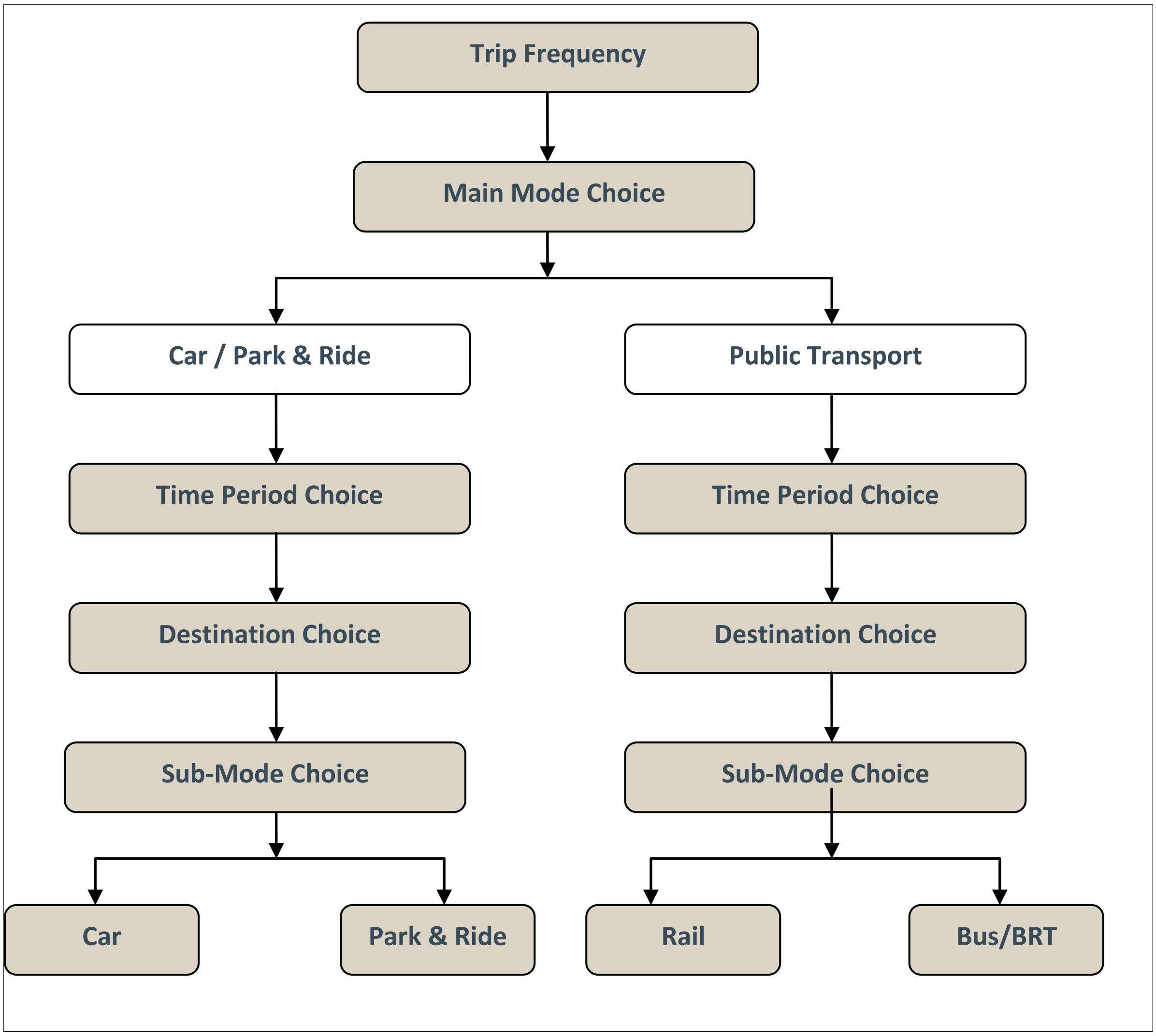
The main mode choice (stage 2) between car and PT operates for the CA person type only. The demand model operates at the 24-hour level until the time of day choice (stage 3) is undertaken. For destination choice modelling (stage 4), the demand model considers all four time periods AM/IP/PM/OP for all 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.

Traditionally smarter choices have been considered through assumptions (for walking and cycling trips) which are applied to the converged highway and public transport matrices before reassignment without further iterations with the demand model. An alternative approach to consider smarter choices adopts a pre main mode choice stage in the demand model hierarchy which identifies walking and cycling trips via defined distance bands. Identified trips are removed prior to main mode choice but are added to the public transport model matrices for assignment. The advantage of this method is the removal of walking and cycling trips from elements of the demand model which might not be appropriate for non-motorised trips such as destination choice. This is a potential upgrade to the model in the future.

Table 3-5 Demand Model Overview

Stage	Model	Temporal Scope	Form	Person Type
1	Frequency Modelling	24-hour	PA Trip Ends	All (CA & NCA)
2	Main Mode Choice	24-hour	PA Trip Ends	CA
3	Time Period Choice	Translate 24-hour to AM (3hr), IP (6hr), PM (3hr) and OP (12hr) periods	PA Trip Ends	All (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	1-hour	OD matrices	All (CA & NCA)

Figure 3-1 Demand Model Choice Structure



3.6. Model Formulation

Incremental Logit-based

The choice modelling for various demand responses follows an incremental approach as required by WebTAG, pivoted off the base year situation. 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 M2, Appendix E). The formulae given below are specified in terms of the WebTAG hierarchical logit 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 (WebTAG Unit M2, paras 4.6.5). WebTAG does not provide illustrative parameters for frequency other than noting its position within the demand model structure. The lambda values for the frequency parameters were 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

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

where:

- i : production end; p: purpose; c: person type such as CA, NCA, or income segment;
- T_{ipc}^{0} : reference zonal production over i.p.c;
- T_{ipc} : output zonal production over i.p.c;
- θ_{freq} : frequency choice structure (or scale) parameter; and
- $\Delta U_{ipc} = \ln(\sum_m T_{ipcm}^{0} e^{\theta_m \Delta C_{ipcm}} / T_{ipc}^{0}$: logsum of lower level main mode choice, where m is mode, θm is the scale parameter for mode choice, and C is generalised cost.

WebTAG does not provide indicative values for theta. Accordingly, the frequency modelling structure theta parameter is 0.05 for both purposes (HBO and NHBO) and for both person types (CA and NCA), imported from experiences in Atkins previous projects.

Main Mode Choice

WebTAG suggests that the main mode choice between car 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:

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

where:

- i: production end; p: purpose; c: person type; m: main mode (car or PT); k: used for summation over main modes car and PT;
- production trip ends over i.p.c.m;
- 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 sensitivity parameter
- T_{ipc} : input zonal production trip ends over i.p.c 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 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 were set to the same value as used in main mode choice – in mathematical terms, they are effectively modelled simultaneously in a multinomial form.

The formula for the time period choice between the four 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 λ_{dist} is the destination choice sensitivity parameter;
- $\Delta U_{ipcmt} = \ln(\sum_j B_{jp} T^0_{ijpcmt} e^{\lambda_{dist} \Delta U_{ijpcmt}} / T^0_{ipcmt})$: 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 was not as straightforward - further details are provided below.

