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DEMAND MODEL DEVELOPMENT



SYSTRA

EAST MIDLANDS GATEWAY

DEMAND MODEL DEVELOPMENT

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1. INTRODUCTION

1.1 Model Background and Application

1.1.1 SYSTRA has been commissioned to develop the East Midlands Gateway Model (EMGM) to appraise a multi-modal access strategy to connect the East Midlands to the proposed HS2 station at Toton between Derby and Nottingham.

1.1.2 EMGM has been developed as a multimodal transport model built following the guidance in WebTAG. The structure of the model is based on the Greater Nottingham Transport Model (GNTM). However it has been developed using information from the existing Greater Nottingham Transport Model, Greater Derby Transport Model (GDTM) and the Leicester and Leicestershire Integrated Transport Model (LLITM). The model has been fully recalibrated and validated in line with WebTAG guidance.

1.1.3 In addition to being used to assess the HS2 access strategy, the model is likely to be used in the future to assess a wide range of development, highway and public transport schemes across the study area.

1.1.4 This report provides information on the development and calibration of the Demand model element of EMGM.

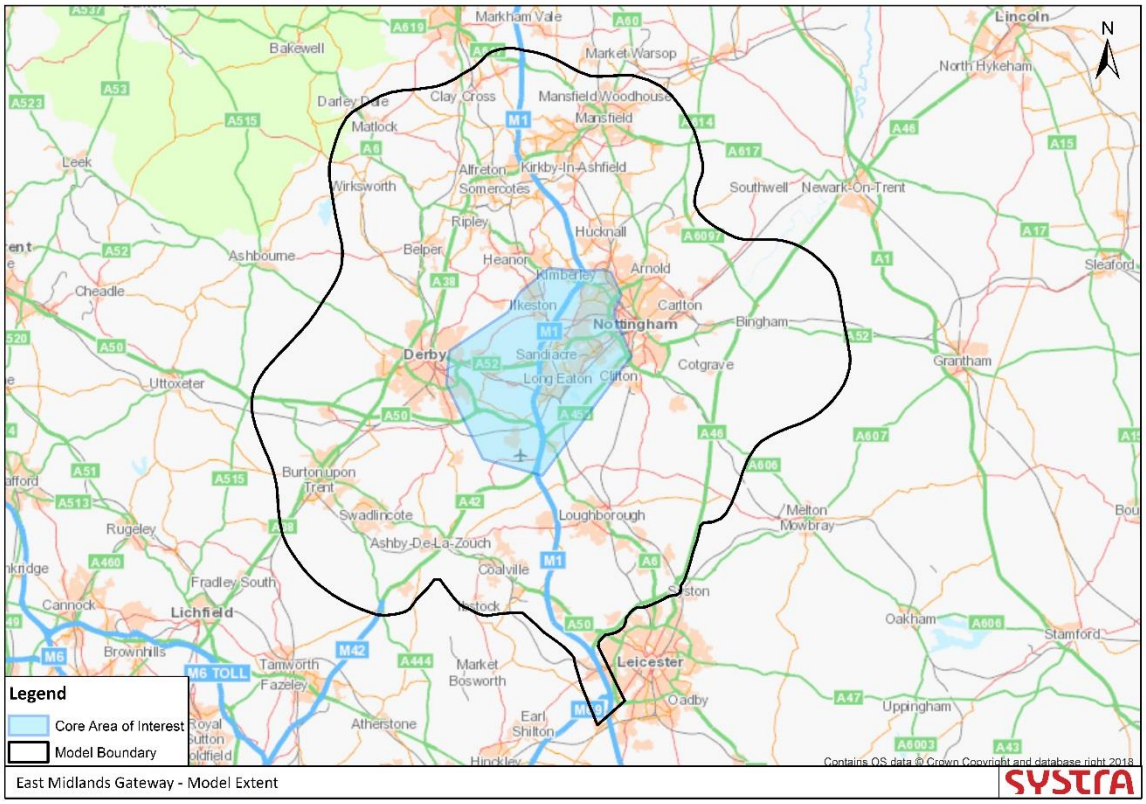
1.2 Model Extent

1.2.1 The geographical extent of the model is shown in Figure 1. The model boundary is shown in black and represents the area of detailed simulation modelling. This includes the authorities of Nottingham City, Ashfield, Broxtowe, Erewash, Gedling, Rushcliffe, Derby City, Amber Valley, South Derbyshire, Charnwood and North-West Leicestershire.

1.2.2 Areas outside of this simulation area are modelled as a skeleton buffer network, this includes Leicester City and areas to the south of the A46.

1.2.3 Figure 1 also shows the Area of Interest boundary which has been specified for the purposes of assessing the impacts of the HS2 station at Toton.

Figure 1. Model Area



1.3 Structure of this Report

1.3.1 The remainder of this report is structured as follows:

- **Chapter 2** provides an overview of the model, giving summaries of its input data and the ways in which data is segmented for use by the demand model;
- **Chapter 3** describes the development of the base year demand matrices;
- **Chapter 4** describes the demand responses within the model and the methods used in the calibration of these models;
- **Chapter 5** provides detailed descriptions of the ways in which the different parts of the EMGM demand model fit together and exchange data between themselves; and
- **Chapter 6** sets out the tests that have been carried out in order to check that the model generates realistic responses.

2. OVERVIEW OF MODEL

2.1 Introduction

2.1.1 This chapter provides an overview of the model, describing the zoning system, the input data required for its operation, the segmentation of trip matrices and the basic operation of the demand response models.

2.2 Model Structure

2.2.1 The model is almost entirely programmed using Citilabs' Cube Voyager software, version 6.4.3, with the single exception being the use of SATURN 11.3.12W for highway assignment.

2.2.2 The model consists of the following stages:

- Mode choice;
- Destination choice;
- Route choice;
- Trip Frequency;
- Time Period Choice; and
- Peak Spreading.

with the first two of these being referred to in this report as "the demand model" and the third stage being "the assignment models". The final three stages are optional modules that can be turned on or off as required.

2.2.3 Once model convergence has been achieved, there is also an additional stage in which a park and ride (P&R) module is run. This modifies the final loop, converged assignment model matrices to split certain trips into legs that are performed with car (i.e. Origin to P&R site) and those that are performed via the available park and ride public transport modes (i.e. P&R site to Destination). These modified trip matrices are then passed back to the assignment models for a final route choice calculation.

2.2.4 The demand model is calibrated for the base year trip matrix data and is used to predict trip matrices in forecast situations. This forecasting depends upon changes in travel costs between the base and forecast cases, which are dependent upon changes to the numbers of trips being made in total and alterations to the networks used in the assignment models.

2.2.5 The demand model makes use of the following inputs:

- Total numbers of trip productions and attractions;
- Generalised costs of travel by highway and public transport modes;
- Mode and destination choice parameters; and
- Factors used in conversion of the whole trip matrix into time-period-dependent matrices

Compliant Splits

2.2.6 The model has been set up in such a way that it can be run either with or without demand being split into Compliant and Non-Compliant segments for the modelling of Clean Air Zone (CAZ) type interventions.

2.2.7 This functionality has been included as CAZ's are being considered in both Nottingham and Derby and so may need to be included in any forecast model runs. The functionality to run the model without these demand splits is included to reduce run times by halving the number of assignment user classes.

2.3 Zoning System

2.3.1 The model comprises 1,500 zones, of which 993 are classified as internal and 63 are classified as external. Of the internal zones, 11 are designated as park and ride locations in the base year with a further 2 park and ride zones available for HS2 in future years. The remaining 442 zones have been allocated for future year developments. These additional development zones are empty and unused in the base year.

2.3.2 Internal and external zones are treated differently by the demand model, with the demand response models (described in Chapter 4) being applied only to the shaded movements shown in the table below:

Table 1. Trip matrix movements processed by Demand Model

		Attraction Zone	
		Internal	External
Production Zone	Internal	■	■
	External	■	

2.3.3 Trips between external zones are treated differently, as is described in Chapter 5.

2.3.4 The zoning system used in the model is shown in Figure 2. Figure 3 and Figure 4 show the zoning system in Derby and Nottingham in more detail.

Figure 2. Model Zoning System

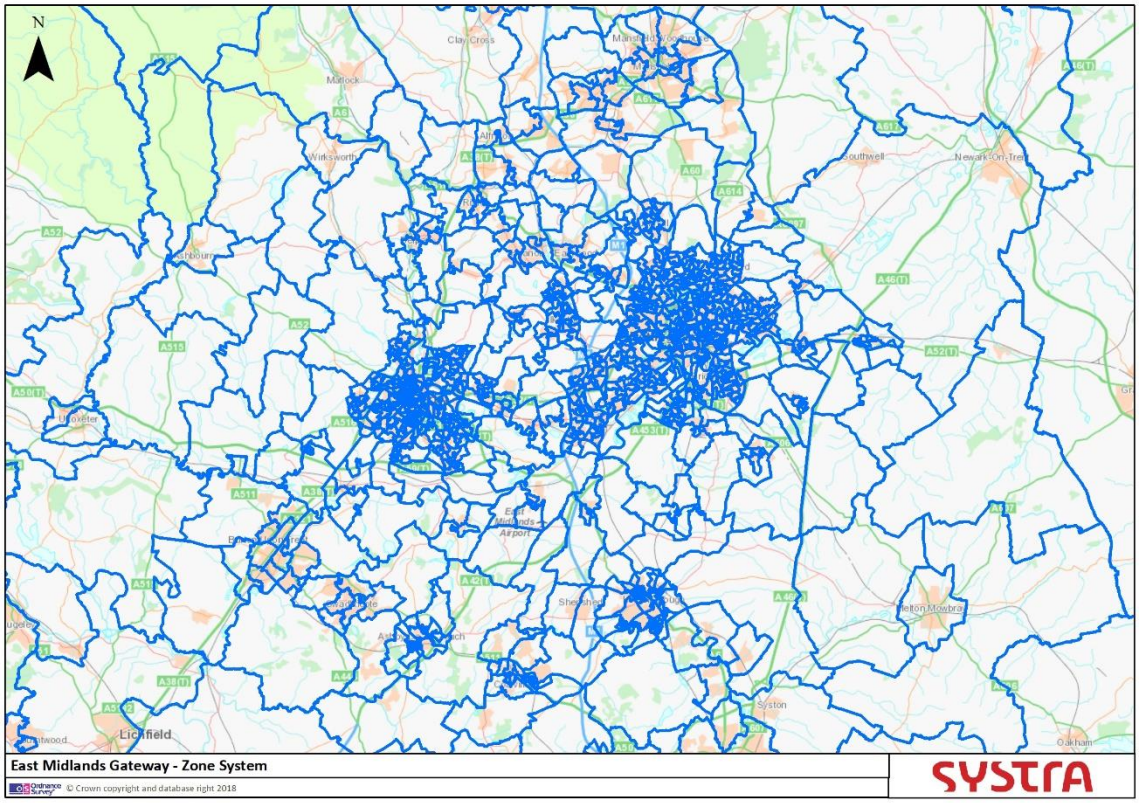


Figure 3. Model Zoning System: Derby

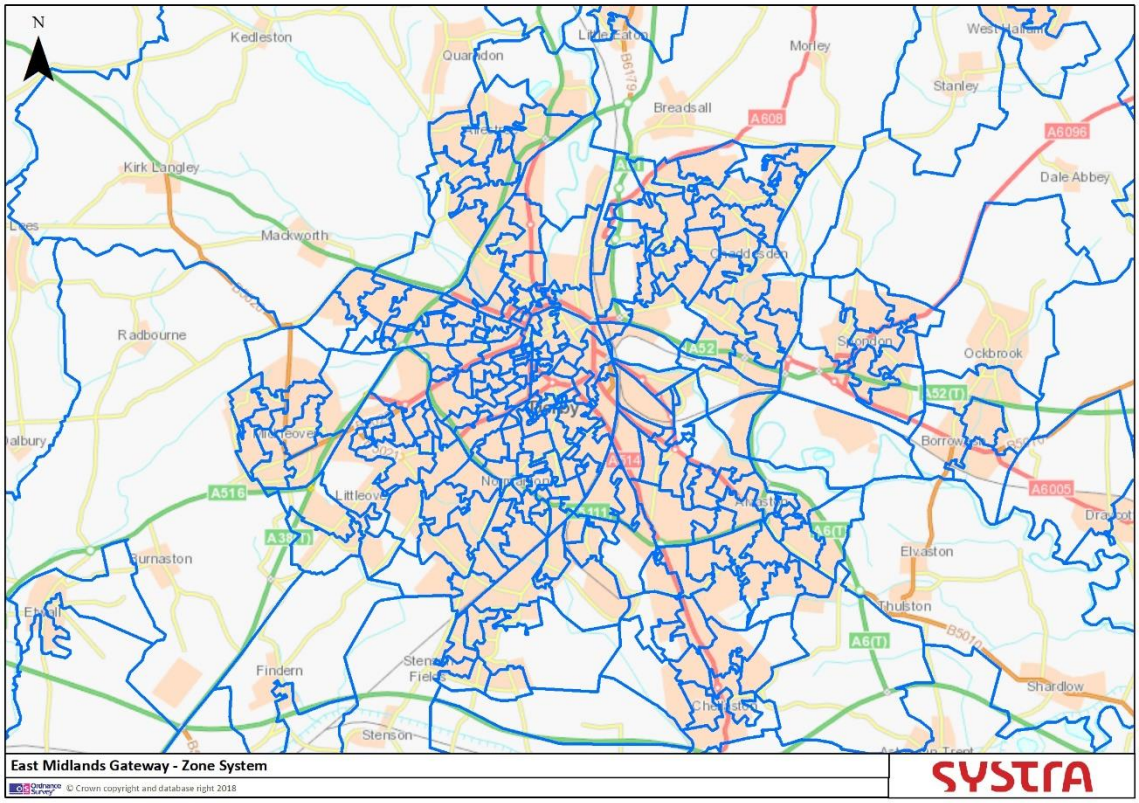
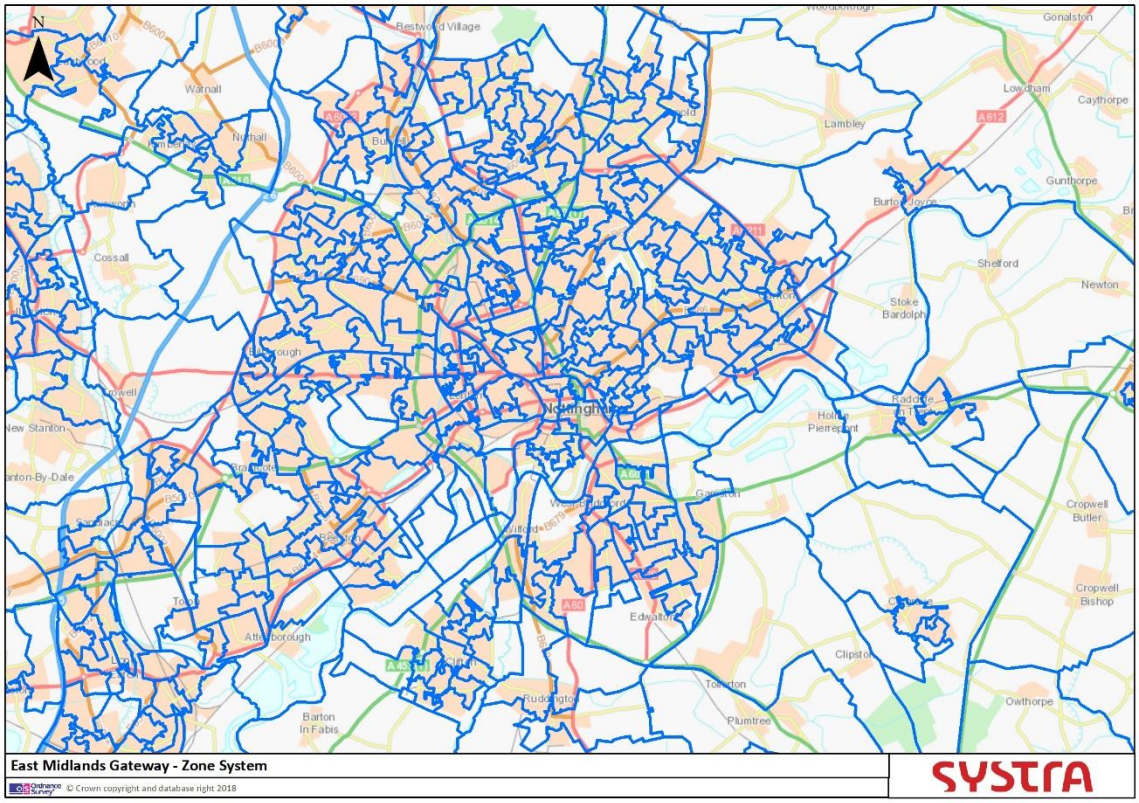


Figure 4. Model Zoning System: Nottingham



2.4 Demand Model Segmentation

2.4.1 The trip data that is processed by the demand model, either as inputs or outputs, is segmented into a number of different categories: journey purposes, main modes, car availabilities, and time periods. There are similar categories used in the assignment models.

Journey Purposes

2.4.2 The demand model works with 5 different journey purposes:

- **Home-based Work (HBW)** – trips made from home to work, i.e. a typical commuting journey. These trips do not take place in work time;
- **Home-based Employer's Business (HBEB)** – trips made from home for the purpose of work but which are not a person's usual commuting journey;
- **Home-based Other (HBO)** – covers all other trips made from home to a non-work-related location. Such activities include, for example, shopping, education and leisure trips;
- **Non-home-based Employer's Business (NHBEB)** – travelling during work time not from one's home, such as travelling from a workplace to a business meeting; and
- **Non-home-based Other (NHBO)** – covers all other travel between non-home locations, for example from a workplace to shops.

2.4.3 The home-based purposes' data is stored as productions and attractions (P/A), while the non-home-based purposes' data is stored in origin-destination format (O/D). In the model a trip's production zone is the home end of both the 'from-home' and 'return-home' legs of round trips. Consequently, a trip's attraction zone is the non-home end of both the 'from-home' and 'return-home' legs of round trips.

2.4.4 The assignment models use demand in O/D format, with the conversion from P/A to O/D carried out using a variety of fixed factors whose derivation is described in Chapter 3.

