Lincoln Eastern Bypass

Variable Demand Model Report

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1 Introduction

1.1 Context

Lincoln Eastern Bypass (LEB) is proposed as a 7.5km single carriageway road linking the existing A158 Northern Relief Road to the A15 Sleaford Road to the south, running through an area of predominantly arable farmland to the east of the city and the villages of Canwick and Bracebridge Heath, and to the west of the outlying villages of North Greetwell, Cherry Willingham, Washingborough and Branston.

The road is a key element of the Lincoln Integrated Transport Strategy (LITS) designed to provide much needed relief to the congested historic core of Lincoln and to permit a range of complementary policies, also identified in LITS, on traffic management and slow modes to be introduced to the city, thereby improving traffic and environmental conditions for a wide range of road users.

In 2011, Mouchel was commissioned under the Lincolnshire County Council Technical Services Partnership to undertake traffic forecasting and scheme appraisal work in support of the Best and Final Bid (BaFB) Business Case for LEB. This followed earlier studies prepared by another consultancy to support the original Major Scheme Business Case (MSBC) submission for the scheme in 2009. The scheme was successful in obtaining Programme Entry status in 2011 and successfully completed the BAFB Stage.

The current exercise provides the Final Funding submission to DfT, based on an update to those elements of the modelling which have changed since 2011.

1.2 Lincoln Variable Demand Model

The Lincoln Variable Demand Model (LVDM) is designed to respond to policy changes in the Greater Lincoln Transport Model (network distance and time costs, and other external costs i.e. fuel costs). The LVDM applies a functional algorithm to the generalised costs output from the assignment models as inputs to the demand model to adjust travel demand matrices, reflecting in traffic induction or suppression dependent upon cost changes.

1.3 Structure of the Report

This report describes the development and calibration of the LVDM and contains the following chapters:

- Chapter 2 – The need for Variable Demand modelling;
- Chapter 3 – Overview of the model structure;
- Chapter 4 – Variable Demand Model Methodology;
- Chapter 5 – Realism Tests for LEB Base Model

- Chapter 6 – Application of VDM for LEB Forecasting; and
- Chapter 7 – Summary

2 The Need for Variable Demand Modelling

2.1 Introduction

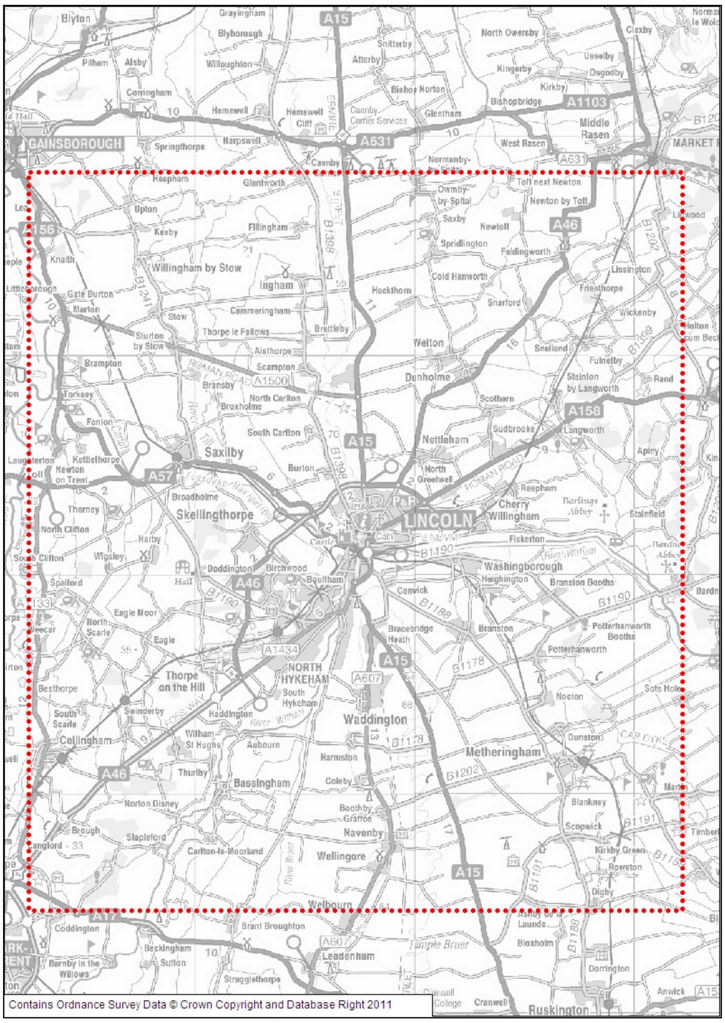
This chapter describes the need for and scope of variable demand modelling to support the appraisal of the LEB scheme.