Destination Choice

WebTAG recommends that the destination choice should be modelled as singly (origin) 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 was developed to undertake the HBW distribution modelling.

The formula for the singly constrained destination choice was:

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

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;
- 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, λsub is the sensitivity parameter for 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 (production end) constraints:

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

For doubly constrained distribution, another set of column (attraction end) constraints is also introduced:

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

The adopted rectangular 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_{dist} : destination choice sensitivity parameter;
- B_{jp} : attraction balance factors for purpose p and destination j, estimated via the rectangular Furnessing procedure;
- 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 are estimated via inner loops between this distribution stage and the time period choice and main mode choice above them. This is necessary because the trip ends from the above two stages are a function of the logsum (or B_{jp}) of this doubly constrained stage, which in turn, is 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 were:

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

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

Note that within the inner loops, before the logsum is evaluated, the attraction balancing 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 choice is 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 3-1), to facilitate the sub-mode switching in forecast years between highway and P&R only.

The formula for the sub mode choice was:

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

where:

- s: sub-mode, k: used for summation over highway submodes car and P&R, or PT sub-modes rail, 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 generalised costs 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 MDM adopts the same value of -01 for both highway and PT sub mode choice.

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 cost differences producing unrealistically high elasticities, if costs are not scaled. More details of the cost damping functions used in the demand model are given in section 3.8.

3.7. Modelling Park and Ride

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

WebTAG Unit M5-1 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.

Currently there are five P&R sites on the outskirt of the city of Oxford, as shown in Table 3-6. Overall the P&R bus service has an average frequency of every 10-15 minutes, a ticket from P&R site to city centre is charged at £1.70 for a single and £2.70 (£2.40 for off-peak) for a return journey[7].

Table 3-6 Oxford P&R Information

Site	Zone	P&R bus services	P&R parking charge	Parking capacity
Redbridge	7000	300, X13, X3, 23	£2/day	approx. 1250 cars
Seacourt	7001	400	£2/day	approx. 800 cars
Pear tree	7002	300	£2/day	approx. 850 cars
Water Eaton	7003	500,700	Up to 11 hours (including the first hour) - £2	approx. 850 cars
Thornhill	7004	400,800,900	Up to 11 hours (including the first hour) - £2	approx. 850 cars

Note: Parking charge was introduced on 11 November 2013 for Water Eaton and Thornhill and therefore is included in the demand model to keep consistent with future demand forecast testing applications.

There is a strict parking control with the Oxford city centre, especially for traffic from the east of the city. Around Oxford, the P&R sites are located as such to intercept relatively long car journeys on the edge of the urban area. As a result, park-and-ride choice is a sub-mode of either car in the OSM.

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 their respective networks.

P&R sites are defined in the model as individual zones, as shown in Table 3-6. 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 reflects what is likely in reality where users normally use sites that are convenient to them (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

The highway and PT network models are used to define the generalised cost for a park and ride journey between zone to zone pairs.

[7] Source, http://www.oxford.gov.uk/PageRender/decTS/Park_and_Ride_occw.htm

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.

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.

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 costs also taking into account a parking charge, PT fare and site specific constant.

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

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, and modelled time period.

Application in the Demand Model

The park and ride generalised costs are passed to the demand model. As shown in Figure 3-1, 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 MDM 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. There is no current guidance on lambda values of sub mode choice -- sensitivity tests may be needed if a higher value is set.

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.

Park and Ride Site Allocation

Outside the MDM an independent park and ride site choice module is implemented. As described above the MDM works using the generalised cost estimated for the least cost park and ride site. However, some overlap of site catchment areas occurs now and can be expected to occur even more as new site locations are implemented. From the Oxford public transport passenger survey it was found there are a number of P&R sites which have potential site choices , as listed below:

- Drivers from West and South to access Redbridge and Searcourt;
- Drivers from North to access Pear Tree and Water Eaton;
- Drivers from West to access Searcourt and Pear tree;
- Drivers from North and East to access Thornhill, Water Easton and Pear Tree;

The allocation model therefore takes the park and ride demand from the MDM and examines the generalised cost of travel to different potential sites for every production-attraction pair. This model is especially important when a number of sites are close alternatives.

The allocation of park and ride between competing sites is modelled also using a logit model, where demand at a site is a function of the average generalised cost between the zones in each catchment area to the available sites and between these sites to the city centre:

$$D_{prq} = D^{c}_{pq} \frac{e^{-\theta_1 C^{car}_{pr} - \theta_2 w_r - \theta_3 C^{PT}_{rq}}}{\sum_k e^{-\theta_1 C^{car}_{pk} - \theta_2 w_k - \theta_3 C^{PT}_{kq}}}$$

where:

- r : Park & Ride site under consideration;
- k : used for summation over all Park & Ride sites
- θ_1 = 0.02, θ_2 = 0.02, and θ_3 = 0.01;
- D_{pkq} : P&R trips from p to q using site r;
- D^{c}_{pq} : input aggregated P&R matrix from the above highway and PT sub mode choice;
- C^{car}_{pr} : average generalised car costs (mins) from origin p to site r;
- C^{PT}_{rq} : average generalised PT costs (mins) from site r to final destination q
- w_r : the total cost of parking (mins) at site r, including site penalties (currently assumed to equate to a cost of six generalised minutes), bus fare and site specific constants(as described on page 29).

The above formula is taken from the EMME manual and has been used in EMME community. It implies a λ (at that level) of only 0.02, lower than destination choice and significantly below a typical route choice λ of around 0.15. It also implies the choice is half as sensitive to the public transport leg of the trip as it is to the car leg, which is not intuitive. It can also be argued that logsum costs should be passed from the site allocation to the MDM, though past experience has indicated this may result in convergence problems.

It is noted that this model is applied as an absolute model, whereas the MDM is incremental. The site choice mechanism is implemented using the EMME matrix convolution methodology. The generalised costs of the car leg (C^{car}_{pr}) and PT leg (C^{PT}_{rq}) are averaged over all the routes produced by the assignment and used in the above formula.

In running the allocation model the choice set of available park and ride sites for given origin (production) zones is restricted using catchment areas, which are determined based on professional judgement. This is to ensure that the allocation process is realistic and avoid the so-called red bus-blue bus problem found in multinomial models when there exists a number of close alternatives, thereby potentially leading to illogical results. Catchment areas can be refined, particularly if new sites are to be considered.

Assignment of Highway and PT networks

The base year P&R demand was derived during PTM development which contains the full leg OD demand between catchment and attraction zones. It was found that for some P&R sites a number of car drivers, though parked their car at the site, didn't use any P&R bus services for the onward journey. For example, at Redbridge some people walked to their office nearby, and at Thornhill some drivers boarded on Oxford Tube in the morning peak travelling to the east to London. These trips are therefore treated as regular highway car instead of P&R demand, to be added to the existing highway car demand.

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 OD trips which are then added to the relevant regular car (after converted into vehicles) and PT OD matrices, before highway and PT assignment.