2.4.5 The highway assignment is carried out for either seven or 14 user classes, depending on whether the demand is split into Compliant/Non-Compliant or not. The seven user classes (ignoring any Compliant splits) are:

- Commuting – no workplace parking;
- Commuting – with workplace parking;
- Employer's Business;
- Other;
- Light goods vehicles;
- Other goods vehicles; and
- Taxis.

2.4.6 Including the compliant splits simply doubles the number of user classes, with each one being repeated twice (compliant and non-compliant).

2.4.7 The single home-based work purpose processed by the demand model is split at time period level into two highway assignment user classes representing, respectively, those trips that do not have the use of workplace parking and those that do. For the same zone pairs, persons with the use of workplace parking can have different travel costs from those who do not have the parking available. For this reason, the two types of commuting trips are modelled as individual user classes in assignment.

2.4.8 The separate home-based and non-home-based versions of the employer's business and other purposes are combined for use in the assignment model.

2.4.9 The fifth, sixth and seventh user classes consist of matrices of goods vehicle and taxi trips. These are not generated by the demand model but are added just prior to assignment from fixed, time period-dependent matrices.

2.4.10 PT assignment is carried out for three user classes:

- Commuting;
- Employer's Business; and
- Other,

with the same merging of home-based and non-home-based purposes as in the highway model.

2.4.11 The PT assignment demand is never split into Compliant and Non-Compliant. However, the demand model demand is, to allow for mode choice between (predominantly) non-compliant trips.

Main Modes

2.4.12 Two main modes are used in the demand model: car and public transport (PT).

2.4.13 Route choices for these modes are modelled by separate highway and PT assignment models. Highway assignment is carried out with SATURN 11.3.12W, while PT assignment is performed by the Cube Voyager program Public Transport.

2.4.14 The PT assignment model also deals with the choices between the bus, tram and rail (conventional and HS2) public transport sub-modes.

Car Availabilities

2.4.15 The demand model uses three household car availability categories:

- C0 – no cars available; this category is therefore assumed to be captive to PT modes;
- C1 – one car available; and
- C2 – two or more cars available ("two-plus").

2.4.16 Trips made by people in the C1 and C2 categories can be shifted between the car and PT main modes in response to changes in generalised costs.

2.4.17 The inclusion of the Compliant Splitting functionality means that the number of car available segments is doubled, giving compliant and non-compliant segments. If the compliant splits are not used then the last four segments will have zero demand, but will still be output to matrices.

2.4.18 There are threfore nine different demand segments treated by the demand model, denoted by:

- C1CC – Car trips by one-car-available persons – Compliant;
- C2CC – Car trips by two-plus car-available persons – Compliant;
- C1PC – PT trips by one-car-available persons – Compliant;
- C2PC – PT trips by two-plus car-available persons – Compliant;
- C0P – PT trips by zero-car-available persons (Captive to PT);
- C1CN – Car trips by one-car-available persons – Non-Compliant;
- C2CN – Car trips by two-plus car-available persons – Non-Compliant;
- C1PN – PT trips by one-car-available persons – Non-Compliant; and
- C2PN – PT trips by two-plus car-available persons – Non-Compliant.

Time Periods and Trip Directions

2.4.19 The mode and destination choice models operate on 12-hour totals of trip productions and trip attractions, while the assignment models use hourly data in O/D format. These hourly trips are derived from the 12-hour demand P/A totals with the use of fixed factors applied to the choice models' outputs.

2.4.20 These factors convert first from 12-hour P/A data into period-level P/A data; these are then split into 'from-home' and 'return-home' legs and then, via person to vehicle conversion values (for highway assignment), to hourly O/D demand.

2.4.21 There are three time periods used in the assignment models, and these are defined as follows:

- AM assignment – Peak hour's demand, 0800-0900;
- Inter-peak assignment – Average hourly demand between 1100 and 1400; and
- PM assignment – Peak hour's demand, 1700-1800.

2.4.22 The full set of 12-hourly P/A trips used in the demand model is assumed to cover the three whole periods:

- AM period 0700-1000;
- Inter-peak period 1000-1600; and
- PM period 1600-1900.

2.5 Generalised Costs

2.5.1 Generalised costs are used within the highway and PT assignment models in order to model the routes that are taken by trips of different user classes and, in the case of PT modelling, the particular modes that are used to travel between zones.

2.5.2 In SATURN, the generalised costs are derived for each user class separately through the equation:

$$GC\ (pence) = (PPK * d) + (PPM * t) + m$$

where:

- GC is the total generalised cost in pence;
- d is the travel distance in kilometres;
- t is the travel time in minutes;
- m is the total money cost paid for the trip (e.g. from tolls) in pence; and
- PPK and PPM are SATURN's "pence per kilometre" and "pence per minute" factors, which represent, respectively, vehicle operating costs and values of time.

2.5.3 These factors are calculated by applying the detailed guidance in the DfT's Transport Appraisal Guidance (TAG) Unit A1.3 to obtain values for each vehicle type. PPM is derived by combining values of time for different user classes with vehicle occupancies and relevant rates of change. PPK is derived by applying fuel consumption equations to an assumed average network speed, also taking into account changes in fuel costs, vehicle occupancies and relevant rates of change.

2.5.4 The demand model works with Generalised Costs in minutes and so uses a modified version of the ones stated above. The formula used in the demand model also converts the costs to be person-based by multiplying by the vehicle occupancy factor (which is the reciprocal of the number of occupants and so less than or equal to 1 – see Table 3).

$$GC\ (mins) = \mathrm{t} + \left(\frac{\mathrm{PPK}}{\mathrm{PPM}} * d * Occ\right) + \frac{m * Occ}{PPM}$$

2.5.5 In the Voyager Public Transport assignment program, generalised costs[1] are derived from fare tables; weighted access, egress and interchange times; in-vehicle times; transfer penalties, and values of time:

$$GC\ (mins) = a * (Initial\ Wait\ Time + Transfer\ Wait\ Time + Walk\ Time)$$
$$+(b *\ Travel\ Time)$$
$$+Boarding\ Penalty + Transfer\ Penalty$$
$$+\left(\frac{Fare}{100} * \frac{1}{VOT}\right) - Value\ of\ Choice$$

where *a* and *b* are weights applied to the respective time components. The value of *a* is 2. The value of *b* differs by PT sub-mode and is 0.9 for train, 0.92 for tram and 1 for bus.

2.5.6 According to TAG, values of time for travel outside of working time are independent of mode, whereas those for travel in working time are mode-dependent. For the highway and PT assignment models, therefore, the values of time used are those appropriate to the relevant modes.

2.5.7 The demand response models process all sub-modes together and so it is not appropriate to use mode-specific values of time with these as the assignment models do. Hence for the processing of employer's business trips in the demand model, the value of time used is the one for "Average of all working persons".

2.6 Trip Ends

2.6.1 The basic input data required by the demand model for the base year and any future years are total numbers of trip productions and trip attractions from and to each model zone.

2.6.2 These productions and attractions are totals for the 12 hour period covering the AM, Inter-peak and PM periods between 0700 and 1900, and as raw inputs they are not segmented by mode, since it is the job of the mode choice model to predict this.

2.6.3 The inputted trip production totals are segmented by journey purpose and, within each of these, by car availability category. By contrast, the inputted trip attractions for each journey purpose are not segmented in this way but expressed simply as totals to each zone.

[1] See Para. 4.4.9 for further information on these terms.

2.6.4 As indicated previously the demand model processes only internal-internal, internal-external, and external-internal movements, with trips between external zones being added in at a time period, O/D level just before the full matrices are passed to the assignment models. Because of this, the total numbers of trip productions from external zones must exclude those which have attraction ends in external zones. Similarly the total numbers of trip attractions to external zones must exclude those which have production ends in external zones.

2.6.5 Base year trip ends have been calculated by "reverse-engineering" the hourly demand matrices for each user class in the two base year assignment models into 12-hour P/A formatted demand matrices. The procedure used for this demand conversion is described in Chapter 3.

2.6.6 For future years the demand model trip end totals are modified by being multiplied by growth factors derived from TEMPRO; for trip productions these factors are extracted for each car availability category, while for trip attractions they are not segmented.

2.7 Mode and Destination Choice Models

2.7.1 Mode and destination choice in the model are performed with absolute logit models that are applied incrementally. These models are arranged hierarchically, with destination dependent upon mode choice.

2.7.2 The destination choice models for all journey purposes are doubly constrained with the exception of the home-based other purpose, which is singly (i.e. production-end) constrained.

2.7.3 The logit models are calibrated to the base year P/A demand matrices with the use of sensitivity parameters in the destination choice model, and scaling factors and mode-specific constants in the mode choice model. For the singly constrained destination choice model, alternative-specific constants (ASCs) for each attraction zone are also calculated. These are not required by the doubly constrained models, because the required values are derived during the trip-balancing process.

2.7.4 The mode constants were derived from the base year P/A data, as were the ASCs for the home-based other purpose. Destination choice sensitivity parameters and mode choice scaling factors we taken as WebTAG Median Illustrative Parameters. The performance of the median parameters was checked against trip length distributions and sectored matrices. A suitable match was found and so the parameters were not altered.

2.7.5 Having been calibrated to the base year P/A demand, the same destination and mode choice parameters are used in forecast years.

2.7.6 A full description of the procedures used to obtain the parameters used in the logit models is given in Chapter 4.

2.8 Other Choice Models

2.8.1 There are three additional choice models which are optional within a model run. They can be turned on or off in any combination depending on the purpose of the model run. These three models are

- Trip Frequency;
- Time Period Choice; and
- Peak Spreading.

Trip Frequency

2.8.2 The Trip Frequency module allows for the total number of trips to increase or decrease depending on changes in cost. This is implemented via a simple elasticity model. The form of the model is:

$$P_{out} = P_{in} * e^{(\lambda(U_{ref} - U_{for}))}$$

Where

- P_{out} are the new trip end productions;
- P_{in} are the input trip end productions;
- U_{for} are the forecast composite utilities;
- U_{ref} are the reference composite utilities; and
- λ are the trip frequency parameters, currently set to 0.5 for all purposes.

Time Period Choice

2.8.3 The demand model works on 12-hour P/A level, with a number of stages prior to the assignment converting the output demand into period, O/D format. The conversion from 12-hour to time period level is done via Day-To-Period (D2P) factors.

2.8.4 The Time Period Choice model modifies these D2P factors based on changes in cost. If AM peak costs increase then the factors will decrease in the AM, reducing the amount of demand allocated to that period. The other periods' factors increase to ensure the total amount of demand remains constant.

2.8.5 The equations for calculating the updated D2P factors are:

$$D2P'_{AM} = \frac{1}{1 + \left(\frac{D2P_{IP}}{D2P_{AM}}\right)\exp\left(\beta(\Delta Util_{IP} - \Delta Util_{AM})\right) + \left(\frac{D2P_{PM}}{D2P_{AM}}\right)\exp(\beta(\Delta Util_{PM} - \Delta Util_{AM}))}$$

$$D2P'_{IP} = \frac{1}{1 + \left(\frac{D2P_{AM}}{D2P_{IP}}\right)\exp\left(\beta(\Delta Util_{AM} - \Delta Util_{IP})\right) + \left(\frac{D2P_{PM}}{D2P_{IP}}\right)\exp(\beta(\Delta Util_{PM} - \Delta Util_{IP}))}$$

$$D2P'_{PM} = 1 - D2P'_{AM} - D2P'_{IP}$$

Where

- $D2P_x$ are the existing Day-to-Period factors for period x;
- $D2P'_x$ are the updated Day-to-Period factors for period x;
- $\Delta Util_x$ are the changes in utilities for period x (with respect to the base); and
- β is a sensitivity parameter, currently set to 0.8.

Peak Spreading

2.8.6 The Peak Spreading model is an incremental logit model, applied to the AM peak demand only. Whereas the Time Period Choice module allows demand to switch time periods the Peak Spreading module allows for AM demand to shift out of the peak hour and into the shoulders. This is implemented via a modification of the Period-to-Hour (P2H) factors which convert the period-level demand into a peak hour.

2.8.7 The logit model uses peak and shoulder costs for both a reference and forecast assignment to calculate the changes in period to hour factors. The sensitivity of the logit model is controlled via a parameter, β, which is set to -0.1 by default.

2.9 Park And Ride Model

2.9.1 The use of Park and Ride is permitted via a module which is run once the rest of the variable demand model's processes have reached demand/supply convergence.

2.9.2 The idea behind the park and ride model is that the final trip matrices produced by the assignment models are first split into those trips that can use park and ride and those which cannot. Those trips, for each mode, for which park and ride is a conceivable option are split into those which choose to use park and ride and those which do not. This splitting is carried out with a logit model based upon the choice between the current mode and the cheapest park and ride site out of the set of those that are available.

2.9.3 Trips which swap to using park and ride are converted from a single leg by their original mode into a car leg from the origin to the park and ride zone, and a public transport leg from the park and ride zone to their final destination.

2.9.4 The module therefore results in a set of assignment matrices that are different from those which were produced at the end of the run of the main model, and so these are re-assigned by the highway and public transport assignment models to produce the final results of the variable demand model.

3. BASE YEAR MATRIX DEVELOPMENT

3.1 Introduction

3.1.1 The main inputs to the base year demand model are the total numbers of trip productions and attractions between model zones for each journey purpose and main mode, with trip productions further segmented into different car availability categories.

3.1.2 The approach taken for the development of these 12-hourly P/A matrices for the base year has been to start from the calibrated, hourly O/D demand matrices built for the highway and PT assignment models and to "reverse engineer" them into the required form, following these steps:

- Convert from hourly O/D demand for assignment user classes into hourly O/D demand for demand model journey purposes;
- Split these O/D movements into those that are going away from home, those that are returning to home, and those that are non-home-based;
- Use vehicle occupancy data to convert vehicle trips (for highway) into person trips;
- Use expansion factors to convert from hourly demand to period demand, for the different directions of travel within each journey purpose;
- Combine period-level from-home and returning-home O/D data appropriately to create period-level P/A data; and, finally,
- Combine period-level P/A data into single 12-hour P/A demand matrix.

3.1.3 In a forecasting situation, the factors and other quantities used in moving from hourly O/D data to 12-hour P/A data are used in the opposite direction during the running of the demand model so as to create the predicted demand that is passed to the assignment models.

3.1.4 The base year highway demand is based on the base demand from the Highways England Regional Traffic Model of the Midlands (MRTM), which provides both P/A and O/D formatted demand. This provided a consistent set of data that could be applied to the Gateway calibrated O/D assignment matrix to generate P/A demand.

3.1.5 For the public transport modes the matrices derived during the calibration process were created from a range of data inputs, but were developed at the required 12-hourly P/A data level.

3.1.6 The rest of this chapter describes the approaches taken to generate the base year P/A trip matrices for the two main modes.

3.2 Development of Highway Matrices

3.2.1 The Base Year Highway assignment matrices were obtained by applying matrix estimation processes to prior matrices developed from the Highways England Regional Traffic Models for the Midlands (MRTM). The MRTM assignment matrices were rezoned, external-external trips masked out and a taxi matric developed. More details on the development of the highway prior matrix are provided in the Highway LMVR.

3.2.2 The MRTM also provided P/A demand and outbound and return factors to convert the P/A demand into O/D format. Splits between Home-Based and Non-Home-Based segments were also taken from MRTM and applied to the EMGM assignment matrices to disaggregate to the required journey purposes.

3.2.3 The remainder of this section describes the sources and values of the various factors required to convert the O/D highway assignment matrices into the P/A format required by the demand model.

Period to Hour factors

3.2.4 The assignment demand covers one hour of demand, which represents the peak hour within the overall period. The first step in the conversion to 12 hour PA is to convert the hourly matrices into period matrices. This allows them to be summed at a later stage to create the full 12 hours of demand.

3.2.5 The highway period to hour factors were calculated from the count data collected for the development of the highway assignment model. As these were calculated from automated count data there was insufficient data to provide different values for the different journey purposes.

3.2.6 Table 2 shows the Period to Hour factors for the AM and PM periods. Within the demand model the Inter-Peak is an average of the six hour period between 10:00 and 16:00 and so the factor for all periods, purposes and modes is a sixth.

Table 2. Highway Period To Hour Factors

JOURNEY PURPOSE	AM	PM
	HY	HY
Home Based Work	0.3713	0.3591
Home Based Employers Business	0.3713	0.3591
Home Based Other	0.3713	0.3591
Non Home Based Employers Business	0.3713	0.3591
Non Home Based Other	0.3713	0.3591

Occupancy factors

3.2.7 The highway assignment demand is a matrix of vehicles. The demand model requires demand in persons for both highway and public transport to enable the mode choice calculations to be undertaken.

3.2.8 Vehicle occupancy factors were applied on a geographic basis with the areas around Nottingham and Derby treated differently. The factors for both areas were taken from previous Nottingham and Derby models.

3.2.9 Table 3 shows the vehicle occupancy values used within the model.

Table 3. Vehicle Occupancy Factors

JOURNEY PURPOSE	NOTTINGHAM			DERBY		
	AM	IP	PM	AM	IP	PM
Home Based Work	0.87	0.89	0.89	0.85	0.85	0.85
Home Based Employers Business	0.81	0.85	0.85	0.62	0.62	0.62
Home Based Other	0.61	0.61	0.59	0.99	0.99	0.99
Non Home Based Employers Business	0.81	0.85	0.85	0.85	0.85	0.85
Non Home Based Other	0.61	0.61	0.59	0.61	0.61	0.61

O/D-to-P/A conversion

3.2.10 The Highways England MRTM provided Outbound and Return factors, which are used within that model to convert P/A demand into O/D. The factors are by journey purpose, mode and time period and at a 10-sector level covering the entire country.

3.2.11 The factors for highway were used to split the highway assignment demand into from-home and to-home demand. The sectoral detail was kept through mapping the Gateway zones to the MRTM sectors as closely as possible.

3.2.12 The P/A demand was then created through combining the From-Home and the transpose of the To-Home demand.

3.2.13 The factors used within the model to reverse the process (i.e. from P/A to O/D) were calculated from the From-Home, To-Home and total P/A matrices and vary on a zonal basis, for each purpose and time period.

Day to Period factors

3.2.14 Day to Period factors are used to convert the 12 hour P/A demand into the three time periods. These factors are calculated from summing the three period P/A matrices developed in the previous step to create the 12 hour P/A demand. The ratio of the period matrix to the 12 hour P/A matrix then provides the appropriate period splitting factors.