2.2 Area of Influence

The area of influence was determined using the current version of the VISUM highway assignment models to identify the area over which traffic flows change significantly when the LEB scheme is introduced.

The area of influence is the part of the model for which most attention has been placed on network coding, density and validation. Beyond this area, network coding and demand representation extends with decreasing level of detail, across the rest of Lincolnshire such as Newark, Sleaford, Gainsborough and Horncastle. Figure 2-1 below provides the area of influence of the model.

Figure 2-1 – Area of Influence



2.3 The Importance of Variable Demand Modelling

WebTAG M2, paragraphs 1.1.2 and 1.1.3 state that any change to transport conditions will, in principle, cause a change in demand. The purpose of variable demand modelling is to predict and quantify these changes. It is of key importance in modelling to establish realistic scenarios in the absence of and with the inclusion of the proposed scheme or strategy.

The LVDM therefore has been developed to reflect change in trip frequency and distribution in responses to changing travel conditions. The inclusion of these travel choice responses is considered the most important for producing realistic future forecasts for the "with scheme" and "without scheme" scenarios which reflect traveller responses to changes in congestion, fuel costs and other changes to the supply.

2.4 The Need for Variable Demand modelling

WebTAG M2, section 2.2 suggests that fixed demand assessments may be acceptable if the following criteria are satisfied:

- The scheme is quite modest, both spatially and in terms of its effect on travel costs. Schemes with a capital costs of less than £5 million can generally be considered as modest;
- There is no congestion on the network in the forecast years;
- The scheme will have no appreciable effect on competition between private and public transport in the corridor containing the scheme.

Assessments of these criteria in the context of the LEB indicates the need for a variable demand modelling as:

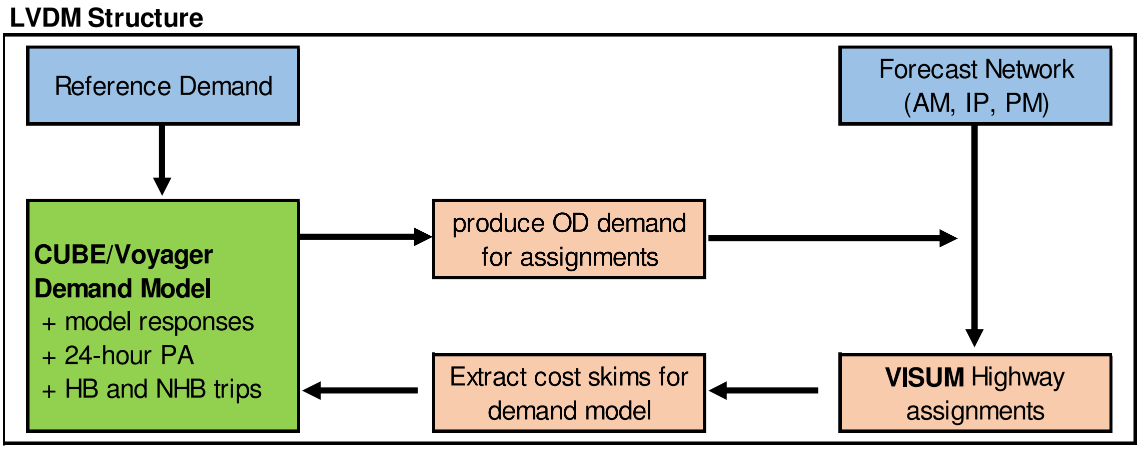
- The scheme is likely to have considerable effect on travel costs and has capital costs of significantly greater than £5 million;
- There is traffic congestion in the base and forecast year networks; however
- The scheme might be expected to have small effect on competition between private and public transport in the corridor containing the scheme.