Base Year P&R Outputs

Table 3-7 shows the comparison of base year OSM demand P&R outputs (car leg) against car park counts. It can be seen that the OSM P&R choice model performs extremely well, with only minor differences to the observed counts for all three time period. During P&R calibration stage, a site penalty equivalent to 8 generalise minutes was applied to the Peartree P&R site in order to achieve a balanced demand outputs between this site and the competing Water Easton site nearby.

Table 3-7 Base year P&R Model outputs vs. counts (car leg in person)

Time Period	OSM Zone	P&R Site	Departure			Arrival		
			Counts	Modelled	Diff.	Counts	Modelled	Diff.
AM Peak 08:00-09:00	7000	Redbridge	2.4	2.5	0.1	202.8	203.0	0.2
	7001	Seacourt	3.5	3.9	0.4	188.2	190.9	2.7
	7002	Peartree	8.3	7.3	-1.0	163.4	155.2	-8.2
	7003	Water Eaton	8.3	9.5	1.2	196.5	197.8	1.3
	7004	Thornhill	32.3	31.5	-0.8	156.3	160.2	3.9
	Total		54.7	54.7	0.0	907.1	907.1	0.0
Inter Peak Ave hour. 10:00-16:00	7000	Redbridge	50.7	52.8	2.1	53.5	53.3	-0.2
	7001	Seacourt	26.5	25.9	-0.6	22.3	24.0	1.7
	7002	Peartree	36.2	36.9	0.7	48.7	39.5	-9.2
	7003	Water Eaton	46.3	43.7	-2.6	44.2	51.2	7.0
	7004	Thornhill	40.0	40.4	0.4	41.5	42.2	0.7
	Total		199.7	199.7	0.0	210.2	210.2	0.0
PM Peak 17:00-18:00	7000	Redbridge	185.9	179.9	-6.0	16.9	16.8	-0.1
	7001	Seacourt	175.8	182.1	6.3	5.6	6.4	0.8
	7002	Peartree	166.1	150.0	-16.1	11.7	11.0	-0.7
	7003	Water Eaton	200.8	212.2	11.4	11.3	12.6	1.3
	7004	Thornhill	87.9	92.5	4.6	34.3	33.0	-1.3
	Total		816.5	816.7	0.2	79.8	79.8	0.0

3.8. Cost Damping

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 are used in Oxfordshire 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

The cost damping function was 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 was that suggested in WebTAG Unit M2, paras 3.3.5:

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

where:

- t, c are the trip time and money cost respectively;

- VOT is the value of time;
- (t + c/v) is the generalised cost (in minutes);
- G' is the damped generalised cost;
- d is the trip length; and
- α and k are parameters

The α and k were set at the commonly used parameters suggested in para 3.3.10 of WebTAG Unit M2. A minimum cut-off distance d' was also set, below which no damping was applied to prevent short distance trips becoming unduly sensitive to cost changes. The parameters used were:

- α = 0.5;
- k = 35; and
- d' = 35 km.

Note that the values of d’ and k were obtained during model calibration stage, which are slightly different to the commonly used parameter value of 30 KM as given in WebTAG.

Varying Non-Working Value of Time with Distance

Variation in non-working VOT with distance is introduced in the way suggested in WebTAG Unit M2 for the following trip purposes:

- Car Available HBO and NHBO trips; and
- All non-work NCA trips

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 (the value 7.58 miles or 12.2 kilometres was used)
- 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).

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.

3.9. Introducing PA-Based Time Period Choice

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 3-1), 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?

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 any guidance on how it may be implemented.

The fundamental assumption underpinning the formulation was 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 were 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.

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 demands factored by the associated return proportions. The return proportions are derived from the information supplied by DfT and further details are provided in Chapter 4.

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

- the return proportions are fixed in forecasting mode; and
- the time of a day choice starts with the AM Peak period and 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.

Details of the PA Formulation

Time Period Specification

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

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.

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

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

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 $t = op$.

The above relationship is illustrated in Table 3-8 where symbol √ indicates available returning time periods for each outward time period.

Table 3-8 Returning Time Period Specification

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

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 the early part of this chapter for Incremental Hierarchical Logit (IHL) formulation.

Table 3-9 provides the notations of variables used for the PA specification (which is arranged according to the appearance of variables in the following text).

Table 3-9 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.	RSI data
$\Pr et^{0}_{pcmsr}$	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 2012 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

Notation	Description	Source Data
$C^{(PA)}_{ijpcmt}$	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
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, which should only be used once to create reference PA matrices by time period and by all other segmentation:

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

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:

$$\sum_{r} \mathrm{Pret}^{0}_{pcmsr} = 1 \qquad (2)$$

Create Reference PA Costs and Demands

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

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

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

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):

$$T_{ijpcm24}^{(PA)0} = \sum_{t} T_{ijpcmt}^{(PA)0} \tag{5}$$

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

$$C_{ijpcmt}^{(PA)} = (C_{ijpcms}^{(OD)} + \sum_{r \geq s} (C_{ijpcmtr}^{(OD)})' \operatorname{Pr} et_{pcmsr}^{0}) / 2, \tag{6}$$

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 was simply defined as:

$$\Delta C_{ijpcmt}^{(PA)} = C_{ijpcmt}^{(PA)} - C_{ijpcmt}^{(PA)0} \tag{7}$$

Based on $\Delta C_{ijpcmt}^{(PA)}$, the composite costs (i.e. the structured logsums over the various stages of the demand model) were calculated in the standard way, as presented in the above (para 2.31 – 2.48).

$$CC = f(\Delta C_{ijpcmt}^{(PA)}, T_{ijpcmt}^{(PA)0}, \lambda, \theta) \tag{8}$$

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:

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

Convert PA Demands to OD for Assignment

The outward PA demand $T_{ijpcmt}^{(PA)}$ output from the demand model was 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:

$$T_{ijpcms}^{(OD)} = T_{ijpcmt}^{(PA)} \tag{9}$$

Return-leg demands were 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:

$$T_{ijpcmtr}^{(OD)} = \sum_{s \le r} \Pr et_{pcmsr}^{0} (T_{ijpcms}^{(OD)})', \qquad (10)$$

where $s \le r$ 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:

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

Final Comments

The demand model calculates the outward estimates of the PA demand directly by the Incremental Hierarchical Logit technique. The return-leg demands were implicitly considered via the outward journeys in the following way:

- Return OD costs were 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.

3.10. Modelling the Off-Peak Period

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

WebTAG does not provide any guidance on how the OP period should be represented. Accordingly, a number of assumptions were 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 were:

- OP car users travel at free-flow conditions in the base year;
- the change in OP costs was 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.

These assumptions ensured 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 was very small in response to the introduction of AM peak tolling (if any). In other words, the introduction of tolling would shift outbound demands 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 was also an important consideration

3.11. Demand and Supply Model Outputs

The output from the demand model after the sub-mode choice (stage 5) included 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
- Bus 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.

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

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

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

.