3.3 Development of Public Transport Matrices

3.3.1 The public transport demand is a combination of data from a number of sources (further detail provided in the Public Transport LMVR), including:

- NTEM trip ends, zoned to Gateway zones using CodePoint postcode data and distributed using a gravity model;
- Electronic Ticket Machine (ETM) data from Trent Barton buses;
- Planet Midlands and Planet Long Distance models provided the rail demand; and

- Tram demand created via running a select link on tram users in the old Nottingham model.

3.3.2 The remainder of this section describes the sources and values of the various factors required to convert the O/D PT assignment matrices into the P/A format required by the demand model.

Period to Hour factors

3.3.3 The period to hour factors are used to convert from time period level to the peak hours used within the assignments. The public transport factors are taken from the previous Nottingham transport model as no other data was available.

Table 4. Public Transport Period to Hour Factors

JOURNEY PURPOSE	AM	PM
	PT	PT
Home Based Work	0.43	0.50
Home Based Employers Business	0.45	0.32
Home Based Other	0.45	0.49
Non Home Based Employers Business	0.45	0.32
Non Home Based Other	0.45	0.49

O/D-to-P/A conversion

3.3.4 The demand matrices for the three PT sub-modes were developed independently of others and then only aggregated at the final step before inputting them into the assignments. This meant that during the development of the matrices all factors could be sub-mode specific where possible.

3.3.5 The outbound and return factors were an example of this, with values for Rail being taken from MRTM (which only included rail for PT), and bus values being taken from the DIADEM User Guide (software which MRTM is built in) which provides standard values for car, bus and rail modes based on NTS analysis. Tram used the same factors as rail as no other data was available.

3.3.6 At the point that the PT assignment matrix had been calibrated and validated all the PT sub-modes were combined, meaning the sub-mode outbound and return factors could not be used. Instead all-mode factors were created by demand weighting the individual sub-mode factors and combining. As this was done at a sector level this gives variation with the type of journey, so shorter journeys within the cities will be more weighted towards bus-type factors than longer rail-based movements.

3.3.7 As for the highway demand, the Outbound and Return factors were used to split the demand into From-Home and To-Home matrices, which were then combined into P/A demand. The factors to reverse the process were calculated from these matrices.

Day to Period factors

3.3.8 Day to Period factors are used to convert the 12 hour P/A demand into the three time periods. This factors are calculated from summing the three period P/A matrices developed in the previous step to create the12 hour P/A demand. The ratio of the period matrix to the 12 hour P/A matrix then provides the period splitting factors.

3.4 Car Availability Splitting

3.4.1 The matrices taken from the base year assignment models are not split by car availability category. However, the demand model processes total trip productions and attractions separately within different car availabilities, and so the 12-hour P/A data obtained through the methods described so far in this chapter had to be further manipulated.

3.4.2 TEMPRO data of the total number of trip productions by different car availabilities for different areas were extracted and used to calculate the proportions of all productions that are made by persons in C0, C1 and C2 households. These splitting proportions were calculated separately for the different demand model purposes, with car driver and passenger data used for the highway matrix split, and combined TEMPRO PT modes used for the public transport split.

3.4.3 Because the model assumes that C0 trips are captive to public transport, C0 trip productions were taken from TEMPRO for public transport modes only, and used only in the split of PT trip productions.

3.4.4 These splitting factors were calculated for each model zone separately by means of correspondence tables which indicate the proportion of each zone contributed to by each TEMPRO zone. The lookup between the Gateway and TEMPRO zones was created using CodePoint postcode data to calculate the proportions for each zone.

3.4.5 The final car availability splitting factors were applied to the car and PT 12-hour P/A matrices to give estimates of the observed C1 and C2 car matrices, and C0, C1 and C2 PT trip matrices

4. DESTINATION AND MODE CHOICE CALIBRATION

4.1 Overview

4.1.1 This Chapter describes the methods used to derive appropriate values of the parameters required by the mode and destination choice models.

4.1.2 Mode and destination choice are calculated using an absolute nested logit model, with destination dependent upon mode choice. Of the five demand model purposes, all but the home-based other purpose are modelled with both production and attraction constraints (doubly constrained models). Home-based other trips are production-zone constrained only (a singly constrained model).

4.1.3 A number of different parameters are required by the logit models and these are obtained by attempting, within the restrictions of the logit equations, to best reflect the base year data. These data are the matrices of 12-hour P/A data, segmented by purpose, mode and car availability, as described in the previous chapter.

4.2 Logit Model Formulation

4.2.1 Logit models are based on discrete choice theory, and the main quantity of interest in the modelling of traveller behaviour is the utility of an option. The higher the utility of an option, the more likely it is to be chosen by a given person.

4.2.2 In the demand model the available options are combinations of a particular mode and destination. In accordance with guidance, the utility of a particular option in the demand model is a function of the generalised cost of that option. In EMGM these "costs" are actually represented as times, using units of (generalised) minutes. The utility is also likely to contain other quantities that represent other attributes of a particular combination of options, which are not captured by the simple generalised cost-dependence.

4.2.3 Because the generalised cost of travelling to a given destination by a given mode depends also on the journey purpose, production zone and car availability category, the utility of a particular destination choice in EMGM is expressed as:

$$U_{ijpmc} = \beta_{pmc} C_{ijpmc} + ASC_{jp}$$

where:

- i is the production zone;
- j is the attraction zone;
- p is the journey purpose for which the trip is being made;
- m is the main mode being used to make the trip – either car or PT;
- c is the car availability category – C0, C1, C2;
- β is a cost-sensitivity parameter, which may depend on purpose, mode and car availability;
- C is the generalised cost, which is likely to depend on all trip attributes; and
- ASC is known as an *alternative-specific constant*, which absorbs all other utility attributes (components of a particular option that are not represented by the cost of travelling), and this varies only by attraction zone and journey purpose.

4.2.4 Destination choice is modelled as either singly constrained or doubly constrained, depending on the journey purpose. In the doubly constrained case changes in utility lead to changes in destination choice, but the overall number of productions from and attractions to each zone, summed over all modes, is forced to correspond to particular supplied values for each car availability category. In the Gateway model only the home-based other purpose is modelled as being singly constrained.

4.2.5 The alternative-specific constants are used only with the singly constrained destination choice model. The values of the ASCs for each zone are set up for the base year by ensuring that the shares of all modelled base year attractions to each zone match the corresponding shares in the observed data. The ASCs reflect realities such as certain zones being more attractive than the cost of travelling to them might otherwise suggest.

4.2.6 ASCs are not required for the purposes whose destination choices are doubly constrained, since these choices are based on a gravity model formulation, which automatically ensures that production and attraction trip end constraints are satisfied.

4.2.7 As the generalised cost of an option increases, the likelihood that the option will be chosen is expected to decrease. This means that the cost-sensitivity parameters, β, should be negative.

Doubly Constrained Destination Choice

4.2.8 The choices of destination for the Home-Based Work (Commuting), Home-Base Employers Business, Non-Home-Based Employers Business and Non-Home-Based Other purposes are doubly constrained, meaning that the total numbers of trip productions and attractions from and to each model zone meet certain targets, which are specified by trip end data files.

4.2.9 The choices of destination for these purposes are dealt with in a gravity model formulation in which the number of trips between zones *i* and *j* (for a given journey purpose *p*, mode *m*, and car availability *c*) is given by the expression:

$$T_{ijpmc} = A_{ipmc} B_{jp} \exp(U_{ijpmc})$$

where, because the utility of a given option is a decreasing function of cost, this represents a gravity model with an exponentially decaying deterrence function. The larger the magnitude of the β parameter, the more quickly the trip distribution will decay as costs increase.

4.2.10 The quantity B_{jp} is a balancing factor which ensures that the total number of trips attracted to each zone is equal to the target. These balancing factors cannot depend upon mode and car availability because the targeted number of trip attractions used in the model is the sum over all five demand segments (C1C, C2C, etc). Hence, for a fixed journey purpose, there is one value of the balancing factor for each model zone.

4.2.11 The gravity model formulation is applied in practice by first generating a matrix of the exponentiated utility values, $\exp(U_{ijpmc})$, and then using a furnessing process on this "prior matrix"-like starting point, iteratively modifying row and column totals until a converged state is reached[2].

Singly Constrained Destination Choice

4.2.12 The choice of destination for the Home-Based Other purpose is singly constrained, meaning that only the number of trip productions from each zone in each car availability category is set to a particular value, while the total number of trip attractions to each zone is permitted to vary.

4.2.13 For this journey purpose, the probability that zone *j* will be chosen as the attraction end of a production from zone *i*, for fixed values of mode and car availability, is given by:

$$P_{ijmc} = \frac{D_j \exp(U_{ijmc})}{\sum_j D_j \exp(U_{ijmc})}$$

4.2.14 where:

- U_{ijmc} is the option's utility, as defined previously, with the inclusion this time of non-zero values of the ASCs; and
- D_j is the total number of attractions to zone *j*, as indicated by the trip end data, across both main modes and all car availability categories, for the Home-Based Other purpose.

4.2.15 The notation $P_{a|b}$ denotes a conditional probability, giving the likelihood that option *a* is chosen given that option *b* has already been selected. Because the logit models used are arranged with destination choice nested inside mode choice, the choice of *j* is conditional on the choice of *m*.

4.2.16 The total number of trips between zones *i* and *j* for a particular demand segment is then calculated from:

$$T_{ijmc} = O_{imc} P_{ij|mc}$$

4.2.17 where O_{imc} is the number of trip productions for each combination of model zone, mode and car availability category. This quantity is calculated by multiplying the total number of trip productions from each zone by car availability by the probability that the given mode is chosen.

4.2.18 Although they are not explicitly applied to the doubly constrained trip purposes, the alternative-specific constants for each attraction zone need to be calculated for the singly constrained purpose.

[2] In practice the trip balancing process terminates when the maximum deviation between the targeted row and column totals is less than some specified amount, chosen to balance the competing concerns of accuracy and model runtimes

4.2.19 The values of these constants, which vary only by attraction zone and purpose, are calculated for the base year model to ensure that the total number of attractions to each zone is equal to the desired value. In this way, the singly constrained model in the base year is, in essence, doubly constrained. The difference between this model and the gravity model approach for the other journey purposes is that these ASCs are applied to the home-based other destination choice modelling in all forecast situations, whereas those for the doubly constrained purposes are recalculated each time they are required.

4.2.20 The required base year ASCs are derived so that each attraction zone's share of all modelled trip attractions is the same as that zone's share of the observed attractions, as denoted by the P/A data that were derived from the validated assignment matrices.

4.2.21 These shares of attractions are calculated overall demand segments, since only the total number of trip ends attracted to each model zone is known, without segmentation into modes and car availability categories.

4.2.22 The $P_{ij|mc}$ values are calculated for each demand segment separately, using the equation given above, but the zonal shares that are to be matched are independent of demand segment. Introducing a demand segment index, s, into the equations, we have that the share of attractions in either the base or synthetic destination choice is given by:

$$\text{Share of all zone attractions that are to zone j is} = \frac{\sum_{is} T_{ijs}}{\sum_{ijs} T_{ijs}}$$

4.2.23 For a fixed set of sensitivity parameters, a given set of *ASCs* leads to a particular set of zonal attraction shares. These are compared with the required shares (from the base P/A data) and the ASCs are modified accordingly.

4.2.24 The ASC modification is worked out with the equation:

$$ASC_{\text{new}} = ASC_{\text{old}} + \ln\left(\frac{share_{\text{observed}}}{share_{\text{modelled}}}\right)$$

which ensures that if the modelled share to a zone is less than observed, the ASC for that zone is increased, and if the modelled share is greater than observed, the ASC for that zone is decreased. When the shares are equal, the logarithm of 1.0 is calculated – which is equal to zero – and no further modification to the relevant ASCs is performed[3].

4.2.25 Because the total over the destination choice probabilities is equal to 1.0, the sum over all attractions must be equal to the sum over all productions. Hence, by ensuring that the ASCs reproduce in the base the attraction shares for each zone in the observed data, this procedure leads to a home-based other matrix in the base in which the productions from

[3] As usual, in practice the data are calculated within some specified tolerance which allows for the twin desires of accuracy and practicality.

and the attractions to each model zone are equal to the corresponding values in the observed data[4].

Mode Choice

4.2.26 The destination choice models are nested within choices of mode, and so mode choice depends on the utilities of all destination choices that are contained within each of these mode nests.

4.2.27 If the utilities of travel to all destinations by public transport are smaller than those for travel by car, then the overall utility of public transport is expected to be lower than that of car, and so the probability that public transport will be chosen should be expected to be smaller than for car.

4.2.28 The probability that mode *m* is chosen for travel for purpose *p* from production zone *i* in car availability category *c* is calculated with the following expression:

$$P_{impc} = \frac{\exp(\theta_p \tilde{U}_{impc} + \alpha_{impc})}{\sum_{m'} \exp(\theta_p \tilde{U}_{im'pc} + \alpha_{im'pc})}$$

where:

- θ_p is the scaling parameter for the mode nest; this varies by purpose *p*, and is required to be positive with a value between 0 and 1;
- $\tilde{U}_{impc}$ is the *composite utility* (defined below) over all options within a given mode nest; this varies by production zone, mode, journey purpose and car availability category – that is, over all trip attributes except attraction zone;
- α_{impc} is a mode-specific constant; this varies by mode and also by production zone, journey purpose and car availability category, and it is used to represent that part of a mode's utility that is not captured by the composite utility over destination choices. It is therefore analogous to the ASCs derived for the destination choice model.

4.2.29 The composite utility is defined in modelling guidance by the expression:

$$\tilde{U}_{impc} = \ln \sum_j B_{jp} \exp(U_{ijmpc}) - \ln \sum_j B_{jp}$$

where B_{jp} denotes the balancing factors defined earlier and *ln* is the natural logarithm function.

4.2.30 Because there are only two modes between which a traveller can choose, mode-specific constants need be defined only for one mode – the addition of a constant to one mode's utility is equivalent to subtracting the same constant from the other mode's utility. The

[4] However, these facts do not imply that individual cells in the modelled and observed matrices will be equal, as will be described in Chapter 5.

arbitrary choice has been made to calculate the mode constants for car, defining those for PT to be zero.

4.2.31 A difficulty encountered with the definition of composite utility given above is that the furnessing procedure used to balance trip productions and trip attractions for the doubly constrained purpose is carried out by a Cube Voyager program that does not give access to the required balancing factors. However, by starting from the gravity model expression for the number of trips between zones and manipulating it, the required quantity can be obtained.

4.2.32 Simplifying the notation a little with the suppression of some attribute indices, the number of trips is expressed as:

$$T_{ij} = A_i B_j \exp(U_{ij})$$

4.2.33 Summing over zones production zones *i*, it is found that:

$$\sum_j T_{ij} = \sum_j A_i B_j \exp(U_{ij}) = A_i \sum_j B_j \exp(U_{ij})$$

and hence also that:

$$\sum_j \frac{T_{ij}}{\exp(U_{ij})} = \sum_j A_i B_j = A_i \sum_j B_j$$

4.2.34 Combining these expressions together leads to the conclusion that:

$$\tilde{U}_{ij} = \ln \sum_j B_j \exp(U_{ij}) - \ln \sum_j B_j = \ln \sum_j T_{ij} - \ln \sum_j \frac{T_{ij}}{\exp(U_{ij})}$$

and so the required composite utility can be calculated from the data that are available within the model.

4.2.35 The same expression is used for the calculation of composite utilities for the singly constrained purpose as well as those for the doubly constrained purposes.

4.2.36 The mode-specific constants, α, are calculated so as to ensure that the base year modal splits of trips for each purpose in each car availability category from each production zone match those in the observed data.

4.2.37 The probability that either car is chosen for a particular movement is given by:

$$P_{\text{car}} = \frac{\exp(\theta\tilde{U}_{\text{car}} + \alpha)}{\exp(\theta\tilde{U}_{\text{car}} + \alpha) + \exp(\theta\tilde{U}_{\text{PT}})}$$

where the mode constant is applied only to car, as discussed above.

4.2.38 This equation can be rearranged to give an expression for :

$$\alpha = \ln\left(\frac{P_{\text{car}}}{P_{\text{PT}}}\right) + \theta\left(\tilde{U}_{\text{PT}} - \tilde{U}_{\text{car}}\right)$$

4.2.39 The composite utilities for each mode are calculated from the results of the destination choice model and the relevant car and PT choice probabilities are taken from the observed base year P/A data. The mode constants are dependent on production zone, journey purpose and car availability category and will reproduce the observed mode shares for trips with those attributes.

4.2.40 Once calculated for the base year model, these mode constants are applied in all forecasting cases, as is the case with the ASCs calculated for the singly constrained journey purpose.

Final P/A-level Trip Matrices

4.2.41 For the singly constrained purpose the final trip matrix is obtained by multiplying the probability that a destination choice is made, for a given mode, by the probability that that mode is chosen, and then multiplying this result by the relevant number of trip productions.

4.2.42 Hence, with the following data:

- O_{ic} – the number of trip productions from zone *i* and car availability category *c*;
- P_{imc} – the probability that mode *m* is chosen for travel from zone *i* in car availability category *c*; and
- $P_{ij|mc}$ – the probability that destination *j* is chosen for travel from zone *i* in car availability category *c*, given that mode *m* has been chosen,

the number of trips for this purpose is given by: $T_{ijmc} = O_{ic}P_{ij|mc}P_{imc}$

4.2.43 The situation for the doubly constrained purposes is similar, although the multiplication of the individual destination and mode choice probabilities is not carried out explicitly but is instead an outcome of the Furnessing process applied to the matrix of option utilities.

4.2.44 The Furnessing process used for the calculation of the required balancing factors requires modally split trip productions as an input, and so these must be provided before the destination choice is carried out. These destination choices lead to composite utilities through the expressions in 4.2.29 and 4.2.34, which are used to calculate mode choice probabilities. These will not necessarily be consistent with those that were just used as the starting point for the trip balancing, and so for the doubly constrained model an iterative process is necessary in order to reach a consistent solution.

4.3 Modifications to Destination Choice Deterrence Function

4.3.1 For both the doubly and singly constrained destination choice models the process of generating the output trip matrices involves the use of a deterrence function, which for this model is the exponential of the utility (which is related to the cost, via the parameter β).