3 Variable Demand Model Structure

3.1 Structure Overview

The LVDM model operates using an "aggregate" modelling approach, which consists of the Mouchel's bespoke demand model and the three peak hour VISUM highway assignment models (AM, IP, PM), representing cumulatively 24-hours coverage of a weekday. The LVDM model structure is shown in Figure 3-1 below.

Figure 3-1 – LVDM Model Structure



The demand model has been developed combining the two software platforms, VISUM for the highway assignment models and CUBE VOYAGER for the bespoke demand models. The functions of the respective software platforms are as follows:

- VISUM provide assignment functionality where trip matrices are assigned to a congested highway network. The resultant traffic volumes impact on traffic speeds, queues and delays. This cost information is fed back to the demand model;

- CUBE VOYAGER provides the demand model structure. Costs from individual time periods of the model are combined to reflect daily costs. The costs govern choice of frequency (how often to travel) and distribution (where to travel to). The resultant travel demand matrices are fed back to VISUM to assign and generate new costs. The process is iterated until stability is reached.

3.2 Form of Models

According to WebTAG M2, Section 4.3, there are number of model forms that can be employed as follows:

- Absolute models: use a direct estimate of the number of trips in each category;

- Absolute models applied incrementally: use absolute model estimates to apply changes to a base matrix; and

- Pivot-point models: use cost changes to estimate changes in the number of trips from a base matrix.

For the purpose of LVDM model, a pivot-point model which uses incremental change in costs to estimate changes in demand from a reference trip matrix (i.e. forecast matrix derived from the base year trip matrix assuming no change in travel costs) has been adopted as recommended by the DfT.

The change in generalised costs is produced by calculating the difference between the 'Pivot-Point Cost' (from the present year 2015 validated model) and 'reference costs' or subsequent assignments costs. The costs are composite costs, and are calculated for each level of the choice hierarchy to reflect the choice made at a lower level in the hierarchy.

3.3 Choice Responses and Hierarchy

Lincoln is primarily a car based travel market. Of motorised travel, bus and rail count for around 8% of travel (all day, 2011, commute). Whilst peak public transport flows will be higher, public transport (PT) use has declined since 2011 and non-commute journeys often make greater use of car. Specific details of this have been included in a recent Technical Note[1]. It was decided, based on the configuration of the bypass and levels of car ownership in eastern Lincoln that the “passive” mode choice element would be excluded from the updated model. The impact of mode share would be subsumed within more responsive frequency and distribution parameters.

The hierarchy determines which choice acts as a constraint on subsequent choices. Choice sensitivity must increase as decision making moves down the hierarchy. Travellers have relatively little discretion to choose the journey frequency. They have greater discretion to choose destination and most discretion to choose route of travel.

On that basis, an incremental hierarchical logit choice model has been developed for the Greater Lincoln Transport Model to represent the two model responses, in the order of hierarchy, as below:

- Trip frequency choice;

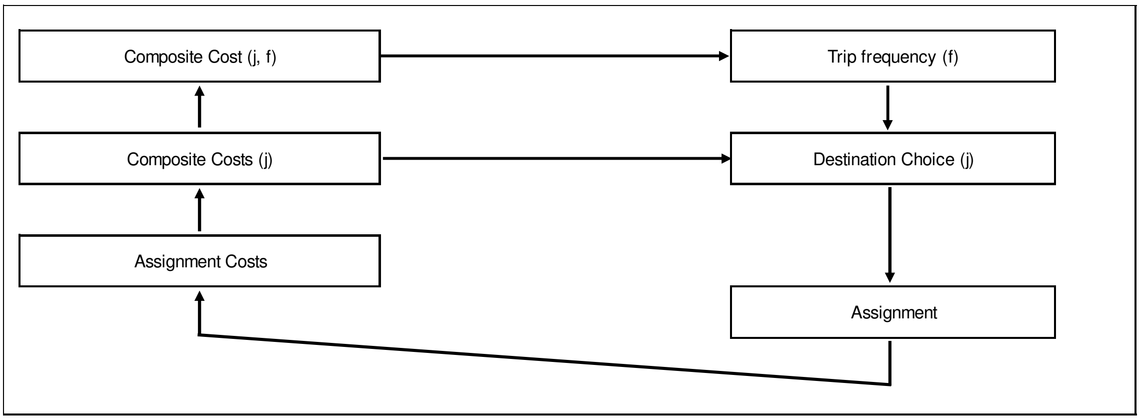
- Trip distribution choice; and

- Assignments.