4. Model Parameters and Factors

4.1. Introduction

This chapter presents parameters and factors that are used to develop the DMD:

- VOTs and the introduction of VOT variation with distance;
- factors derived from traffic survey data and other sources such as NTS, including segmentation factors, occupancies and others; and

4.2. Value of Time (VOT) Variation with Distance

Table 4-1 presents the base year 2013 VOT parameters by person for demand modelling, based on the values given in WebTAG DataBook (January 2014 release v1.1). The values applied in the demand model are all with a common 2010 price base.

Table 4-1 2013 Value of Time by Person-Type (2010 prices)

Demand Segment	Purpose	Value of Time (pence / minute)
Car Available	Commuting (HBW) <£20,000	6.11
	Commuting (HBW) £20,000 - £40,000	9.06
	Commuting (HBW) >£40,000	13.47
	Other (HBO+NHBO) <£20,500	7.94
	Other (HBO+NHBO) £20,000 - £40,000	9.65
	Other (HBO+NHBO) >£40,000	11.66
	Work (HBEB+NHBEB)	36.38
Non-Car Available[8]	Commuting (HBW)	9.06
	Other (HBO+NHBO)	8.04
	Work (HBEB+NHBEB)	29.1

Table 4-2 below presents a summary of the VOTs used in the MDM for the CA HBO and NHBO and NCA HBO, NHBO and HBW trip purposes, where the VOT variation by distance was applied (see chapter 3 on Cost Damping above for further details). The table shows the average value of VOT (i.e. as given in Table 4-2) as well as the matrix average, minimum and maximum.

[8] WebTAG Databook doesn't provide VOT values by car availability. It is then assumed a factor of 0.8 is applied to the core value (i.e. not segregated buy income) of the individual VOT by purpose for the corresponding non-car available segment.

Table 4-2 Variation of VOT with Distance (2010 prices, 2013 values)

Purpose	Car Available (HBO/NHBO)			Non Car Available	
	Income Low	Income median	Income High	HBW	HBO/NHBO
Average Value	6.11	9.06	13.47	9.06	8.04
Matrix Average	11.43	13.90	16.80	15.03	11.58
Matrix Minimum	5.60	6.80	8.22	5.66	5.67
Matrix maximum	29.01	35.26	42.60	51.48	29.37

It is noted that the VOT variation by distance has been applied to all non-work purposes for non-car available users, but only to the HBO and NHBO demand segments for car available users. Initially, the variation was also applied to the CA HBW demand segment but the outturn elasticities appeared too low in realism tests. After discussions with the Department, the central VOT values were applied to the CA HBW segment.

It is also noteworthy that the variation of VOT with distance is applied only to the MDM, and not to the assignment models.

4.3. Factors Derived from Survey Data

The development of the demand model involved 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 was the 2007 RSI survey data[9], supplemented by other data sources such as traffic counts and RSI in 2013, TEMPRO and the National Travel Survey where necessary.

The following factors derived from the survey data are listed as:

- Household income band factors (as shown in Table 3-1 above);
- Purpose splitting factors; and
- Car occupancy factors by purpose, household income band, and time period.

For car, purpose split factors were derived from the 2007 RSI surveys at a 13 sector to sector basis[10]. Table 4-3 below provides the average factors by purpose and time period in the base year 2013.

[9] The OSM has used mobile phone data as the main source for producing highway prior matrices. The RSI surveys were conducted at 3 selected sites overlapping with the site location in 2007 RSI surveys. This is mainly for comparison purpose to examine if there are substantial changes of travel patterns between 2007 and 2013. A technical note has been prepared to summarise the evidence which concludes that there isn't any significant substantial variations in terms of trip length distribution, traffic level, car occupancy etc, as given in Atkins TN09 2007-2013 RSI Comparison_v2.docx.

[10] The sector system is shown in Table 2-2

Table 4-3 Demand Segmentation Factors by Purpose (Car)

Purpose	AM	IP	PM
HBO	0.234	0.390	0.240
NHBO	0.120	0.221	0.130
NHBEB	0.089	0.195	0.062
HBEB	0.083	0.052	0.082
HBW	0.474	0.142	0.486
Total	1.000	1.000	1.000

For bus, purpose split factors were derived from the 2013 bus passenger interview surveys at a more aggregated 4 sector to sector basis due to the lumpiness of the samples comparing to RSI data. The average bus segmentation factors by purpose are given in Table 4-4 below.

Table 4-4 Demand Segmentation Factors by Purpose (Bus)

Purpose	AM	IP	PM
HBO	0.417	0.223	0.429
NHBO	0.108	0.015	0.130
NHBEB	0.011	0.013	0.010
HBEB	0.010	0.309	0.010
HBW	0.455	0.577	0.420
Total	1.000	1.000	1.000

For rail, due to the low sample rate from the 2013 rail passenger surveys, the purpose split factors were derived at a global level, as shown in Table 4-5 below.

Table 4-5 Demand Segmentation Factors by Purpose (Rail)

Purpose	AM	IP	PM
HBO	0.22	0.58	0.31
NHBO	0.06	0.11	0.12
NHBEB	0.03	0.03	0.04
HBEB	0.06	0.05	0.05
HBW	0.63	0.23	0.48
Total	1.00	1.00	1.00

For P&R demand, the purpose split factors were also derived at a global level (again due to low sample rates) from 2013 bus passenger surveys, as shown in Table 4-6 below. It can be seen that the splits for employer business trips are zero as the P&R trips are predominately formed by journeys with commuting and other purpose.

Table 4-6 Demand Segmentation Factors by Purpose (P&R)

Purpose	AM	IP	PM
HBO	0.17	0.58	0.43
NHBO	0.17	0.18	0.10
NHBEB	0	0	0
HBEB	0	0	0
HBW	0.66	0.24	0.47
Total	1.00	1.00	1.00

Table 4-7 shows highway car occupancy factors for the base year 2013 by purpose, and by time period. Note that no distinction was made between home-based and non home-based trips within a purpose.

Table 4-7 Car Occupancy Factors

Time Period / Segment	Commuting	Work	Other
AM Peak	1.12	1.18	1.60
Inter-Peak	1.12	1.16	1.46
PM-Peak	1.13	1.13	1.54

The factors to convert demand from the peak hour to peak period (or inverse for the reverse), derived from the 2013 traffic counts and RSI data, are presented below in Table 4-8 by time period, purpose and mode.

Table 4-8 Peak Hour to Peak Period Factors

Demand Segment	AM	IP	PM
Car			
Commuting (HBW)	2.20	6.00	2.41
Other (HBO+NHBO)	2.80	6.00	3.29
Work (HBEB+NHBEB)	2.64	6.00	2.74
P&R			
All Purposes	2.54	6.00	2.48
Bus			
All Purposes	2.80	6.00	2.69
Rail			
All Purposes	2.33	6.00	2.46

Local household survey data was not available and the car availability person type factors were derived for the PT segmentation using the 2006 Avon Rail Surveys and the 2009 Bus origin-destination surveys for bus and rail respectively. Table 4-9 presents the Car-available (CA) and non-Car available (NCA) splitting factors for rail and bus users, derived from 2013 bus and rail passenger surveys.