4.3.2 Taking the doubly constrained gravity model the demand between zones *i* and *j* (for a given journey purpose *p*, mode *m*, and car availability *c*) is given by the expression:

$$T_{ijpmc} = A_{impc} B_{jp} \exp(U_{ijpmc})$$

where $\exp(U_{ijpmc})$ is the deterrence function.

4.3.3 The demand model actually uses a modified deterrence function, including two factor matrices

- K factors; and
- PT Boarding Flag.

4.3.4 The K factors are calculated at a 12-sector level as the ratio between the observed demand and the output of the demand model without the K factors. They are applied to the deterrence function to produce a better match to the observed distribution than is possible without them.

4.3.5 The PT Boarding flag takes a value of one if the route for a given zone pair required at least one public transport boarding in the base year (i.e. at least one service was used). It takes a value of 0.001 if there was no boarding made. The purpose of this flag matrix is to reduce the number of trips made on very short, low cost movements that don't require public transport.

4.3.6 As the PT demand was developed entirely from demand that does use PT all trips should be making at least one boarding. However, a certain number of trips are allowed (hence a value of 0.001 rather than 0) to give a better match to the observed data.

4.3.7 The application of these two factor matrices to the deterrence function results in:

$$KFac_{ijpmc} * PTFlag_{ijpmc} * \exp(U_{ijpmc})$$

Where:

- $KFac_{ijpmc}$ is the K factor for a given origin *i*, destination *j*, purpose *p*, mode *m* and car availability *c*; and

- $PTFlag_{ijpmc}$ is the PT Boarding Flag for a given origin *i*, destination *j*, purpose *p*, mode *m* and car availability *c*.

4.3.8 The deterrence function is altered in exactly the same way for the single constrained destination choice process.

4.4 Obtaining Demand Model Sensitivity and Scaling Parameters

4.4.1 The mode and destination choice models make use of a number of parameters, as described in the previous section:

- β – Destination choice cost-sensitivity parameters;
- θ – Mode choice composite cost scaling parameters;
- ASC – Destination choice alternative-specific constants (HB Other purpose only); and
- α – Mode choice mode-specific constants.

4.4.2 Of these parameters, the last two are determined entirely from the base year observed data and the values of β and θ.

4.4.3 In this section, the method used for obtaining appropriate values of the cost-sensitivity and cost scaling parameters is described. The first step is to obtain generalised costs for the base year observed data.

Base Year Generalised Costs

4.4.4 The utilities used in the calculation of destination choice, and hence also mode choice, are dependent upon the generalised costs of travel between zone pairs by each mode for each journey purpose.

4.4.5 For the base year these costs are derived by assigning the calibrated demand matrices to the relevant networks, and outputting time, distance, fare and other similar matrices of trip information for the routes and PT services chosen.

4.4.6 The generalised cost, in units of minutes, for car trips is calculated from:
$GC_{car} = Time + (Distance * PPK) / (occupancy * VOT)$

where:

- *Time* = Travel time between zones, in units of minutes;
- *Distance* = Distance between zones, in units of kilometres;
- *PPK* = Value of the pence per kilometre parameter, used in the SATURN highway assignment to represent vehicle operating costs;
- *occupancy*[5] = Vehicle occupancy, varying by purpose and time period, used to convert travel costs per vehicle into costs per occupant; and
- *VOT* = Value of time in units of pence per minute.

[5] The model actually uses an "Occupancy Factor", which is the reciprocal of a traditional occupancy value (i.e. the number of people per car) and so represents the number of cars per people. The highway demand is multiplied by this factor to convert from persons to vehicles.

4.4.7 The times and distances that are outputted from SATURN for the generalised cost calculations are weighted averages over all routes in what SATURN terms a *forest*, rather than being simply the time and distance for the minimum cost path.

4.4.8 The data outputted for the two commuting user classes (with/without workplace parking) are combined into a single commuting purpose by weighting them with the proportions of all commuting trips which they represent.

4.4.9 The generalised cost, in units of minutes, for public transport are derived from a number of outputs of the Cube Voyager Public Transport assignment program. The data used are:

- Perceived initial waiting time – Average actual time incurred at the start of a trip. This is multiplied by a waiting time factor;
- Perceived transfer wait time – Average actual time incurred at transfer points during a trip. This is multiplied by a waiting time factor;
- Perceived travel time – Average in-vehicle run time;
- Perceived walk time – Average "non-transit" time, including access, egress and transfer movements;
- Perceived boarding penalty;
- Transfer penalty;
- Fare – Average monetary fare paid, in units of pounds; and,
- Value of choice – this is the difference between average and composite cost values, and represents the benefit that is gained by travellers from having alternatives to choose between.

4.4.10 The generalised cost for public transport trips is calculated as the sum of all of these components except the value of choice, which is subtracted from this sum. The monetary fare is converted into time by dividing by the value of time.

4.4.11 The results of running the assignment models are thus generalised costs for highway and PT trips in each time period. To produce costs for use in the demand model, the separate time period costs are combined for a given mode by weighting them with the 12-hour to whole period P/A factors that were derived as described in Chapter 3.

4.4.12 The values of time and PPK parameters used by the demand model are given in Table 5, for 2016 values in 2010 prices. These are calculated from values in the December 2017 version of the WebTAG databook.

Table 5. Values of Time and Pence Per Kilometre parameters (2016 values in 2010 prices)

QUANTITY	PURPOSE	VALUE (PENCE)
Value of Time (Pence Per Minute)	Employer's Business	30.21
	Commuting	20.26
	Other	13.98
Pence Per Kilometre	Employer's Business	13.90
	Commuting	10.23
	Other	10.23

Calibration of Sensitivity and Scaling Parameters

4.4.13 The values of β and θ that have been used in the model have not been derived through a full estimation with software such as ALOGIT. Instead, illustrative values of these quantities were taken from section 5.6 of TAG Unit M2[6] and used as a starting point for analysis.

4.4.14 The mode and destination choice models process only trips with at least one end in an internal model zone (see Table 1), and so the demand model input files containing the required numbers of trip productions and attractions include only those row and column totals from P/A matrices from which movements between external zones have been omitted.

4.4.15 As with the matrices of goods vehicle trips, external-to-external trips are added just before the assignment models are run.

4.4.16 When the demand model runs, the modes and destinations chosen by trip productions from each zone depend on the costs of travel and the values of the sensitivity and scaling parameters. The larger the value of the β cost-sensitivity parameter is for a particular mode, the less likely it is for that mode to be chosen as generalised costs increase. Likewise, as the value of β is decreased, the effect of cost plays a smaller role in the choice of destination.

4.4.17 The base year observed data has been used to create observed trip length distributions, showing how the levels of trips differs across generalised cost bands. These can be compared with the trip length distributions for each mode that result from the application of the choice models.

4.4.18 The cost-sensitivity parameters used in the destination choice model are permitted to vary by mode and journey purpose.

[6] TAG Unit M2 "Variable Demand Modelling" section 5.6, dated March 2017.

4.4.19 For both doubly constrained and singly constrained destination choice models the median illustrative parameters were deemed to give a good enough fit to the observed trip length distributions. However, in both cases K-factors were also used to improve the fit of the modelled demand to the observed.

4.4.20 The ultimate test of a particular set of chosen parameters is to run realism tests to check the responses of the mode and destination choice models to changes in highway and public transport costs.

4.4.21 These realism tests have been carried out and their results are described in Chapter 6. The outcomes of these tests, and the results of these are elasticities of vehicle-kilometres (for highway cost changes) and public transport trips (for PT fare changes). These elasticities were compared with targets specified in TAG.

4.4.22 The sensitivity and scaling parameters used in the model are shown in Table 6, below. The sensitivity parameters vary by mode and purpose, but not by car availability category.

Table 6. Mode and Destination Choice Parameters

PARAMETER	HB WORK	HB EMP BUS	HB OTHER	NHB EMP BUS	NHB OTHER
β_{car}	-0.065	-0.067	-0.090	-0.081	-0.077
β_{PT}	-0.033	-0.036	-0.036	-0.042	-0.033
θ	0.68	0.45	0.53	0.73	0.81

4.5 K-Factors

4.5.1 The K-factors applied in the distribution model are calculated at a 12-sector level by comparing the observed demand to the modelled demand without the K-factors. The factors produced where then capped to be between a minimum of 0.25 and a maximum of 4 to ensure no excessively large or small factors were applied.

4.5.2 Table 7 shows the (demand-weighted) average factor applied across all sectors, which are all slightly above 1. It also shows the maximum and minimum factors applied (excluding the cap values of 0.25 and 4), which shows that the factors do vary across the whole range.

4.5.3 Figure 5 shows the full sectored matrix of K-factors for Home-Based Work C1C. The other matrices of K-factors are in Appendix A.

Table 7. Average, Maximum and Minimum K Factors

Purpose	Car Avail Class	Average	Min > 0.25	Max < 4
HBW	C1C	1.07	0.29	3.65
HBW	C2C	1.07	0.31	3.59
HBW	C1P	1.11	0.26	3.11
HBW	C2P	1.17	0.26	3.28
HBW	C0P	1.10	0.29	3.29
HBEB	C1C	1.21	0.34	3.75
HBEB	C2C	1.20	0.35	3.68
HBEB	C1P	1.66	0.25	3.76
HBEB	C2P	1.55	0.25	3.51
HBEB	C0P	1.94	0.26	3.96
HBO	C1C	1.20	0.25	3.97
HBO	C2C	1.20	0.25	3.57
HBO	C1P	1.15	0.28	3.41
HBO	C2P	1.13	0.27	3.53
HBO	C0P	1.20	0.28	3.86
NHBEB	C1C	1.15	0.40	3.93
NHBEB	C2C	1.14	0.40	3.83
NHBEB	C1P	1.30	0.30	3.36
NHBEB	C2P	1.33	0.25	3.86
NHBEB	C0P	1.35	0.26	3.65
NHBO	C1C	1.11	0.30	3.82
NHBO	C2C	1.12	0.30	3.97
NHBO	C1P	1.19	0.28	3.68
NHBO	C2P	1.24	0.25	3.87
NHBO	C0P	1.22	0.26	3.96

Figure 5. K-factors for Home-Based Work C1C

HBW C1C		Central Nottingham	Outer Nottingham	Central Derby	Ilkeston & Long Eaton	Derbyshire	Burton & Leicestershire	Newark & Mansfield	West Midlands	North England	South England	Wales	Scotland
	C1C	1	2	3	4	5	6	7	8	9	10	11	12
Central Nottingham	1	1.11	1.08	0.36	0.62	0.60	0.51	0.96	1.14	1.73	1.86	4.00	4.00
Outer Nottingham	2	1.05	1.18	0.47	0.96	0.74	0.66	1.05	1.56	1.38	1.62	4.00	4.00
Central Derby	3	0.32	0.35	1.27	0.82	0.94	0.64	0.33	0.77	1.60	1.82	0.68	4.00
Ilkeston & Long Eaton	4	0.80	1.27	0.85	1.50	0.81	0.65	0.87	1.38	2.00	1.39	1.50	4.00
Derbyshire	5	0.53	0.66	1.00	1.09	1.23	0.91	0.73	0.97	1.51	2.12	0.66	4.00
Burton & Leicestershire	6	0.36	0.62	0.55	0.50	0.85	1.19	0.34	0.99	3.65	0.64	0.65	4.00
Newark & Mansfield	7	0.64	1.18	0.29	0.48	0.65	0.42	1.20	2.07	1.33	3.26	4.00	4.00
West Midlands	8	1.02	1.08	0.97	0.79	0.68	1.10	0.62					
North England	9	0.71	0.79	0.87	1.56	1.40	1.59	0.89					
South England	10	1.45	1.20	2.63	1.77	1.71	0.48	3.50					
Wales	11	4.00	4.00	0.42	2.05	0.82	0.63	4.00					
Scotland	12	1.11	0.49	2.97	1.92	1.06	4.00	0.25					

4.6 Trip Length Distributions

4.6.1 Figure 6 to Figure 10 show the outturn trip length distributions (TLDs) for each purpose. The first graphs show the TLDs for the five car availability and mode combinations (C1C, C2C, etc.), showing both relative and cumulative frequency for the observed and two modelled datasets. The modelled data is shown both with and without the application of the K-factors. The sixth graph shows the R^2 values between the observed data and two modelled data sets for total trips, relative frequency and cumulative frequency.

4.6.2 Typically, the highway TLDs show a better match to the observed data than the PT. The PT observed data shows spikes at very short distances and also around 50 minutes that are difficult to match via a synthetic demand building approach.