[1] Lincoln Eastern Bypass PT Mode Share Review – July 2016

Sensitivity is provided by the parameters of **θ** for frequency and **λ** for destination choice. The cost matrices, supplied by the Greater Lincoln Transport Model VISUM highway models, provide origin/destination generalised costs by time period trip purpose, and mode. The cost matrices and **θ, λ** parameters determine the level of sensitivity in order to forecast a new trip matrix, based on a change in generalised costs. The hierarchy of the demand model is illustrated in the Figure 3-2 below.

Figure 3-2 – Choice Hierarchy adopted for LVDM



WebTAG M2 paras 4.5.5 and 4.5.6 state that the sequence of calculation is that, during each cycle, the composite costs must be calculated for each level in the hierarchy, since each level refers to different combinations of choice lower in the hierarchy. Thus the composite cost calculation starts at the bottom of the hierarchy and works its way up the levels, adding one more choice into the composite cost at each level. The choice calculations are then made down the hierarchy and the whole cycle is recalculated in the next iteration until an acceptable degree of convergence is achieved.

“Appendix E – Incremental Model Formulation” of the WebTAG M2 guidance states that when specifying an incremental hierarchical model, scaling parameters (thetas) that refer to the probability of nests of alternatives or composite alternatives, reflect the ratios of the lambdas for different response mechanisms as one moves up the mode structures and should have a value between 0 and 1 if the responses have been included in the correct order in the model, such as the sensitivity of the responses changes down the hierarchy from lower to higher.

The standard incremental multinomial logit model is given as:

$$p_p = \frac{p_p^0 exp(\theta \Delta_p)}{\sum_q p_q^0 exp(\theta \Delta_q)}$$

Where:

- $\mathrm{p_p}$ is the forecast probability of choosing alternative p

- p_p^0 is the reference case probability of choosing alternative p (calculated from input reference demand)
- θ is the scaling parameter (always = 1 for the bottom level of the hierarchy)
- Δ_p is the change in the utility of alternative p

For the choice at the bottom level of the hierarchy the change in utility is given by:

$$\Delta U_p = -\lambda * \left(GC_p^1 - CG_p^0\right)$$

Where:

- GC_p^1, CG_p^0 is the forecast and reference generalised costs, skimmed from the reference and latest assignments respectively; and
- λ is the spread or dispersion parameter (defined by the user); it should be positive

For the choice above the bottom level of the hierarchy the change in utility is the composite change over alternatives in the bottom level:

$$\Delta U_p^* = ln \sum_p p_p^0 \, exp(\Delta U_p)$$

Details of the incremental model formulation that were applied for the LVDM is provided in Chapter 5.

3.4 Matrix Forms and Demand Segmentation

WebTAG M2 recommends that for variable demand modelling, Production/Attraction (PA) matrices should be used in preference to Origin/Destination (OD) matrices and should represent an all-day model for Home-Based (HB) trips. For Non-Home-Based trips (NHB), it is satisfactory to use O/D based matrices for the purpose of variable demand modelling.

The P/A matrices for the base year demand were constructed from the observed travel movements based on road-side interviews (RSI) in 2006 during the development of the GLTM base year model. The RSI data provides information on trip purposes including by time periods. The information obtained from the RSI data was applied to the O/D validated base year matrices to construct the P/A base year matrices for the purpose of LVDM.

For the forecast year demand, “reference case” matrices require reference case growth factors/assumptions (i.e. NTEM growth plus development assumptions) and involve adjustments of both rows and columns of the base P/A matrices at an all-day level to reflect expected land-use and car ownership changes (taking no account of cost changes).

Six journey purposes were constructed for the LVDM demand model, in which HB trips operate at 24-hours P/A format, and NHB trips operate at time period O/D format, as below:

- HB Commuting (24-hour P/A);
- HB Education (24-hour P/A);
- HB Other (24-hour P/A);
- HB Employers Business (24-hour P/A);
- NHB Employers Other (time period O/D); and
- NHB Employers Business (time period O/D).