Table 4-9 CA / NCA Splits for Rail & Bus Users

Demand Segment	AM	IP	PM
Rail CA / NCA	0.59 / 0.41	0.57 / 0.43	0.59 / 0.41
Bus CA / NCA	0.78 / 0.22	0.62 / 0.38	0.68 / 0.32

5. Demand Model Validation

5.1. Introduction

The validity of the demand model has been assessed through realism tests . 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.

The target elasticities for the realism tests, as defined by WebTAG Unit M2 Section 6.4, 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.

WebTAG recommends the use of locally calibrated demand parameters if they are available from Revealed Preference and Stated Preference data. If these are not available, as is the case with OSM, WebTAG recommends the use of illustrative sensitivity parameters provided in WebTAG Unit M2 Section 5.6. In either case, the robustness of the demand model validation needs to be demonstrated through the application of a set of realism tests.

This chapter presents the demand model elasticities derived from the realism tests, by using the sensitivity parameters and structure parameters presented in Chapter 4, together with the introduction of cost damping and VOT variation with distance for non-Work trips.

5.2. Convergence between Supply and Demand

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 demand model. Convergence was achieved by passing costs from the RTM and PTM to the MDM and subsequently passing trips from the five-stage demand model back to the assignment models; the process terminates once the convergence criterion had been met.

Two convergence algorithms were implemented to create a stable converged solution between the cycl of demand and supply responses. The convergence algorithms were:

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

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

The recommended criterion by WebTAG Unit M2 Section 6.3, 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.

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). Table 5-1 gives an example of the %GAP values during OSM fuel realism test to show the convergence of the demand model.

Table 5-1 Example of Convergence from OSM fuel Realism Tests

Demand/Supply Iteration	%GAP
1	3.6281
2	1.2179
3	0.4035
4	0.2402
5	0.1504

5.3. Realism Tests

The realism tests undertaken identified a set of sensitivity parameters which were the most appropriate for the sub-region (with respect to the demand hierarchy form presented in Figure 3.1). The demand response parameters presented later in this chapter were the result of testing the range of illustrative parameters in WebTAG via an iterative process of tuning.

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

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

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.

The realism tests were 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.

5.4. Car Fuel Cost Elasticities

Network-Based

The Car fuel cost elasticities in terms of car vehicle kilometres with respect to (w.r.t) fuel costs, are shown below in Table 5-2, presented by segmentation of highway assignment user classes, i.e. by household income and by purpose work/non-work. Note that it was not possible to separately calculate the elasticities for “commuting” and “other” purposes (nor the non-work categories) at network level as they were combined together for assignment purposes.

The network-based fuel cost elasticities in Table 5-2 are given for each of the three peak hours. It also distinguishes between the various network areas (i.e. simulation, buffer link and buffer centroid connectors). The simulation area covers the most area of Oxfordshire County Council. The elasticity values presented are obtained by direct calculation using SATURN output network statistics.

Table 5-1 demonstrates a pattern of fuel cost elasticities by user class or household income consistent with the equal split between the income bands.

Table 5-2 Network-based Car Fuel Cost Elasticity

PCU-Kms w.r.t Fuel Cost	AM	IP	PM	Annual
Car –Non Work				
Simulation Area	-0.245	-0.239	-0.248	-0.239
Buffer Area (B)	-0.227	-0.301	-0.157	-0.300
Buffer Area (BCC)	-0.030	-0.051	-0.021	-0.051
Total	-0.233	-0.279	-0.188	-0.279
Car - Work				
Simulation Area	0.007	-0.082	-0.003	-0.082
Buffer Area (B)	-0.139	-0.146	-0.107	-0.146
Buffer Area (BCC)	0.007	-0.016	-0.004	-0.016
Total	-0.093	-0.127	-0.077	-0.126
Total Cars				
Simulation Area	-0.198	-0.197	-0.210	-0.197
Buffer Area (B)	-0.205	-0.255	-0.148	-0.254
Buffer Area (BCC)	-0.024	-0.042	-0.019	-0.042
Total	-0.201	-0.235	-0.168	-0.235

These elasticities are on the lower side of the range and have been affected by fixed elements within the matrix (external to external trips).

Matrix-Based

The matrix-based vehicle-km fuel cost elasticities are presented below in Table 5-3 with the elasticities reported by time period, by ‘super’ sector (i.e. Internal or External of the 2 sector system as shown in Table 2-2), and by purpose (i.e. HBW / HBO / NHBO / Work).

It is noted that the demand model does not consider the impact on external to external trips. Table 5-3 includes demand responses for internal to internal (I-I), internal to external (I-E), external to Internal (E-I) movements. It also gives the demand response for combined I-I and I-E movements, as used for checking purpose during fuel realism tests.

The car vehicle-kilometre elasticities shown in Table 5-3 demonstrate that the demand model replicates published elasticities of vehicle-kilometres with respect to fuel cost. The overall average fuel cost elasticity is -0.32, which is in the middle of the range of -0.25 to -0.35 recommended by WebTAG.

Table 5-3 Matrix-based Car Fuel Cost Elasticity

Time Period	Movement Type	HBEB	HBO	HBW	NHBEB	NHBO	*Total Non-Work*	Work	*All*
AM	I - I	0.04	-0.11	-0.45	0.09	-0.04	-0.28	0.07	-0.24
	I - E	-0.20	-0.70	-0.22	-0.38	-0.66	-0.40	-0.30	-0.37
	I - I&E	-0.14	-0.41	-0.31	-0.25	-0.41	-0.35	-0.20	-0.32
	E - I	-0.03	-0.26	-0.18	-0.01	-0.05	-0.18	-0.02	-0.15
	Total	-0.09	-0.37	-0.26	-0.17	-0.31	-0.29	-0.13	-0.26
IP	I - I	0.03	-0.13	-0.35	0.00	-0.17	-0.18	0.00	-0.14
	I - E	-0.15	-0.56	-0.26	-0.44	-0.80	-0.57	-0.36	-0.51
	I - I&E	-0.12	-0.41	-0.29	-0.32	-0.60	-0.44	-0.27	-0.40
	E - I	-0.10	-0.47	-0.18	-0.02	-0.12	-0.31	-0.04	-0.22
	Total	-0.11	-0.43	-0.24	-0.18	-0.41	-0.39	-0.16	-0.32
PM	I - I	0.00	-0.15	-0.45	0.03	-0.11	-0.30	0.01	-0.26
	I - E	-0.06	-0.41	-0.16	-0.37	-0.69	-0.28	-0.22	-0.27
	I - I&E	-0.04	-0.28	-0.26	-0.25	-0.42	-0.29	-0.14	-0.26
	E - I	-0.13	-0.34	-0.15	-0.01	-0.06	-0.18	-0.09	-0.16
	Total	-0.09	-0.31	-0.21	-0.14	-0.25	-0.24	-0.11	-0.22
Annual	I - I	0.02	-0.13	-0.42	0.01	-0.14	-0.23	0.01	-0.18
	I - E	-0.14	-0.56	-0.21	-0.43	-0.77	-0.49	-0.34	-0.45
	I - I&E	-0.11	-0.39	-0.28	-0.31	-0.56	-0.39	-0.25	-0.36
	E - I	-0.10	-0.43	-0.17	-0.02	-0.10	-0.26	-0.04	-0.20
	Total	-0.10	-0.41	-0.24	-0.18	-0.38	-0.34	-0.15	-0.29

When examining the matrix-based fuel elasticities by purpose, Table 5-3 shows that the Annual elasticities are generally within the recommended range -0.25 to -0.35 for all purposes. As would be expected:

- Discretionary trips such as HBO and NHBO trips exhibit higher elasticities than more obligatory HBW trips which are doubly-constrained;
- Work trips exhibit the lowest elasticities as they have the highest values of time; and
- The annual average fuel cost elasticity lies on the right side of -0.3.