4.6.3 In all cases the application of K-factors improves the match to the observed data.

Figure 6. Trip Length Distributions: Home-Based Work

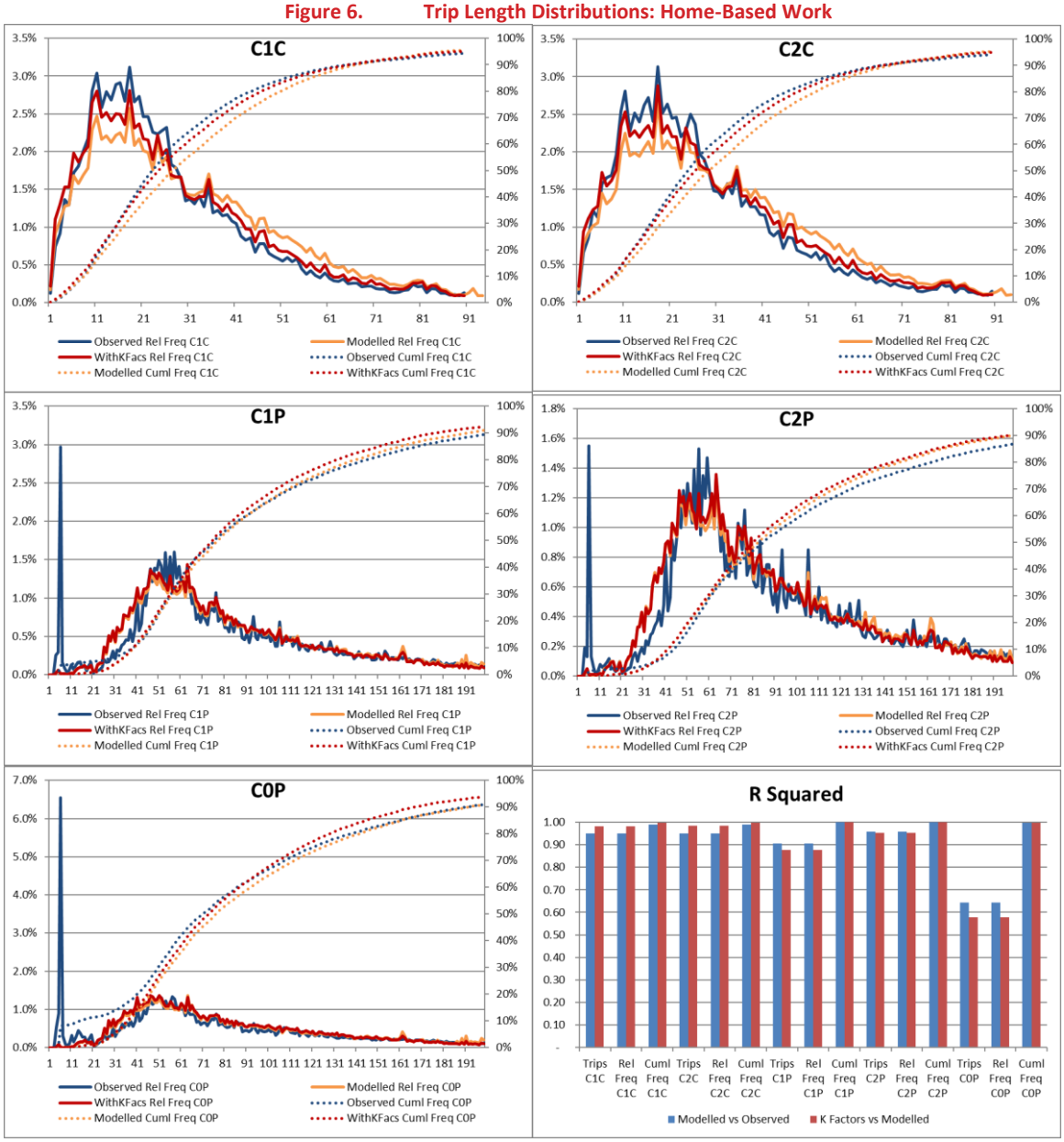


Figure 7. Trip Length Distributions: Home-Based Employers Business

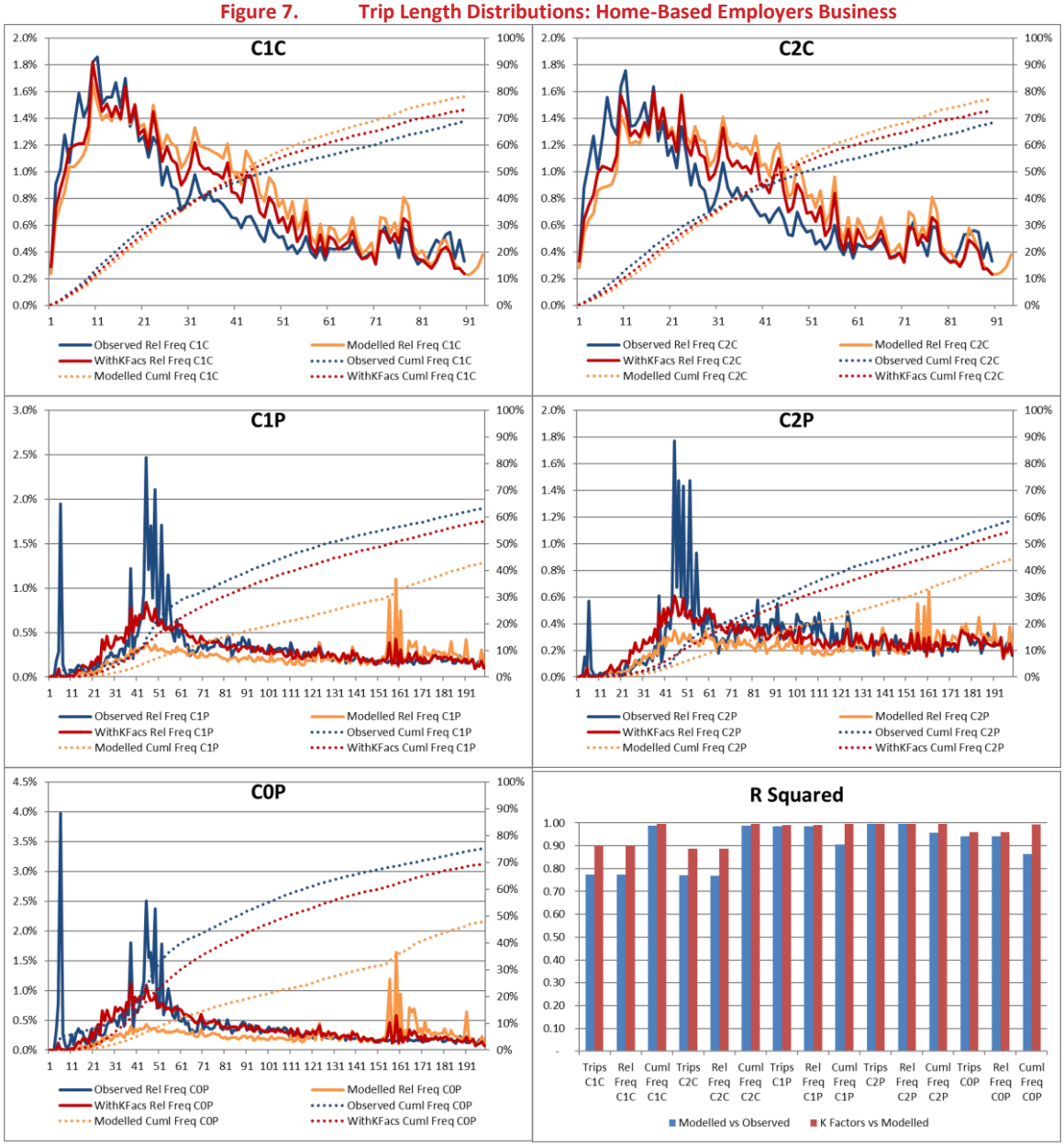


Figure 8. Trip Length Distributions: Home-Based Other

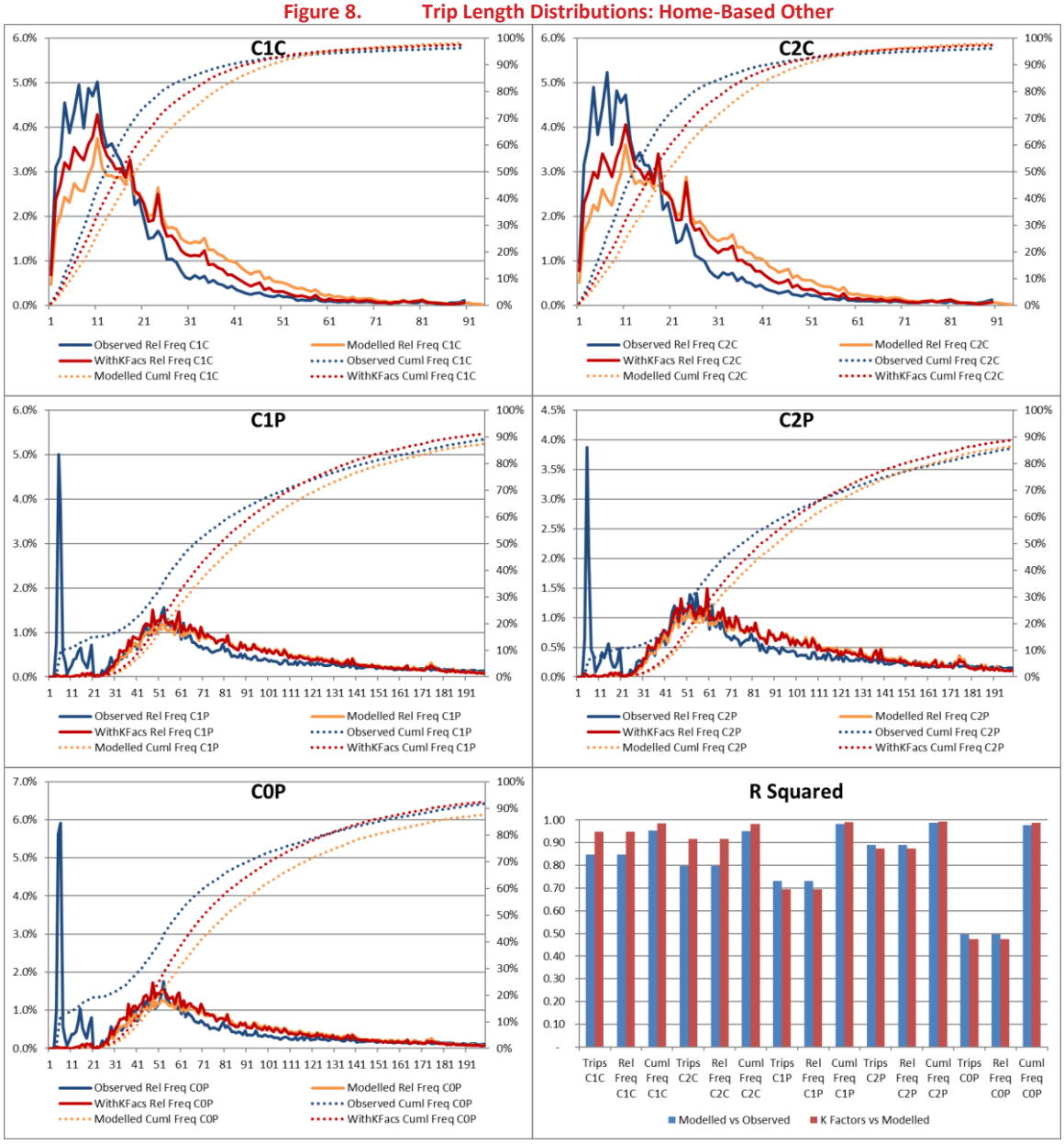


Figure 9. Trip Length Distributions: Non-Home-Based Employers Business

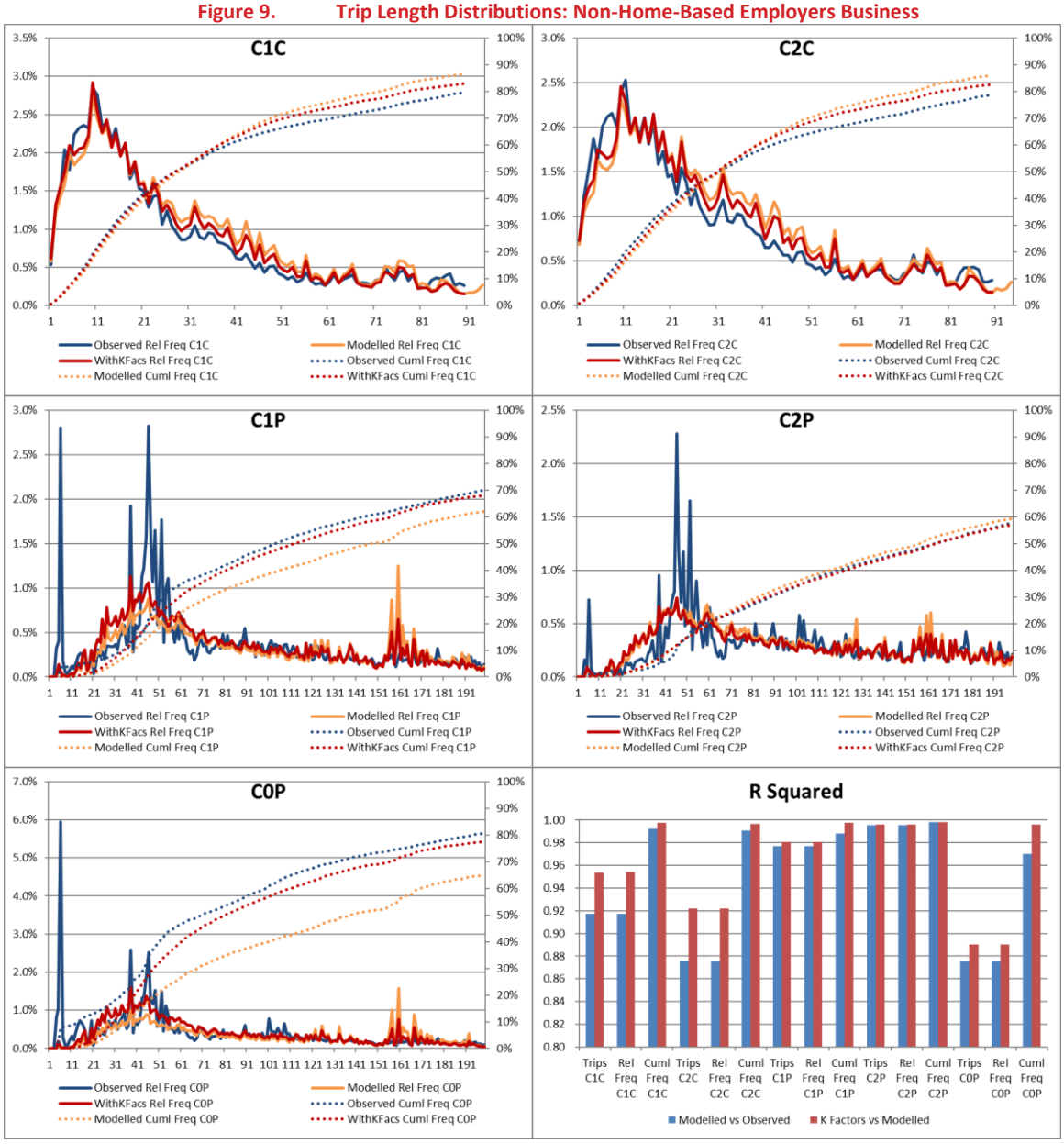
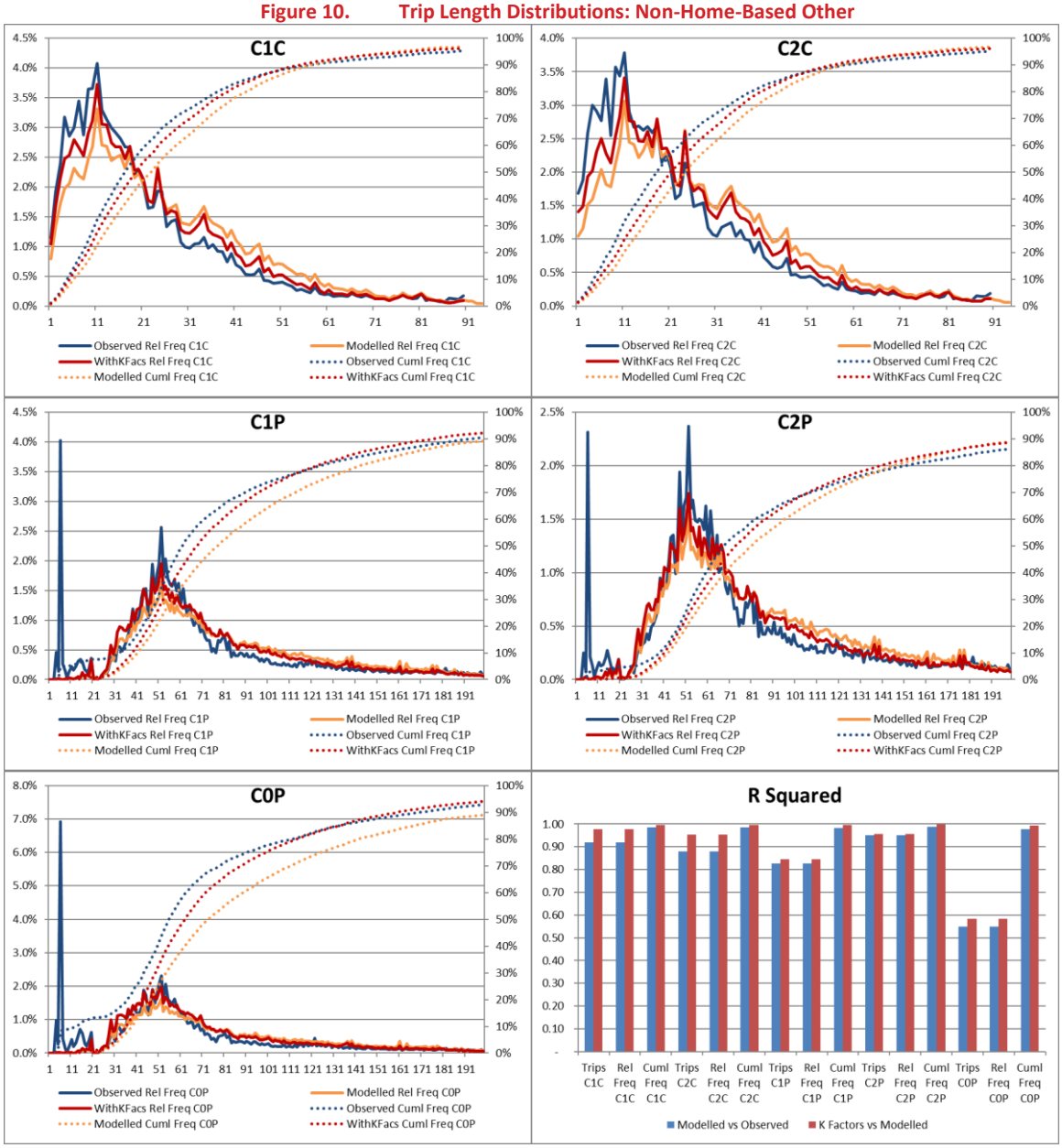


Figure 10. Trip Length Distributions: Non-Home-Based Other



5. DEMAND MODEL PROCESSES

5.1 Introduction

5.1.1 This chapter describes the way in which the different parts of the demand model fit together, and provides information about all of the different data that is required for the base year model and how they are used.

5.1.2 The model is composed of a number of separate modules, each of which deals with a particular aspect of the modelling process:

- Demand model – consisting of the mode and destination choice models (see Chapter0), conversion of P/A to O/D data (see Chapter3), and calculation of convergence information;
- Highway assignment model – using SATURN;
- Public Transport assignment model – using Cube Voyager's Public Transport program;
- Calculation of generalised costs; and
- Park and Ride model.

5.1.3 These separate modules are linked by the exchange of data. For example, the end product of the demand model is a set of matrices of hourly O/D-formatted trips by highway and PT user classes for each time period. These matrices are passed to the relevant assignment model, leading to outputs which are used to calculate generalised costs. These generalised costs are used by the demand model for the generation of new sets of hourly O/D trip matrices. The process of generating new trips and new costs continues until the model reaches a point at which successive outputs of the model are no longer varying significantly. At this point the model is said to have converged to within a specified tolerance. Once the model has converged, the park and ride model is run, which modifies the final assignment matrices, leading to the requirement of a last run of the assignment models.

5.1.4 The behaviour of the assignment models has been covered earlier – their purpose is to calculate the paths (and sub-modes, for PT assignment) taken by trips between model zones in each time period for each journey purpose, and the model uses these paths and their attributes to calculate generalised cost outputs.

5.1.5 In the rest of this Chapter the different processes used within the demand model are described.

5.2 Mode and Destination Choice Models in Practice

5.2.1 The demand model consists of a number of loops in which different actions are taken. The most important of these loops are termed outer loops. The generation of a set of hourly O/D data, their assignment to the highway and PT networks, and the calculation of new generalised costs from the results of these assignments all take place within a single outer loop.

5.2.2 During each outer loop after the first the model calculates a convergence statistic in order to examine how much the new model results have changed since the previous outer loop. When the results of consecutive outer loops have changed by less than a specified amount, the model terminates in a converged state.

5.2.3 The outer loops contain other loops, one of which visits each journey purpose in turn, and calculates its 12-hour P/A demand and, ultimately, hourly O/D matrices.

5.2.4 Each of these journey purpose loops consists of the following components:

- Mode and destination choice;
- P/A to O/D matrix conversion; and
- Calculation of the convergence statistic.

5.2.5 The mode and destination choice models are described in detail in Chapter 4, and they are run inside the loop over journey purposes, processing each one separately. In the case of the doubly constrained purposes they are also themselves contained within a set of inner loops. The need for these inner loops is brought about by the existence of the trip attraction constraint, and they are used to reach a self-consistent solution of the choice models before the resulting data are passed to the assignment models.

5.2.6 At the start of a given outer loop the current generalised costs for the current purpose are used to generate the utilities discussed in the previous chapter. These utilities are used as the starting data on which the choice models operate. In the very first outer loop for any model run the inputted generalised costs are those which were calculated from the observed base year demand. In subsequent outer loops the generalised costs will updated by assignment model outputs.

5.2.7 In the case of the singly constrained purpose, these utilities are used to calculated destination choice probabilities for travel by each mode, and the composite costs over destinations within each mode nest are used to calculate mode choice probabilities. Combining these results leads to the final probability of a given option being chosen, and the number of trips choosing each option is therefore obtained by multiplying the probability by the number of trip productions. These probabilities are calculated independently for each of the different car availability categories.

5.2.8 The situation is more complicated in the case of the doubly constrained journey purposes because all of the modes and car availability categories are processed simultaneously – necessarily so, because only the total number of trip attractions to a given zone for each purpose is constrained, and so trips by different demand segments compete with one another.

5.2.9 Hence, for the doubly constrained purposes the model begins with a particular modal split of the trip productions in each car availability category, and these are used as the row totals to be achieved by the furnessing process through which the gravity model of destination choice is obtained.

5.2.10 The matrix of choice utilities and the sets of modally split trip productions and the trip attraction totals are used together to obtain a final trip matrix which satisfies the trip end constraints. Composite costs can be calculated from the resulting destination choices within each demand segment, and mode choice probabilities can be calculated from these. The mode choice probabilities will not necessarily be consistent with the modal splits that were just used as the starting point for the furnessing process, and in that case the trip matrix that was just generated would not be a valid solution of the choice models.

5.2.11 This is the reason why inner loops are used in the model: after each completed set of furness iterations the final trip matrix is used to calculate mode choice probabilities, and these are used to split once again the trip productions from each model zone. These new matrix row totals are applied to the same starting set of choice model utilities as before, and the furness procedure is run again as a new inner loop.