Each of the six journey purposes correspond to the relevant user classes for the VISUM highway assignments, as shown in Table 3-1 below.

Table 3-1 – LVDM Purposes to Assignment User Classes

No	Assignment User Classes	LVDM Journey Purposes
1	Commuting	HB Commuting (24Hr P/A)
2	Other	HB Education (24Hr P/A)
		HB Other (24Hr P/A)
		NHB Other (Period O/D)
3	Business	HB Business (24Hr P/A)
		NHB Business (Period O/D)
4	LGV	LGV (Not used)
5	HGV	HGV (Not used)

During the demand modelling process, trip matrices must be converted from a P/A basis to an O/D basis for the purpose of highway assignments.

3.5 Division into Time Periods

The LVDM demand model operates at the aggregate 24-hours P/A level for the HB trips and at period O/D level for NHB trips. A HB trip is defined a single outbound movement with an associated return movement. In this way the demand responses are consistent and, for example, trip destination choice matches between time periods. The outward and return proportions of trips are based on the original data in the 2006 model, including surveyed proportions. The VISUM highway assignment models, however, represent three individual peak hours, as allocated as follows.

- AM Peak Hour (8:00-9:00);
- Inter Peak Average Hour (10:00-16:00); and

- PM Peak Hour (17:00-18:00).

It was therefore necessary that, for HB trips, for a mechanism to be developed to disaggregate and convert from 24-hour P/A trips to peak hour O/D trips for the highway assignment purpose. The process is described in more detail in the next chapter.

3.6 Singly or Doubly Constrained

The doubly constrained choice model is applied to Home Based commuting and Home Based Education purposes, as per DfT guidance, since more confidence can be placed on the absolute level of attractions (employment and student numbers).

The singly constrained choice model (production/origin end) is applied to other purposes.

The LGV and HGV origin and destination matrices are not subjected to the choice model but are included within the assignment process and contribute to travel costs for other modes.

4 Variable Demand Model Methodology

4.1 Introduction

VISUM provides the model supply side, time cost, distance cost, and route choice. Cost matrices skims are produced by trip purpose and time period for time and distance.

CUBE determines the new demand forecast matrix utilising the skim cost matrices provided by VISUM and the incremental logit choice model. The skim cost matrices are converted into generalised cost matrices and converted to a 24 hour average cost. They are then subtracted from the reference case generalised cost matrices to produce cost difference matrices by trip purpose and time period.

This chapter describes the methodology, assumptions and mathematical notations that have been adopted for the purpose of the LVDM model.

4.2 Conversion O/D to P/A

As per WebTAG M2, variable demand models require matrices in P/A form for HB trips and O/D form for the NHB trips.