Table 5-3 also shows that the fuel cost elasticity is greatest in the Inter Peak, followed by the AM peak, with the PM Peak being the slightly higher than the AM peak. These patterns are generally in line with the conventional view drawn from experience of models developed, which suggests that it is travel in the IP which is expected to most sensitive to changes in fuel costs, primarily because of a higher proportion of discretionary travel in the Inter-peak period.

The above tables and analysis demonstrate that the OSM demand model is a robust tool for forecasting highway demand in scheme tests.

5.5. Journey Time Elasticities

Elasticity by single demand model run

The journey time elasticities derived from the realism tests should reflect the TAG values of less than -2.00 and are presented below in Table 5-4; which shows that journey time elasticities were all less than -2.00 as recommended by WebTAG. The overall journey time elasticities for the three time periods are-0.48, -0.64, and -0.38, for AM Peak, Inter-peak and PM Peak respectively, and the annual journey time elasticity all day is –0.57.

Table 5-4 Journey time elasticities by single demand model run

Time Period	Movement Type	HBEB	HBO	HBW	NHBEB	NHBO	*Total Non-Work*	Work	*All*
AM	I - I	-0.12	-0.47	-0.64	-0.30	-0.53	-0.57	-0.22	-0.52
	I - E	-0.52	-1.51	-0.15	-1.06	-1.55	-0.66	-0.81	-0.70
	I - I&E	-0.41	-0.98	-0.34	-0.85	-1.14	-0.62	-0.65	-0.63
	E - I	-0.08	-0.64	-0.16	-0.13	-0.29	-0.26	-0.10	-0.23
	Total	-0.27	-0.89	-0.27	-0.60	-0.90	-0.49	-0.44	-0.48
IP	I - I	0.00	-0.23	-0.38	-0.06	-0.21	-0.25	-0.05	-0.21
	I - E	-0.39	-1.16	-0.20	-1.18	-1.69	-1.12	-0.96	-1.07
	I - I&E	-0.33	-0.83	-0.26	-0.88	-1.20	-0.83	-0.74	-0.80
	E - I	-0.26	-0.95	-0.12	-0.05	-0.19	-0.56	-0.10	-0.40
	Total	-0.30	-0.88	-0.20	-0.49	-0.80	-0.72	-0.44	-0.64
PM	I - I	-0.09	-0.45	-0.58	-0.39	-0.54	-0.53	-0.22	-0.49
	I - E	-0.14	-0.83	-0.13	-1.04	-1.58	-0.44	-0.58	-0.46
	I - I&E	-0.12	-0.64	-0.28	-0.84	-1.09	-0.47	-0.46	-0.47
	E - I	-0.33	-0.70	-0.11	-0.05	-0.19	-0.26	-0.22	-0.25
	Total	-0.24	-0.66	-0.21	-0.48	-0.65	-0.38	-0.34	-0.38
Annual	I - I	-0.05	-0.30	-0.53	-0.12	-0.30	-0.37	-0.10	-0.32
	I - E	-0.38	-1.15	-0.17	-1.16	-1.66	-0.92	-0.90	-0.91
	I - I&E	-0.31	-0.82	-0.29	-0.88	-1.18	-0.72	-0.70	-0.72
	E - I	-0.25	-0.90	-0.13	-0.05	-0.20	-0.45	-0.12	-0.35
	Total	-0.28	-0.85	-0.22	-0.50	-0.79	-0.61	-0.43	-0.57

Elasticity by matrix-basis

WebTAG requires the journey time elasticities should also be derived on a matrix-basis using times from the networks, for each trip purpose in each time period. The approach, termed the "Crude Method" in DfT's DIADEM[11] manual, is applied with the following formula:

$$E^{time}=E^{fuel}*a*T/(b*K)$$

Where:

- E^{fuel}: Fuel elasticity derived from matrix-based method;
- a: VOT (pence per hour) from the generalised function;
- b: VOC (pence per kilometre) from the generalised cost function;
- T: Total vehicle hours from the base year model; and
- K: total vehicle kilometres from the base year model.

The results are shown in Table 5-5. It can be seen that all journey time elasticities are all less than -2.00, and the annual elasticity for all purpose trips has the similar elasticity derived from single demand model calculation as given in Table 5-4

[11] DIADEM version 5.0 manual.

Table 5-5 Journey time elasticities calculated by matrix basis

Time Period	Movement Type	HBEB	HBO	HBW	NHBEB	NHBO	*Total Non-Work*	Work	*All*
AM	I - I	0.16	-0.30	-1.17	0.39	-0.11	-0.74	0.29	-0.72
	I - E	-0.46	-0.96	-0.30	-0.87	-0.90	-0.54	-0.69	-0.60
	I - I&E	-0.39	-0.77	-0.58	-0.70	-0.78	-0.66	-0.56	-0.70
	E - I	-0.07	-0.45	-0.32	-0.03	-0.08	-0.32	-0.05	-0.25
	Total	-0.17	-0.75	-0.53	-0.31	-0.64	-0.60	-0.25	-0.52
IP	I - I	0.11	-0.33	-0.87	-0.01	-0.41	-0.72	0.01	-0.43
	I - E	-0.33	-0.77	-0.35	-0.98	-1.10	-1.28	-0.49	-0.86
	I - I&E	-0.32	-0.71	-0.50	-0.85	-1.03	-1.17	-0.47	-0.83
	E - I	-0.22	-0.64	-0.25	-0.04	-0.16	-0.68	-0.05	-0.37
	Total	-0.20	-0.69	-0.39	-0.45	-0.65	-0.72	-0.26	-0.62
PM	I - I	0.00	-0.39	-1.20	0.11	-0.30	-1.29	0.03	-0.81
	I - E	-0.15	-0.59	-0.23	-0.86	-1.00	-0.64	-0.31	-0.44
	I - I&E	-0.12	-0.54	-0.50	-0.75	-0.81	-0.85	-0.27	-0.58
	E - I	-0.30	-0.47	-0.21	-0.03	-0.09	-0.40	-0.12	-0.26
	Total	-0.17	-0.52	-0.36	-0.37	-0.43	-0.44	-0.19	-0.43
Annual	I - I	0.09	-0.34	-1.06	0.04	-0.37	-0.93	0.03	-0.56
	I - E	-0.32	-0.77	-0.30	-0.96	-1.08	-1.10	-0.47	-0.74
	I - I&E	-0.30	-0.71	-0.51	-0.84	-1.01	-1.07	-0.45	-0.77
	E - I	-0.22	-0.60	-0.24	-0.04	-0.15	-0.59	-0.06	-0.33
	Total	-0.19	-0.67	-0.39	-0.45	-0.63	-0.62	-0.26	-0.57

5.6. Public Transport Fare Elasticities

Fare elasticities derived from PT realism tests should reflect WebTAG values between -0.2 and -0.9. Matrix-based PT fare elasticities are presented below in Table 5-6 and Table 5-7 for car availability (CA) and non-car availability (NCA) uses.