5.2.12 Each new inner loop leads to a new matrix of trips, which is used to calculate new mode choice probabilities. With each successive inner loop the variance between the successive sets of mode choice probabilities is expected to decrease, until eventually a self-consistent doubly constrained trip matrix is obtained.

5.2.13 Unlike the sequence of outer loops, which can terminate early once a given level of convergence has been achieved, the number of inner loops carried out for each journey purpose in a given outer loop is fixed at a user-specified value, and this number of loops is always performed.

5.2.14 While the inner loops are being performed a convergence statistic is calculated by the model using consecutive trip matrix results of the furnessing procedure and the input generalised costs which led to the utilities for each option. This statistic is calculated in the same way as that which is used to assess the whole model's convergence but it is used only for diagnostic purposes by the user.

5.2.15 During model development it was found that 4 inner loops appeared to be sufficient for a good level of convergence between the mode and destination choice models in the doubly constrained case. This number of loops has been used in all runs of the model that are reported in this document, for both the base and forecasting scenarios.

5.2.16 The final, self-consistent trip matrix is next passed to a sub-module which converts its 12-hour P/A-formatted data into hourly O/D-formatted data ready for use by the assignment models.

5.3 PA to OD Conversion

5.3.1 The conversion of P/A data to O/D data is necessary for the creation of the trip matrices that are to be used by the assignment models, and this step takes place for each purpose after the mode and destination choice models have been run.

5.3.2 The data used by the conversion process are almost exclusively those that were derived during the calculation of the base year 12-hour P/A matrices for each journey purpose and demand segment. The exception is the set of car occupancies which were taken from previous Derby and Nottingham models.

5.3.3 The full procedure with which the 12-hour P/A data are converted into hourly O/D data for use in the assignment models is:

- Convert 12-hour P/A demand into P/A demand for each whole period with factor matrices for each journey purpose;
- Split whole-period P/A demand into those trips that are going away from home and those that are returning to home. This is achieved with time-period-dependent factor matrices for each journey purpose, leaving matrices still in P/A format;
- Transpose the return-home P/A trips so that they are equivalent to O/D format, and add them to the from-home trips to produce the final person-trip matrix in O/D format;
- Convert the O/D matrices from persons into vehicles by multiplying by time-period- and purpose-dependent person-to-vehicle factors. These are different from 1.0 only for the car mode, and are equal to the reciprocals of the car occupancies appropriate to the current model year; and, finally,
- Multiply the period O/D demand by period-to-hour factors, which convert from the whole period's trips into the fraction which take place during the peak hours (for the AM and PM) or the average of the 1000-1600 period (for the Inter-peak).

5.4 Incremental Adjustment Factors

5.4.1 The model uses absolute logit models that are applied incrementally, as described in TAG Unit M2, Section 4.

5.4.2 The application of the incremental approach is to take the synthetic base matrices produced by the choice models and to apply adjustment factors to these data so that the observed base year demand is reproduced. These adjustment factors are then used in all other runs of the model, whether for the base or for forecast years[7].

5.4.3 The method used in the demand model applies a combination of multiplicative and additive adjustment factors. The multiplicative factors are calculated in the following way:

$$F = S_F \times \delta = S_F \times \frac{B}{S_B}$$

where:

- B is the observed base year matrix;
- F is the forecast year matrix;
- S_B and S_F are, respectively, the synthetic base and forecast year matrices resulting from the absolute model, and
- δ is the matrix of incremental adjustment factors.

[7] A different approach is applied to new "development zones" which contain entirely new developments because these will not have existed in the base model and so there can be no application of incremental adjustments in this situation. Moreover, there are no base year ASCs or mode constants for zones that did not exist in the base year and so values of these have to be calculated with the use of some simplifying assumptions.

5.4.4 This formulation can, however, cause problems if the observed base demand is non-zero but the synthetic data are being calculated, because of the combinations of splitting factors and logit model parameters, as zero. In this case, the multiplicative factor, δ, cannot be calculated because of the need to divide by zero, and so the base year matrix would not be able to be reproduced exactly.

5.4.5 Because of this, in those cases where the value of S_B is equal to zero but B is not, the model makes use of additive incremental adjustments, defined so that:

$$F = S_F + \delta = S_F + (B - S_B),$$

and this approach ensures that the base observed matrix can be reproduced by the base model.

5.4.6 In addition, the additive approach is also taken if the multiplicative factor δ is calculated to be greater than 2. This is to ensure that very large factors aren't applied to forecast demand which could give erroneous results.

5.5 Analysis of Incremental Adjustment Factors

5.5.1 Table 8 shows the average multiplicative and additive and maximum additive Incremental Adjustment Factors (IAFs) for each time period, mode and journey purpose. As the additive factors are always positive this leads to the multiplicative factors being less than one.

5.5.2 The average additive factors are small, and for in most cases the maximum value is also small, with "Other" being the exception.

Table 8. Average Values for Multiplicative and Additive IAFs

PERIOD	PURPOSE	AVERAGE MULTIPLICATIVE		AVERAGE ADDITIVE		MAXIMUM AVERAGE	
		Highway	PT	Highway	PT	Highway	PT
AM	In-Work	63%	34%	0.06	0.01	28.1	7.1
AM	Commute	63%	42%	0.33	0.06	96.5	63.9
AM	Other	56%	44%	0.56	0.05	459.6	29.6
IP	In-Work	61%	33%	0.04	0.01	25.1	6.1
IP	Commute	58%	35%	0.07	0.01	39.9	10.0
IP	Other	59%	39%	0.72	0.05	380.9	34.8
PM	In-Work	63%	33%	0.05	0.01	17.0	6.2
PM	Commute	61%	40%	0.28	0.07	75.8	56.8
PM	Other	55%	36%	0.72	0.04	455.8	38.5

5.5.3 Figure 11 to Figure 16 show the distributions of the multiplicative and additive factors, for each mode, time period and journey purpose.

5.5.4 The multiplicative factors vary over a range of zero to two, with the graphs showing the pre-IAF demand (modelled, blue), the post-IAF demand (observed, red) and the count of the cells for each factor (green). Obviously, the closer to one the factors are the better the match.

5.5.5 The additive factors can take any value greater than zero. The graphs show both the absolute demand added for each band and the percentage of the total demand that this represents. For values greater than five the demand has been grouped into (mutually exclusive) larger bands (>5, >10, >50, >100) for clarity. Obviously, the closer the additive factors are to zero, the better the match between modelled and observed demand.

5.5.6 Across all modes, time periods and journey purposes the multiplicative factors are skewed towards zero, with the highway factors peaking around 0.2 and the PT factors peaking much closer to zero. The additive factors are generally close to zero.