The PT fare elasticities presented below are evaluated as the change of the total number of public transport trips (including all PT sub modes) with respect to the 10% increase of bus and rail fare. It should be noted that the concession fare has been taken account in the bus fare matrices as described in Chapter3.

For car available public transport users, Table 5-6 shows that the annual PT fare elasticity is -0.38 across all segments for car available users and -0.38 and -0.32 for the Non-Work purposes and Work purpose, respectively. It is noticed that the elasticities for I-E and E-I movements across all purposes are very strong, which indicates these movements are very sensitive to the fare and are likely switch to car mode if the ticket charge becomes more expensive.

It also shows that in general the discretionary trip purpose exhibits higher elasticities than commuting and employer business purpose, which indicates that these passengers are more sensitive to the fare price. However, as the proportion of concession fare users is generally greater for discretionary trips than commuting and business journeys, the elasticity for overall discretionary users in response to fare price will be less sensitive. This can also explain why a lower elasticity is reported in the inter peak than AM and PM peak, as shown in Table 5-6.

Table 5-6 Matrix-based PT Fare Elasticities for Car Availability (CA) Users

Time Period	Movement Type	HBEB	HBO	HBW	NHBEB	NHBO	*Total Non-Work*	Work	*All*
AM	I - I	0.08	-0.24	-0.14	-0.10	-0.31	-0.20	0.00	-0.19
	I - E	-0.74	-1.56	-1.36	-1.15	-1.48	-1.42	-0.88	-1.38
	I - I&E	-0.28	-0.40	-0.41	-0.43	-0.47	-0.41	-0.34	-0.41
	E - I	-0.49	-1.09	-1.38	-0.86	-1.28	-1.29	-0.61	-1.24
	Total	-0.33	-0.45	-0.54	-0.51	-0.53	-0.51	-0.40	-0.50
IP	I - I	0.07	-0.19	-0.07	-0.07	-0.22	-0.17	0.00	-0.16
	I - E	-0.55	-0.96	-1.01	-0.87	-1.03	-0.98	-0.67	-0.96
	I - I&E	-0.12	-0.29	-0.17	-0.24	-0.30	-0.26	-0.18	-0.26
	E - I	-0.59	-1.09	-1.11	-0.80	-0.87	-1.06	-0.67	-1.04
	Total	-0.23	-0.37	-0.26	-0.34	-0.35	-0.34	-0.28	-0.34
PM	I - I	0.05	-0.26	-0.11	-0.09	-0.20	-0.19	-0.02	-0.18
	I - E	-0.46	-0.84	-1.08	-0.70	-1.05	-0.99	-0.57	-0.96
	I - I&E	-0.13	-0.34	-0.28	-0.30	-0.33	-0.31	-0.21	-0.31
	E - I	-0.68	-0.99	-1.25	-0.67	-0.84	-1.09	-0.68	-1.06
	Total	-0.29	-0.43	-0.43	-0.40	-0.41	-0.43	-0.34	-0.42
Annual	I - I	0.07	-0.21	-0.10	-0.08	-0.23	-0.17	-0.01	-0.17
	I - E	-0.59	-1.02	-1.16	-0.89	-1.11	-1.09	-0.70	-1.06
	I - I&E	-0.16	-0.31	-0.26	-0.29	-0.33	-0.30	-0.22	-0.29
	E - I	-0.59	-1.07	-1.24	-0.77	-0.90	-1.11	-0.66	-1.08
	Total	-0.27	-0.39	-0.37	-0.38	-0.38	-0.38	-0.32	-0.38

Table 5-7 Matrix-based PT Fare Elasticities for Non-Car Availability (NCA) Users

Time Period	Movement Type	HBEB	HBO	HBW	NHBEB	NHBO	*Total Non-Work*	Work	*All*
AM	I - I	0.25	0.00	0.10	0.15	-0.04	0.04	0.20	0.05
	I - E	-0.61	-0.95	-0.89	-0.85	-0.88	-0.90	-0.69	-0.89
	I - I&E	-0.01	-0.07	-0.03	-0.05	-0.11	-0.05	-0.03	-0.05
	E - I	-0.14	-0.39	-0.25	-0.21	-0.47	-0.31	-0.17	-0.30
	Total	-0.03	-0.09	-0.05	-0.07	-0.13	-0.07	-0.05	-0.07
IP	I - I	0.24	0.07	0.15	0.17	0.08	0.09	0.20	0.10
	I - E	-0.30	-0.51	-0.40	-0.59	-0.67	-0.51	-0.41	-0.50
	I - I&E	0.09	0.01	0.10	0.03	0.02	0.03	0.06	0.03
	E - I	-0.23	-0.51	-0.36	-0.08	-0.11	-0.41	-0.17	-0.40
	Total	0.02	-0.04	0.06	0.01	0.01	-0.01	0.02	-0.01
PM	I - I	0.23	0.02	0.13	0.14	0.02	0.07	0.19	0.07
	I - E	-0.11	-0.40	-0.07	-0.41	-0.65	-0.26	-0.24	-0.26
	I - I&E	0.12	-0.02	0.10	-0.01	-0.06	0.03	0.06	0.03
	E - I	-0.31	-0.42	-0.64	0.11	0.01	-0.45	-0.12	-0.43
	Total	0.01	-0.07	0.01	0.02	-0.05	-0.03	0.01	-0.03
Annual	I - I	0.24	0.06	0.13	0.16	0.06	0.08	0.20	0.08
	I - E	-0.32	-0.53	-0.43	-0.58	-0.69	-0.52	-0.42	-0.51
	I - I&E	0.08	-0.01	0.07	0.01	-0.01	0.02	0.05	0.02
	E - I	-0.24	-0.48	-0.42	-0.04	-0.09	-0.41	-0.16	-0.40
	Total	0.01	-0.05	0.02	0.00	-0.02	-0.02	0.01	-0.02

It is worth mentioning that 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 demand model only and thus may have an influence in the fare elasticity patterns presented.

Table 5-7 shows that the NCA fare elasticities are considerably smaller than their counterparts with CA users, reflecting that there is very limited choice available for this type of captive PT user.

5.7. Sensitivity Parameters from Realism Tests

Initially values for the demand modelling sensitivity parameters were imported from WebTAG Unit M2. A number of iterations were then undertaken where these values were changed until reasonable elasticites were obtained and these are given below as derived from the realism tests presented in the above sections.

Destination Choice

Highway destination choice sensitivity parameters for OSM demand model are presented below in Table 5-8 (ignoring the negative signs). WebTAG illustrative values are shown along with lambda parameters used in the demand model. Highway destination choice sensitivity parameters adopted for OSM are all within the WebTAG recommend value range.

Table 5-8 Destination Choice Parameters (Highway)

Purpose	HIGHWAY	
	WebTAG (Minimum / Median / Maximum)	**OSM**
HBO	0.074 / 0.090 / 0.160	0.099
NHBO	0.073 / 0.077 / 0.105	0.092
NHBEB	0.069 / 0.081 / 0.107	0.069
HBEB	0.038 / 0.067 / 0.106	0.040
HBW	0.054 / 0.065 / 0.113	0.100

The PT destination choice sensitivity parameters for OSM are presented below in Table 5-9 (ignoring the negative signs also as highway). Again, WebTAG illustrative values are shown along with lambda parameters used in the demand model. PT destination choice sensitivity parameters adopted for G-BATS3 are all within +/- 25% of the WebTAG median values.

Note that for PT demand modelling, as recommended by WebTAG, the same sensitivity parameters were used for both Car Available (CA) and Non-Car Available (NCA) person types.

Table 5-9 Destination Choice Parameters (PT)

Purpose	Public Transport	
	WebTAG (Minimum / Median / Maximum)	**OSM**
HBO	0.033 / 0.036 / 0.062	0.036
NHBO	0.032 / 0.033 / 0.035	0.033
NHBEB	0.038 / 0.042 / 0.045	0.045
HBEB	0.030 / 0.036 / 0.044	0.044
HBW	0.023 / 0.033 / 0.043	0.033

Main Mode Choice and Time Period

The tree structure parameters for the main mode choice are given in Table 5-10 below, together with the range of illustrated scale parameters specified in Unit 3.10.3. Clearly, they all lie within the recommended ranges, more accurately, they all are set as WebTAG median thetas exactly by purpose (during the realism tests, the theta values were fixed as such that only lambda parameters for destination choices were allowed to vary).

Table 5-10 Main Mode / Time Period Choice Parameters

Purpose	WebTAG Theta (Minimum / Median / Maximum)	Demand Model Theta
HBO	0.27 / 0.53 / 1.00	0.63
NHBO	0.62 / 0.81 / 1.00	0.75
NHBEB	0.73 / 0.73 / 0.73	0.73
HBEB	0.26 / 0.45 / 0.65	0.45
HBW	0.50 / 0.68 / 0.83	0.68

Note that WebTAG suggests the main mode choice and time period choice should be considered simultaneously; therefore, the same theta values are used for the time period choice and main mode choice in the OSM.

Realism test results presented earlier in this Chapter show that the above parameters lead to satisfactory elasticities, when both Value of Time (VOT) variation and cost damping with distance has been introduced for the HBO and NHBO trip purposes as described in Chapter 4.

6. Summary

The OSM demand model was developed to assess the transport impacts of a range of potential transport interventions and development proposal in the Oxfordshire County Council. These interventions may include demand management schemes as well as Major Scheme Bids.

The demand model is a five-stage multi-modal incremental model that considers the impact of changes in generalised costs for highway and public transport on frequency choice, main mode choice, time period choice, destination choice, and sub mode choice .

The demand model represents travel demand over a 24-hour period. It is a Production-Attraction (PA) based model with explicit time period choice modelling based on the use of fixed return proportions derived from national average values obtained from DfT NTEM/TEMPRO datasets.

Following the latest WebTAG guidance Unit M2 as well as related parameters, OSM demand model iterates between the hourly-based AM, IP and PM supply models and the 24-hour demand model. Two convergence algorithms were implemented, namely the Method of Successive Average algorithm and the average algorithm to achieve convergence in the demand/supply interactions. The latter was selected based on its performance following testing. The demand model achieves the required levels of convergence stipulated by WebTAG.

VOT variation with trip length has been introduced into the demand model for car available HBO and NHBO trips, and non car available non-work purposes including HBW. Cost damping in generalised cost calculation was also introduced in the model. This technique has helped in achieving WebTAG required elasticities especially for longer distance trips due to the nature of the logit-based demand modelling framework.

The theta parameters and highway/PT lambda parameters adopted are mostly within WebTAG illustrative values. The realism tests undertaken have successfully identified a set of demand response parameters that replicated both the local conditions and conformed to the hierarchical tree structure recommended by WebTAG, that is, FMTD (Frequency, Mode, Time period, and Destination choice).

The derived car fuel elasticity, car journey time elasticity and PT fare elasticity, established through the realism tests, have been reported by purpose, time period and spatial locations. All outturn elasticity values by purpose are within WebTAG required ranges. The overall fuel cost and PT fare elasticities (for CA users) are -0.29 and -0.38 respectively – both within the range of WebTAG target values. The realism tests showed that, as expected, discretionary trips (HBO/NHBO) exhibited higher fuel cost elasticities than non-discretionary trips (HBW/EB). The pattern of elasticities by time period shows that in general the Inter Peak period is most sensitive.

On this basis, the OSM demand model is considered to be ‘fit for purpose’ as described in Chapter 1.

Appendix A. Oxfordshire Bus Fare

Table A-1 AM Peak distance based bus fare (£, in 2010 Price)

Distance band (KM)	EB	Commuting	Other	All Purpose
0-2	1.21	0.49	0.68	0.60
2-5	1.82	0.98	1.17	1.09
5-10	2.18	1.69	1.72	1.71
10-15	2.31	2.21	2.08	2.14
15-20	2.33	2.33	2.15	2.24
20-25	2.35	2.46	2.25	2.35
25-50	3.72	3.14	2.73	2.93
>50				4.02

Table A-2 Inter Peak distance based bus fare (£, in 2010 Price)

Distance band (KM)	EB	Commuting	Other	All Purpose
0-2	1.25	0.46	0.45	0.47
2-5	1.93	0.99	0.77	0.84
5-10	2.37	1.79	1.11	1.29
10-15	2.53	2.41	1.29	1.57
15-20	2.55	2.53	1.32	1.62
20-25	2.58	2.66	1.36	1.69
25-50	3.74	3.08	1.68	2.05
>50				4.02

Table A-3 PM Peak distance based bus fare (£, in 2010 Price)

Distance band (KM)	EB	Commuting	Other	All Purpose
0-2	1.25	0.44	0.53	0.50
2-5	1.92	0.86	0.93	0.92
5-10	2.46	1.46	1.41	1.45
10-15	2.60	1.94	1.70	1.82
15-20	2.62	2.14	1.79	1.96
20-25	2.64	2.35	1.92	2.12
25-50	4.83	3.07	2.67	2.88
>50				4.02

Appendix B. Oxfordshire Rail Fare

Table B-1 OSM demand model distance based Rail fare (£/KM), in 2010 Price)

Distance band (KM)	AM	IP	PM
0-20	0.195	0.25	0.202
20-40	0.142	0.132	0.110
40-60	0.140	0.130	0.108
60-90	0.123	0.119	0.099
>90	0.113	0.137	0.113
In/out of London	0.214	0.184	0.148

Contact name:
Graham Bown

Address:
Epsom Gateway
Ashley Avenue
Epsom
Surrey
KT18 5AL
Email: graham.bown@atkinsglobal.com
Telephone: 01372 756899