Figure 11. Incremental Adjustment Factors: AM HY

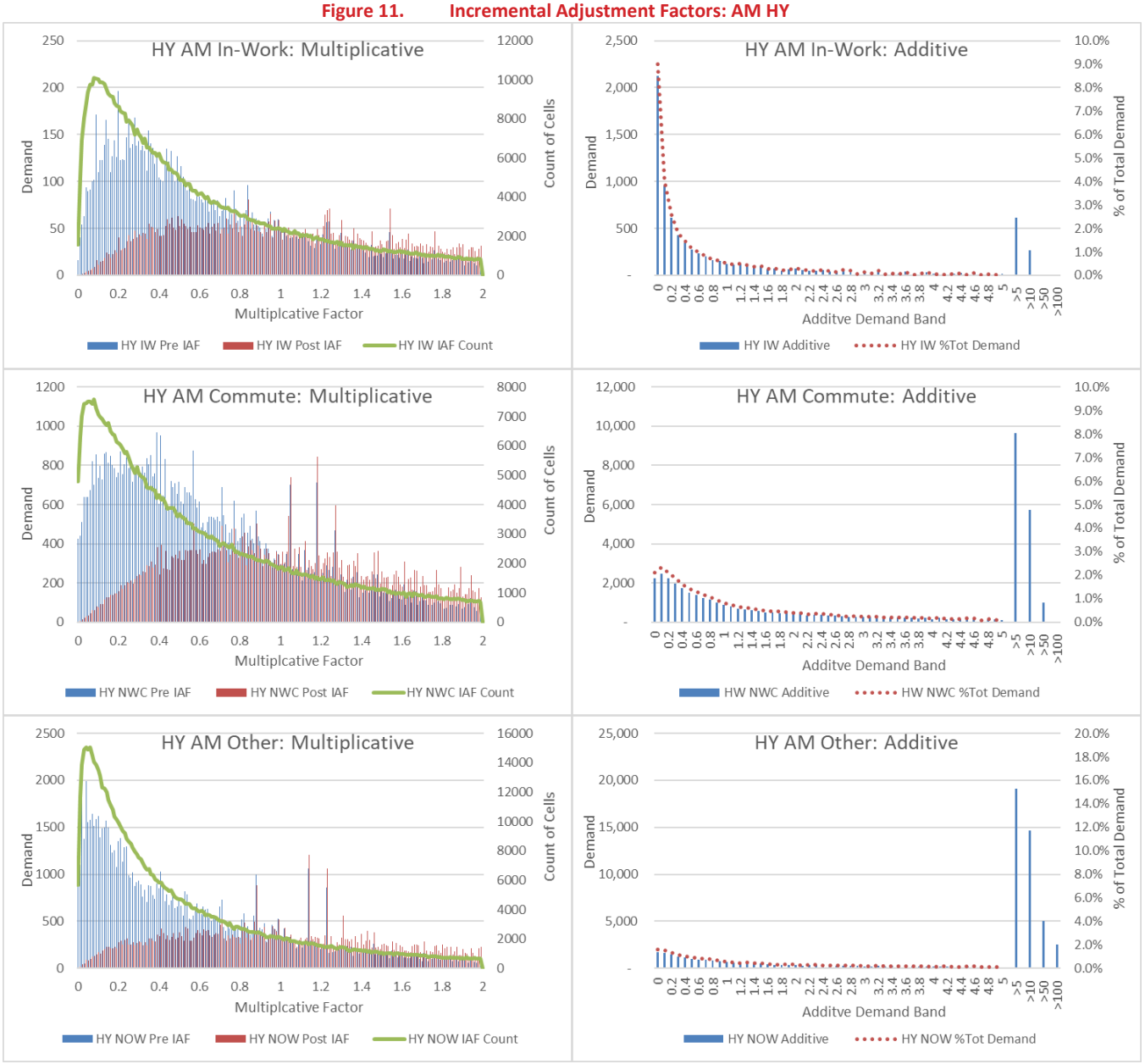


Figure 12. Incremental Adjustment Factors: IP HY

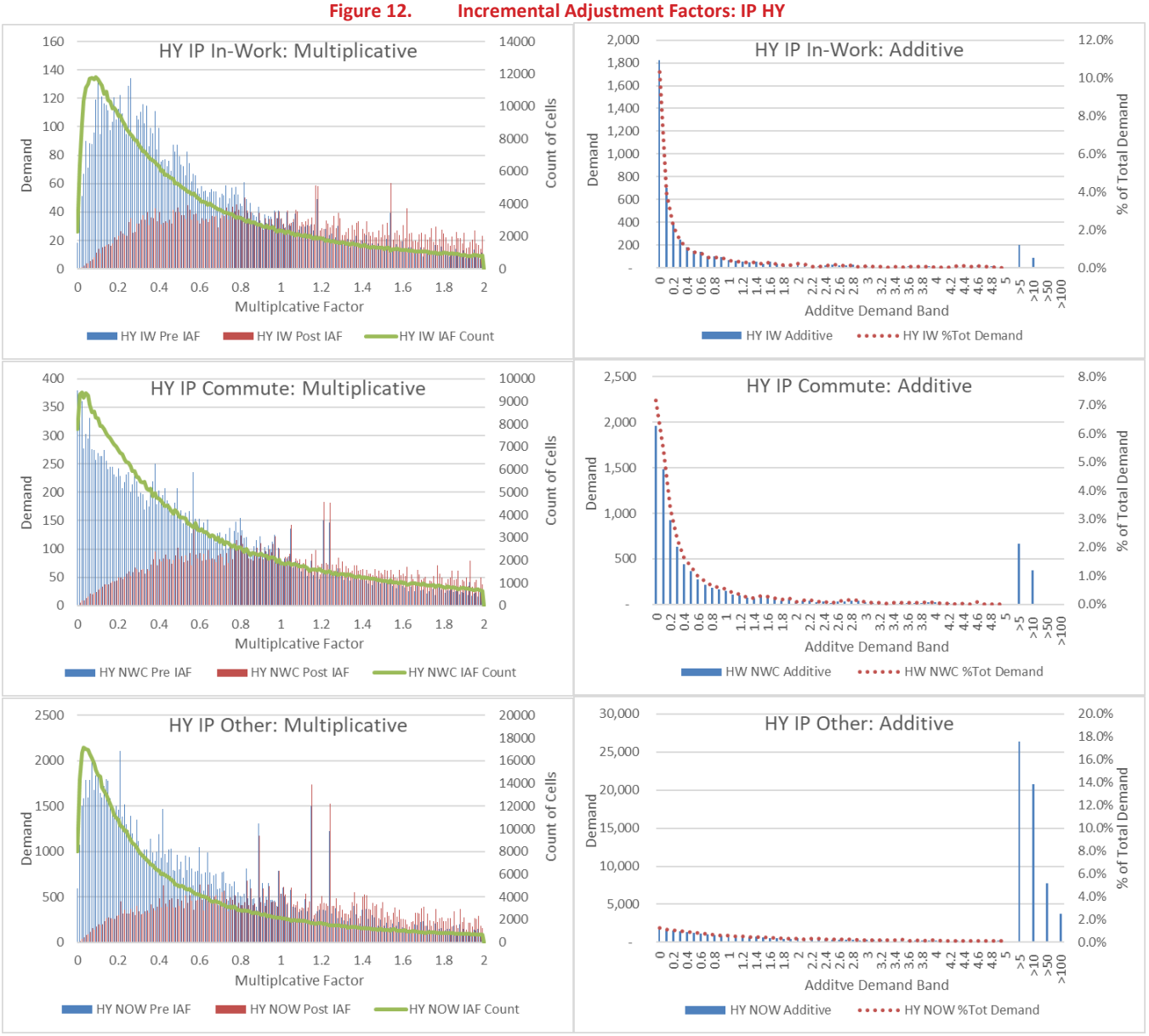


Figure 13. Incremental Adjustment Factors: PM HY

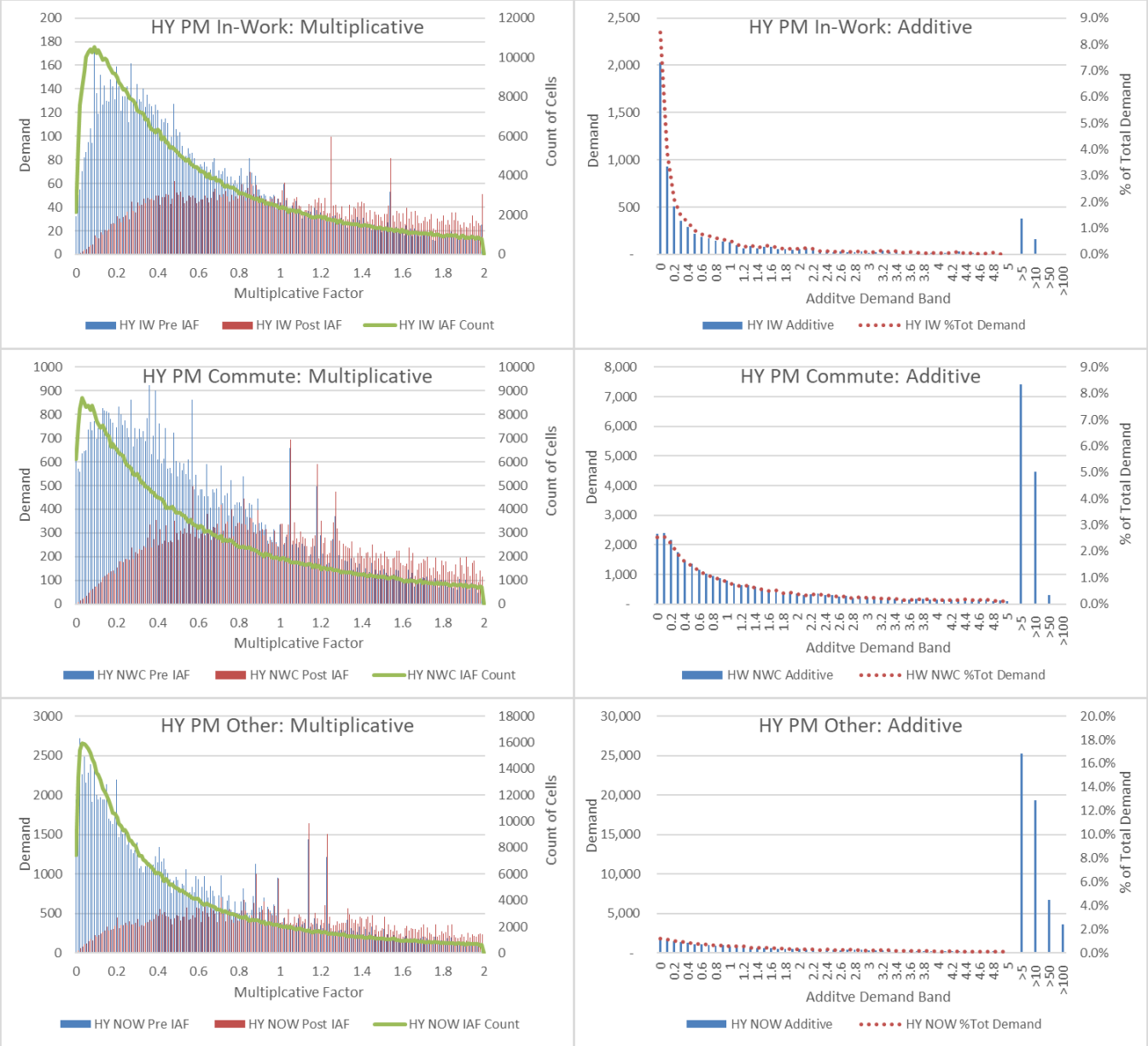


Figure 14. Incremental Adjustment Factors: AM PT

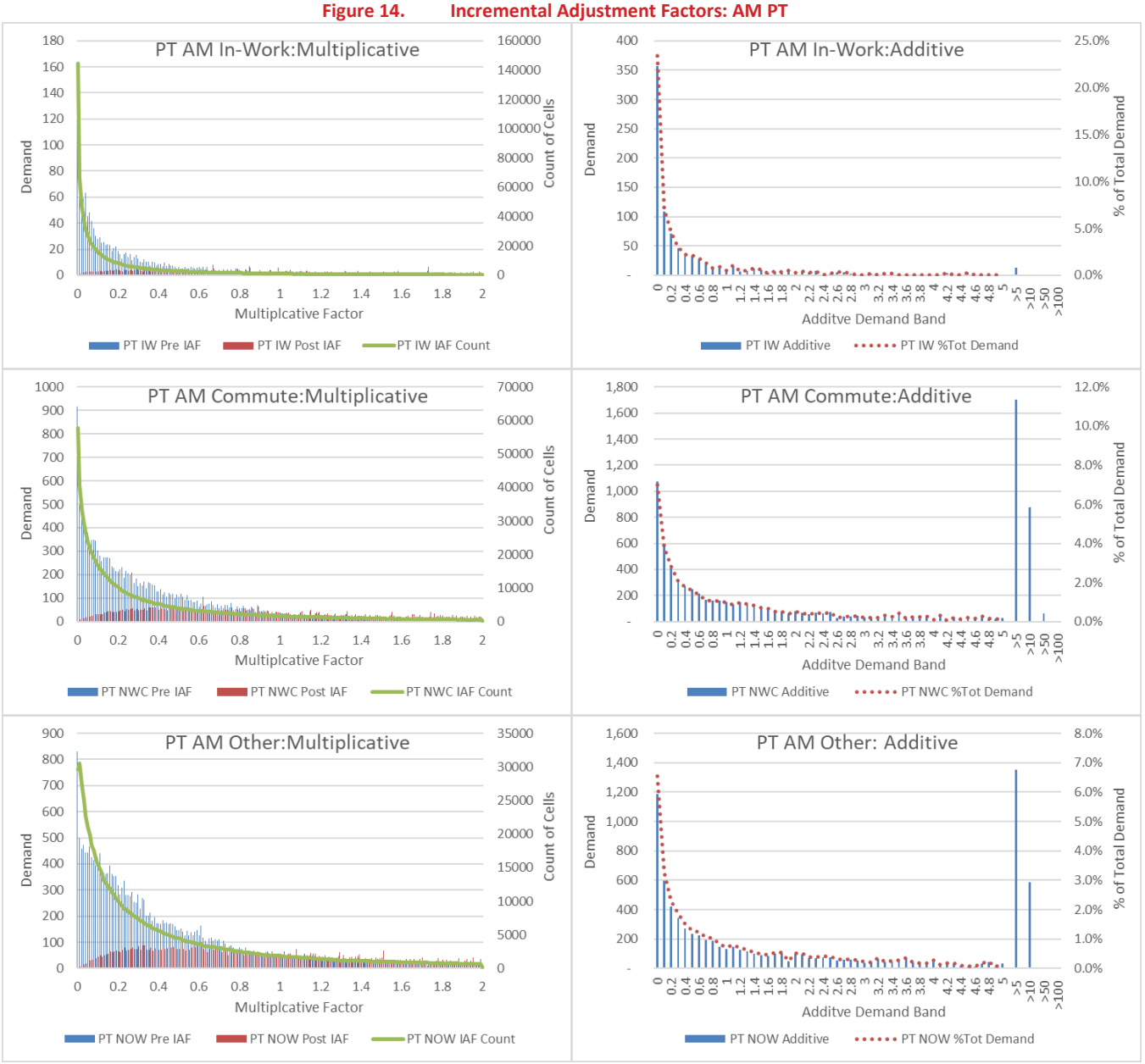


Figure 15. Incremental Adjustment Factors: IP PT

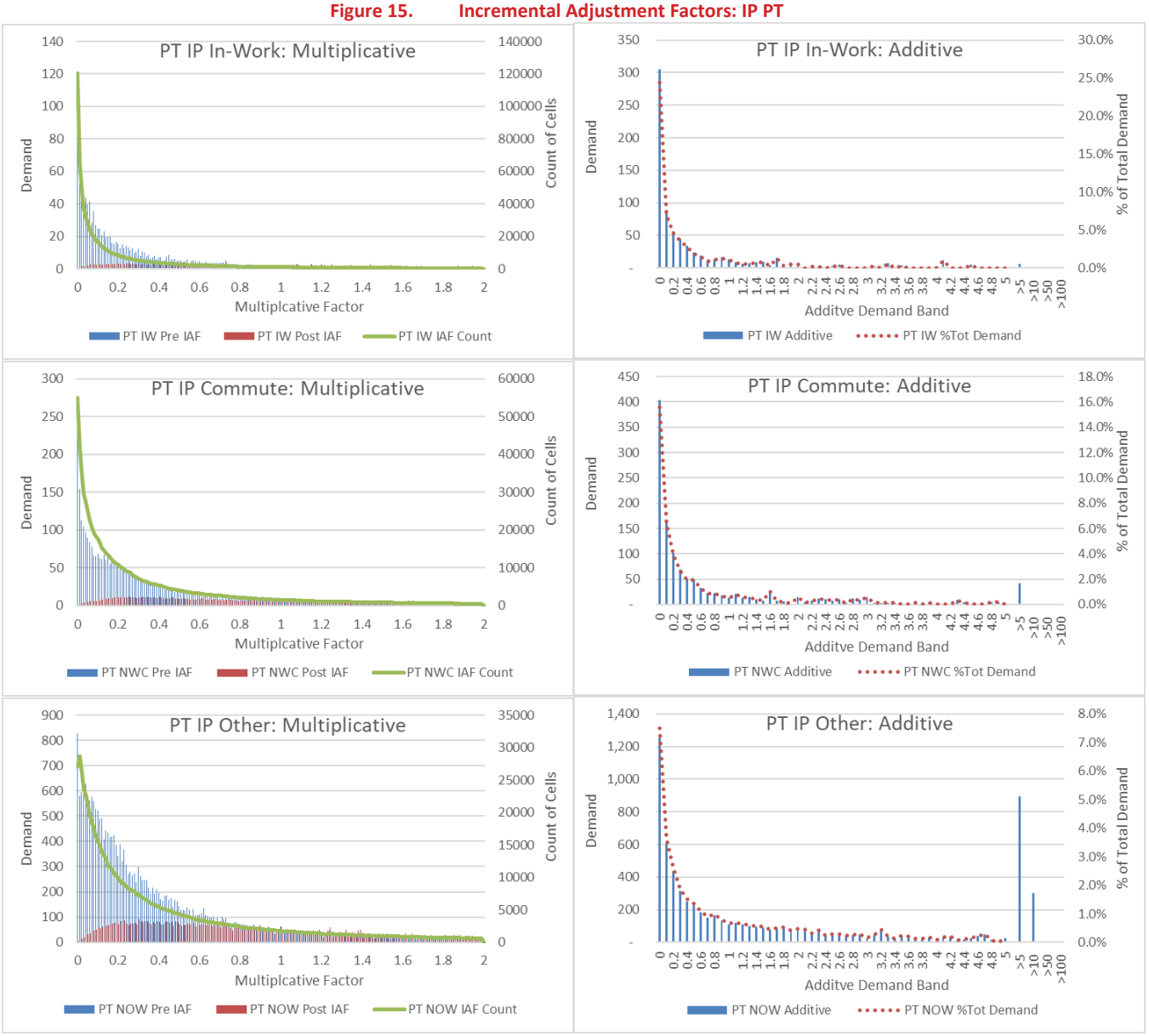
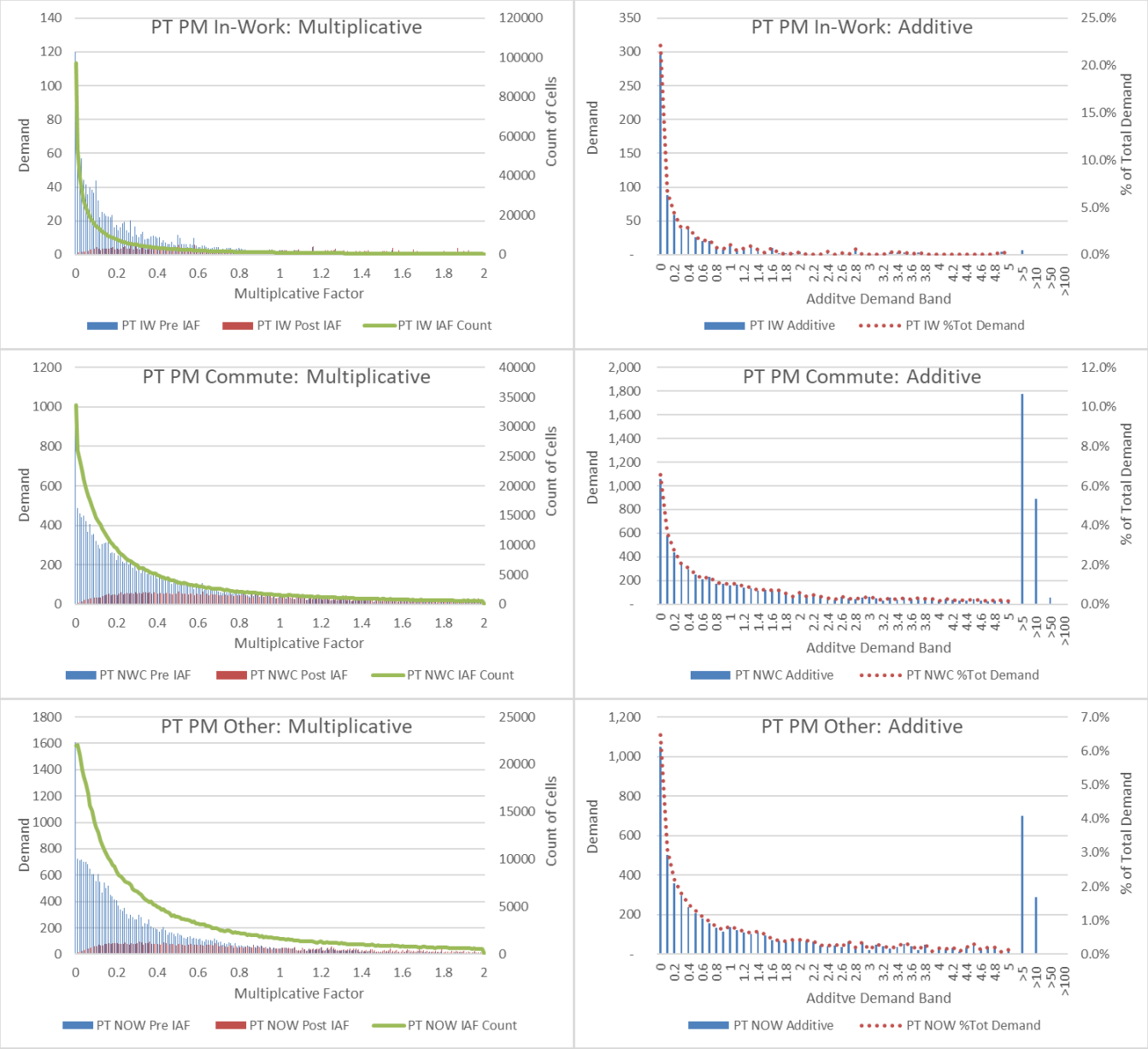


Figure 16. Incremental Adjustment Factors: PM PT



5.6 Convergence Calculations

5.6.1 The demand model uses estimates of generalised costs to produce different trip matrices in each outer loop, and these are assigned to the relevant networks to produce new estimates which are used to produce new trip matrices. As the number of completed outer loops increases it is expected that the difference between successive matrices of generalised costs and, therefore, successive trip matrices, will decrease until the model reaches a point at which its outputs can be considered to be unchanging within acceptable bounds.

5.6.2 When this has occurred, the trip matrices generated by a given set of costs will be almost exactly the same as the trip matrices which led to the calculation of those costs. The model will therefore have reached a fixed point of the interplay between demand and supply.

5.6.3 As described above, the model continues to iterate around the outer loop until the maximum number of loops has been reached, or the model's outputs have been found to have converged to within a specified tolerance. The measure of convergence that is used by the model is the one defined in TAG Unit M2, which is called the %GAP statistic[8].

5.6.4 The %GAP is defined as:

$$\%GAP = \frac{\sum_{ijctm} C(X_{ijctm}) \left| D(C(X_{ijctm}) - X_{ijctm} \right|}{\sum_{ijctm} C(X_{ijctm})\, X_{ijctm}} \times 100$$

where:

- the index combination *ijctm* denotes a particular combination of origin zone *i*, destination zone *j*, demand segment *c*, time period *t* and mode *m*;
- X_{ijctm} is the previous outer loop's set of trip matrices, in O/D format, that are used by the assignment models;
- $C(X_{ijctm})$ is the matrix of generalised costs generated for each time period by each of the assignment models for the previous loop's trip matrices; and
- $D(C(X_{ijctm}))$ is the current trip matrix, which results from running the demand model with the updated costs, *C*.

5.6.5 The demand segment *c* used here denotes the assignment user class, of which there are seven defined for the highway assignment (or 14 if compliant/non-compliant splits are included) and three for the PT assignment.

5.6.6 The %GAP statistic represents a cost-weighted average change in demand, normalised by the total cost of all trips in the previous iteration.

5.6.7 The aforementioned TAG Unit specifies that a %GAP value of less than 0.1% should be achievable in many cases, and so the target tolerance at which the model terminates has been set to this value. Currently, the maximum number of outer loops the model will run for is 10.

[8] TAG Unit M2 Section 6.3, "Variable Demand Modelling – Convergence". Paragraph 6.3.4 defines the %GAP quantity.

6. MODEL REALISM TESTS

6.1 Introduction

6.1.1 The particular values of the parameters required by the mode and destination choice models lead to certain strengths of response of the demand model to changes in costs. The sensitivity parameters govern the decay of trips with increasing costs, while the scaling parameters control the propensity for mode shift to occur as a result of changes in the composite costs over all destinations.

6.1.2 As described in the previous chapter, the parameters chosen for use were the WebTAG Illustrative Median Parameters. These parameters are, however, only as good as realism tests show them to be.

6.1.3 Three tests were carried out in the base year using different "Do Something" scenarios, and the results of these tests are described in the remainder of this Chapter.

6.1.4 Guidance set out in WebTAG M2 Section 6.4 states that the primary realism tests require that car fuel cost, car journey time and public transport fare elasticities be calculated and there are ranges within which their values are expected to lie.

6.1.5 These elasticities are calculated using the base year model by changing the appropriate input data to impose the necessary changes. Increases of 10% are applied to the fuel costs and PT fares in turn, holding all other quantities at their base year Do Minimum values, and the demand model is run to convergence.

6.1.6 The journey time test increases the total car generalised cost by 10%, though is only run through the demand model for a single iteration, rather than running to convergence as with the other tests.

6.1.7 The sensitivity of the model is examined by looking at changes in total number of vehicle kilometres (for the fuel price test), changes in the total number of public transport trips (for the PT fares test) and changes in the total number of car trips(for the journey time test). These changes are converted into elasticities, and these are compared with target values reported in WebTAG.

6.2 Fuel Test

6.2.1 Changes in fuel price are imposed on the model by changing two sets of inputs: data in the SATURN assignment model's network data file, and data used in calculating generalised costs for use by the choice models.

6.2.2 The values of time (used by the choice models) and the PPM parameter (pence per minute – used by the SATURN assignment model) are unchanged from their base year values, but the PPK (pence per kilometre) parameters for each purpose/user class need to be recalculated.

6.2.3 Using the same calculations which led to the calculation of the base year values of PPK, the underlying fuel cost value was increased by 10%, and PPK values recalculated for each of the assignment user classes. These values were used in place of those in the base year Do Minimum SATURN network files and demand model input data.

6.2.4 The PPK values used and their Do Minimum values are shown in Table 9. Note: the percentage change in the PPK values is less than 10% as it is made up of a combination of fuel-based and non-fuel-based costs and the non-fuel costs remain constant.

Table 9. PPK Values used in Base and Fuel Realism Test

PURPOSE	BASE	10% FUEL INCREASE	% CHANGE
Employers Business	13.90	14.43	4%
Commute	10.23	10.87	6%
Other	10.23	10.87	6%

6.2.5 To assess the sensitivity to this fuel price increase, total car vehicle kilometres are calculated from model outputs for each of the five journey purposes, aggregated to five sectors. Elasticities are calculated from the changes in vehicle kilometres relative to the base demand.

6.2.6 Responses have been calculated using the arc-elasticity expression[9]:

$$e = \frac{\ln T_1 - \ln T_0}{\ln C_1 - \ln C_0},$$

where *T* denotes the total number of vehicle kilometres, *C* denotes the cost element that has been altered, and the indices 0/1 denote, respectively, the Do Minimum and Do Something scenarios. With a 10% increase in fuel costs, the denominator becomes ln(1.1).

6.2.7 The elasticities reported in the table below have been calculated over all trip movements that are processed by the demand model: these are the vehicle-kilometres derived from I-I, I-X and X-I movements, with the traffic contribution for external to external movements (which remain constant) excluded.

6.2.8 Section 6.4 of WebTAG Unit M2 indicates that plausible targets for car fuel price elasticities for those trips that are subject to the processes of the demand model are:

- An overall average value with the range -0.25 to -0.35;
- For employer's business trips, a value of around −0.1;
- For discretionary (i.e. Other) trips, a value of around −0.4; and
- For commuting trips, a value around the average; i.e. approximately −0.3.

[9] See WebTAG Unit M2, paragraph 6.4.5.

6.2.9 It is also suggested in the same guidance that elasticities will be more plausible if those for the peaks are weaker (that is, less negative) than those in the inter-peak.

Table 10. Fuel Price Realism Test Results

PURPOSE	AM	IP	PM	12HR
Home Base Work	-0.16	-0.21	-0.18	**-0.18**
Home Based Employers Business	-0.10	-0.11	-0.10	**-0.10**
Home Based Other	-0.45	-0.41	-0.43	**-0.43**
Non Home Based Employers Business	-0.16	-0.13	-0.12	**-0.17**
Non-Home Based Other	-0.20	-0.17	-0.17	**-0.17**
Total	-0.25	-0.28	-0.25	**-0.26**

6.2.10 Comparing the values given in Table 10 with the targets, it is seen that:

- The overall value of -0.26 sits towards the lower end of the range;
- At a 12hr level (which is the level the demand model is working at) the variation between journey purposes is mostly as expected, with Home-Based Other having the highest sensitivity.
- Home-Based Work is probably slightly weaker than expected, though traditionally this purpose would have zero non-fuel costs and therefore feel the full 10% of the fuel price increase, which is not the case in this model and this will have the effect of reducing the sensitivity of the response;
- Home-Based Employers Business is around the expected value; and
- Between periods, the Inter-Peak is typically slightly more sensitive than the other periods, though this difference is not large.

6.2.11 Figure 17 shows the sectored elasticity results for the 12-hour level. As expected the values tend to increase (in absolute terms) the longer the average movements (i.e. trips to external areas are more sensitive than those between the cities). Given that the longer the journey the more the impact of the increase in fuel price this is intuitive.

6.2.12 The positive values for intra-Nottingham and Derby movements are the result of trips re-distributing to shorter distance journeys to reduce their fuel costs.

Figure 17. Fuel Price Realism Test Results (12 hour, Sectored)

HBW		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	0.01	-0.03	-0.33	-0.28	-0.30	-0.17
2	Outer Nottingham	-0.02	-0.04	-0.31	-0.21	-0.25	-0.16
3	Central Derby	-0.34	-0.29	0.06	-0.23	-0.43	-0.21
4	Outer Derby	-0.28	-0.21	-0.22	-0.10	-0.17	-0.15
5	External	-0.36	-0.33	-0.47	-0.23		-0.28
	Total	-0.17	-0.17	-0.20	-0.16	-0.23	-0.18

HBEB		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	0.06	0.02	-0.10	-0.12	-0.12	-0.10
2	Outer Nottingham	0.03	0.00	-0.11	-0.10	-0.10	-0.09
3	Central Derby	-0.11	-0.11	0.05	-0.11	-0.18	-0.15
4	Outer Derby	-0.12	-0.10	-0.10	-0.04	-0.09	-0.08
5	External	-0.14	-0.12	-0.19	-0.11		-0.12
	Total	-0.12	-0.10	-0.15	-0.09	-0.11	-0.10

HBO		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	0.04	-0.05	-0.44	-0.39	-0.95	-0.27
2	Outer Nottingham	-0.05	-0.06	-0.42	-0.27	-1.05	-0.29
3	Central Derby	-0.43	-0.40	0.03	-0.28	-1.24	-0.30
4	Outer Derby	-0.38	-0.26	-0.27	-0.15	-0.97	-0.32
5	External	-0.95	-1.02	-1.25	-1.03		-1.04
	Total	-0.29	-0.30	-0.27	-0.34	-1.01	-0.42

NHBEB		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	0.02	-0.05	-0.22	-0.23	-0.43	-0.29
2	Outer Nottingham	0.02	-0.02	-0.17	-0.15	-0.35	-0.23
3	Central Derby	-0.13	-0.15	0.05	-0.17	-0.37	-0.26
4	Outer Derby	-0.11	-0.11	-0.11	-0.04	-0.21	-0.14
5	External	-0.09	-0.01	-0.15	-0.03		-0.06
	Total	-0.07	-0.04	-0.12	-0.05	-0.29	-0.13

NHBO		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	0.02	-0.08	-0.44	-0.42	-0.77	-0.30
2	Outer Nottingham	-0.02	-0.05	-0.36	-0.26	-0.51	-0.22
3	Central Derby	-0.32	-0.32	0.06	-0.28	-0.48	-0.23
4	Outer Derby	-0.28	-0.23	-0.23	-0.11	-0.27	-0.17
5	External	-0.16	-0.02	-0.30	-0.01		-0.07
	Total	-0.12	-0.11	-0.18	-0.13	-0.39	-0.17

6.3 Fares Test

6.3.1 Sensitivity to public transport fares was tested by increasing all values in the Voyager Public Transport assignment model's fare tables by 10% and running the model to convergence.

6.3.2 The sensitivity of the model was assessed by calculating total public transport trips for each of the five journey purposes, aggregated to five sectors, and elasticities calculated from the changes in O/D trips between these aggregate areas.

6.3.3 Elasticities are calculated using the same formula as in the fuel price sensitivity test. The results for each time period and journey purpose, for trips excluding external to external movements, are shown in the table below.

Table 11. PT Fare Realism Test Results

PURPOSE	AM	IP	PM	12HR
Home Base Work	-0.37	-0.38	-0.36	**-0.37**
Home Based Employers Business	-0.56	-0.52	-0.55	**-0.54**
Home Based Other	-0.37	-0.52	-0.58	**-0.49**
Non Home Based Employers Business	-0.73	-0.64	-0.78	**-0.70**
Non-Home Based Other	-0.44	-0.53	-0.58	**-0.53**
Total	-0.38	-0.50	-0.46	**-0.45**

6.3.4 Guidance in WebTAG unit M2, paragraph 6.4.21, states that the elasticity of public transport trips in response to changes in fares should lie in the range −0.2 to −0.9. The PT fare elasticities may also be regarded as plausible if they exhibit the following traits:

- Elasticities for non-discretionary trips are weaker than those for discretionary trips; and
- Peak period elasticities are weaker than inter-peak.

6.3.5 Comparing the values given in Table 11 with the target values, it is seen that:

- The overall value of -0.45 sits roughly in the middle of the required range;
- The journey purpose specific values are also within the required range;
- Other purpose trip are more sensitive than commuting; and
- The total peak period elasticities are weaker than those for the inter-peak.

6.3.6 Figure 18 shows the realism results for the 12-hour level at a 5-sector level. As above, the higher sensitivities are for longer distance journeys, where the fare is a larger component of the overall cost.

Figure 18. PT Fare Realism Test Results (12 hour, Sectored)

HBW		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	- 0.02	- 0.12	- 0.56	- 0.60	- 1.51	- 0.19
2	Outer Nottingham	- 0.11	- 0.16	- 0.52	- 0.53	- 2.16	- 0.26
3	Central Derby	- 0.67	- 0.56	0.01	- 0.57	- 1.94	- 0.55
4	Outer Derby	- 0.59	- 0.48	- 0.55	- 0.28	- 1.64	- 0.51
5	External	- 1.74	- 2.13	- 1.96	- 1.73		- 1.87
	Total	- 0.17	- 0.27	- 0.58	- 0.54	- 1.74	- 0.37

HBEB		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	0.17	0.25	- 0.00	- 0.24	- 1.39	- 0.18
2	Outer Nottingham	0.25	0.29	0.18	- 0.06	- 1.45	- 0.35
3	Central Derby	- 0.02	0.19	0.73	0.13	- 1.28	- 0.60
4	Outer Derby	- 0.22	- 0.03	0.12	0.17	- 1.33	- 0.45
5	External	- 1.37	- 1.47	- 1.28	- 1.34		- 1.36
	Total	- 0.12	- 0.34	- 0.73	- 0.52	- 1.37	- 0.54

HBO		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	- 0.08	- 0.13	- 0.53	- 0.67	- 3.14	- 0.24
2	Outer Nottingham	- 0.13	- 0.16	- 0.65	- 0.53	- 3.12	- 0.35
3	Central Derby	- 0.49	- 0.68	0.06	- 0.54	- 3.98	- 0.52
4	Outer Derby	- 0.58	- 0.44	- 0.55	- 0.27	- 3.00	- 0.47
5	External	- 3.15	- 3.12	- 3.76	- 3.24		- 3.31
	Total	- 0.23	- 0.32	- 0.56	- 0.51	- 3.27	- 0.49

NHBEB		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	0.05	0.05	- 0.33	- 0.44	- 1.62	- 0.40
2	Outer Nottingham	0.03	0.02	- 0.29	- 0.32	- 1.63	- 0.69
3	Central Derby	- 0.35	- 0.27	0.13	- 0.37	- 1.12	- 0.86
4	Outer Derby	- 0.52	- 0.32	- 0.42	- 0.18	- 1.61	- 0.95
5	External	- 2.31	- 2.64	- 1.89	- 1.90		- 2.19
	Total	- 0.15	- 0.18	- 0.43	- 0.46	- 1.51	- 0.70

NHBO		1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1	Central Nottingham	- 0.20	- 0.26	- 1.03	- 0.94	- 2.42	- 0.35
2	Outer Nottingham	- 0.28	- 0.32	- 0.89	- 0.70	- 2.46	- 0.48
3	Central Derby	- 0.89	- 0.85	- 0.25	- 0.82	- 2.65	- 0.98
4	Outer Derby	- 0.82	- 0.68	- 0.85	- 0.52	- 2.49	- 0.89
5	External	- 2.94	- 2.78	- 1.43	- 1.12		- 1.62
	Total	- 0.29	- 0.35	- 0.48	- 0.64	- 2.50	- 0.53

6.4 Journey Time Test

6.4.1 Sensitivity to car journey time was tested by increasing the total generalised costs for car trips within the demand model by 10% and running the model for one iteration.

6.4.2 The sensitivity of the model was assessed by calculating total car trips for each of the five journey purposes, aggregated to five sectors, and elasticities calculated from the changes in O/D trips between these aggregate areas.

6.4.3 Elasticities are calculated using the same formula as in the fuel price sensitivity test. The results for each time period and journey purpose, for trips excluding external to external movements, are shown in the table below.

6.4.4 WebTAG guidance (Unit M2, paragraph 6.4.26) requires elasticities to be calculated using changes in trips. However, historically elasticities based on vehicle-kilometres have been reported for this type of model. Both sets of values are provided here for comparison.

Table 12. Highway Journey Time Realism Test Results (Vehicles)

PURPOSE	AM	IP	PM	12HR
Home Base Work	-0.10	-0.26	-0.20	**-0.17**
Home Based Employers Business	-0.44	-0.56	-0.37	**-0.46**
Home Based Other	-0.09	-0.01	-0.05	**-0.04**
Non Home Based Employers Business	-0.66	-0.72	-0.66	**-0.69**
Non-Home Based Other	-0.22	-0.09	-0.16	**-0.13**
Total	-0.13	-0.10	-0.14	**-0.12**

Table 13. Highway Journey Time Realism Test Results (Vehicle Kilometres)

PURPOSE	AM	IP	PM	12HR
Home Base Work	-0.87	-1.03	-0.94	**-0.94**
Home Based Employers Business	-0.85	-0.94	-0.83	**-0.88**
Home Based Other	-1.80	-1.60	-1.69	**-1.67**
Non Home Based Employers Business	-1.44	-1.20	-1.08	**-1.23**
Non-Home Based Other	-1.04	-0.86	-0.91	**-0.92**
Total	-1.19	-1.27	-1.19	**-1.22**

6.4.5 Guidance in WebTAG unit M2, paragraph 6.4.28, states that the elasticity of car trips in response to changes in journey time should not be stronger than -2.0.

6.4.6 Comparing the values given in Table 12 and Table 13 with the target values, it is seen that:

- All values are within the required range.

6.4.7 Figure 19 shows 12-hour elasticity values at a 5-sector level for both the trips (left) and vehicle kilometre values (right)

Figure 19. Car Journey Time Realism Test Results (12 hour, Sectored)

HBW	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 0.39	- 0.29	- 2.26	- 1.44	- 1.91	- 0.59
2 Outer Nottingham	- 0.26	0.33	- 1.53	- 0.43	- 1.10	- 0.15
3 Central Derby	- 2.35	- 1.46	0.31	- 0.72	- 1.16	- 0.15
4 Outer Derby	- 1.62	- 0.42	- 0.72	0.19	- 0.18	- 0.03
5 External	- 2.27	- 1.30	- 1.18	- 0.30		- 0.63
Total	- 0.56	- 0.16	- 0.07	- 0.06	- 0.54	- 0.17

HBW	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 0.62	- 0.58	- 2.32	- 1.83	- 2.01	- 1.35
2 Outer Nottingham	- 0.53	- 0.34	- 1.73	- 1.07	- 1.34	- 0.91
3 Central Derby	- 2.42	- 1.65	0.12	- 1.21	- 1.71	- 1.07
4 Outer Derby	- 2.02	- 1.07	- 1.18	- 0.51	- 0.72	- 0.72
5 External	- 2.36	- 1.60	- 1.82	- 0.94		- 1.27
Total	- 1.38	- 0.97	- 0.98	- 0.80	- 1.08	- 0.94

HBEB	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 2.88	- 1.18	- 3.92	- 2.24	- 2.18	- 2.25
2 Outer Nottingham	- 2.18	0.47	- 1.66	- 0.26	- 0.18	- 0.32
3 Central Derby	- 4.73	- 1.71	- 0.11	- 1.00	- 0.84	- 0.65
4 Outer Derby	- 3.94	- 0.31	- 1.03	0.25	0.17	- 0.04
5 External	- 3.69	- 0.28	- 0.93	0.11		- 0.57
Total	- 3.11	- 0.20	- 0.59	- 0.00	- 0.26	- 0.46

HBEB	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 3.45	- 1.35	- 3.90	- 2.61	- 2.48	- 2.50
2 Outer Nottingham	- 2.44	- 0.22	- 1.86	- 0.88	- 0.48	- 0.61
3 Central Derby	- 4.75	- 1.90	- 0.29	- 1.49	- 1.31	- 1.35
4 Outer Derby	- 4.37	- 0.94	- 1.53	- 0.31	- 0.28	- 0.45
5 External	- 3.74	- 0.60	- 1.41	- 0.36		- 1.02
Total	- 3.75	- 0.67	- 1.38	- 0.47	- 0.69	- 0.88

HBO	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	0.31	- 0.25	- 2.71	- 2.06	- 3.96	- 0.03
2 Outer Nottingham	- 0.26	0.34	- 2.08	- 0.67	- 3.61	- 0.03
3 Central Derby	- 2.68	- 2.02	0.34	- 1.04	- 3.20	0.00
4 Outer Derby	- 2.02	- 0.64	- 1.01	0.25	- 2.07	0.05
5 External	- 3.84	- 3.29	- 3.12	- 2.21		- 2.58
Total	- 0.06	- 0.01	0.07	0.04	- 2.52	- 0.04

HBO	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 0.03	- 0.68	- 2.82	- 2.50	- 4.07	- 1.40
2 Outer Nottingham	- 0.67	- 0.56	- 2.37	- 1.53	- 3.89	- 1.39
3 Central Derby	- 2.79	- 2.30	0.02	- 1.61	- 4.24	- 1.30
4 Outer Derby	- 2.46	- 1.49	- 1.56	- 0.78	- 3.18	- 1.32
5 External	- 4.02	- 3.66	- 4.16	- 3.35		- 3.54
Total	- 1.47	- 1.39	- 1.14	- 1.38	- 3.50	- 1.67

NHBEB	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 2.76	- 2.92	- 6.52	- 4.74	- 6.47	- 3.33
2 Outer Nottingham	- 1.18	0.54	- 1.83	- 0.30	- 1.79	- 0.49
3 Central Derby	- 3.94	- 2.28	- 0.04	- 1.55	- 2.25	- 0.76
4 Outer Derby	- 2.29	- 0.22	- 0.86	0.32	- 0.46	- 0.10
5 External	- 1.87	0.43	- 0.81	0.28		- 0.15
Total	- 2.20	- 0.42	- 0.48	- 0.02	- 1.43	- 0.69

NHBEB	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 3.50	- 3.09	- 6.59	- 5.37	- 7.03	- 5.73
2 Outer Nottingham	- 1.27	- 0.27	- 2.05	- 1.19	- 2.53	- 1.84
3 Central Derby	- 3.95	- 2.48	- 0.30	- 2.16	- 3.16	- 2.58
4 Outer Derby	- 2.69	- 0.90	- 1.37	- 0.32	- 1.31	- 1.00
5 External	- 1.93	0.26	- 1.10	0.02		- 0.39
Total	- 2.20	- 0.28	- 1.20	- 0.37	- 2.35	- 1.23

NHBO	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 0.15	- 0.63	- 3.17	- 2.44	- 4.12	- 0.53
2 Outer Nottingham	- 0.25	0.38	- 1.86	- 0.57	- 2.04	- 0.13
3 Central Derby	- 2.39	- 1.64	0.35	- 1.02	- 1.36	- 0.13
4 Outer Derby	- 1.58	- 0.48	- 0.85	0.17	- 0.35	- 0.03
5 External	- 1.17	0.11	- 0.80	0.25		- 0.03
Total	- 0.38	- 0.09	- 0.07	- 0.01	- 0.96	- 0.13

NHBO	1 Central Nottingham	2 Outer Nottingham	3 Central Derby	4 Outer Derby	5 External	Total
1 Central Nottingham	- 0.51	- 1.01	- 3.25	- 2.85	- 4.42	- 2.05
2 Outer Nottingham	- 0.54	- 0.41	- 2.07	- 1.34	- 2.49	- 1.22
3 Central Derby	- 2.46	- 1.89	0.12	- 1.52	- 1.96	- 1.20
4 Outer Derby	- 1.94	- 1.17	- 1.33	- 0.57	- 1.11	- 0.85
5 External	- 1.12	0.03	- 1.07	0.00		- 0.26
Total	- 1.08	- 0.67	- 0.96	- 0.65	- 1.76	- 0.92

7. CONCLUSIONS

7.1 Conclusions

7.1.1 The East Midlands Gateway demand model has been developed using the existing GNTM as a starting point, which included Mode and Destination Choice, Trip Frequency and Park and Ride modelling. To this has been added the functionality to model Macro Time Period Choice and Peak Spreading.

7.1.2 Demand matrices have been developed from multiple different sources, including the National Trip End Model (NTEM), Census Journey to Work (JtW), Highways England's Regional Traffic Models (RTM) and Electronic Ticket Machine (ETM) data, plus some data from the existing Nottingham and Derby models.

7.1.3 The demand model responses have been calibrated to ensure the modelled matrices produce similar trip length distributions to that from the input "observed" matrices. WebTAG median parameters were used as a starting point and were found to provide a good fit, both with and without the application of K-factors.

7.1.4 Realism tests have also been run to ensure that the model responds as expected with all tests producing values within the expected ranges. In addition, the relative values between purposes and periods were largely as expected.

7.1.5 All of the above suggests that the model is fit for purpose for forecasting highway and public transport schemes.

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Other locations:

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