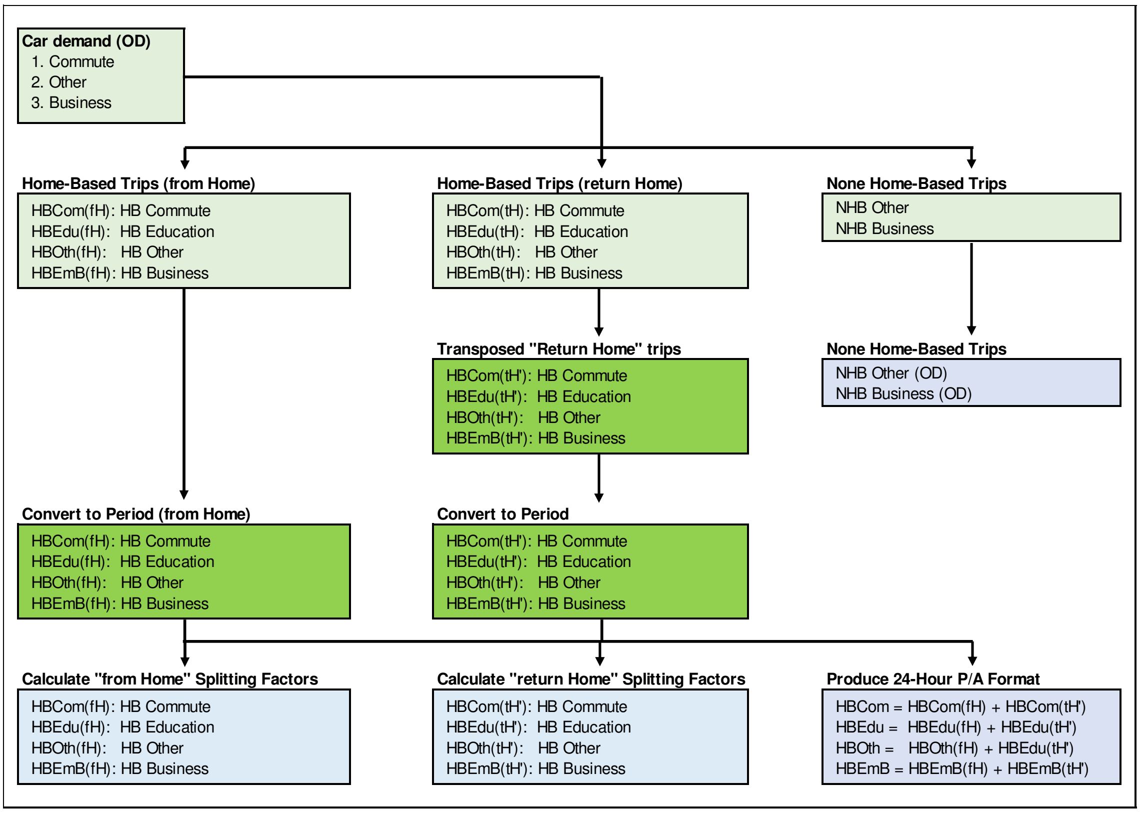
According to WebTAG M2, para 4.4.1, it is essential that the demand and assignment models are correctly connected, with consistent cost definitions and appropriate conversion between the P/A demand model matrices and the assignment O/D matrices.

This section describes in more detail the process of constructing the demand matrices in P/A format and conversion from P/A to O/D for the purpose of the assignments. The process involves the following steps:

- Convert O/D demand matrices by time period to 24-hour P/A format using the trip purpose split information that was obtained from the RSI data;
- Calculate "from Home/return Home" proportion for each time period, by trip purposes; and,
- Convert 24-hour P/A format to period O/D format for assignment purpose.

The process of converting O/D period car demand to 24-hour P/A format is provided in Figure 4-1 below.

Figure 4-1 Conversion of O/D Period Demand to 24-Hour P/A Format



The splitting factors calculated from the process above were then used to undertake two purposes:

- Conversion of assignment travel costs from O/D time period format to 24-hour P/A format for HB trips; and,
- Conversion of demand from 24-hour P/A format to time period O/D format for the purpose of assignments.

According to WebTAG M2, Appendix B.1.8, if no assignment matrix is in existence, then the first step should be to see whether the derived base P/A matrices can, when converted to O/D form, be satisfactorily validated at the assignment level. On that basis, the resultant O/D base year matrices were checked against the validated base year matrices to ensure that no change had occurred during the conversion process. This was to minimise ‘noise’ during the demand modelling that would cause the demand model not to produce a realistic estimation of the forecast demand.

4.3 Incremental Modelling

The highway assignment model was calibrated to a base year of 2006, including an update most recently from 2016, concentrating on an update of the VISUM software, adherence to the most recent WebTAG calibration criteria and testing of the impact updated values of time have within the process.

Beyond this, the model was projected to a 2015 present year. The outturn results of this process were compared against a limited set of count and journey time data and found to be plausible, albeit not strictly compliant to WebTAG criteria. This was presented in the Present Year Comparison note[2].

On the basis that 2015 requires less of a pivot on cost change than 2006 then 2015 was selected as the reference year. Projections to 2018 DM/DS and 2033 DM/DS were all pivoted from 2015. The resultant cost changes over the period and choice sensitivities impacted the outturn results.

As mentioned in the previous chapter, the LVDM adopts the Pivot-Point model with incremental change in costs, with three distinct forms as below:

- Incremental P/A model: applied for HB trips at 24-hour level;
- Incremental O/D model: applied for NHB trips at time period level; and
- Fixed demand: applied for car trips externally of the area of influence and LGV, HGV.

The LVDM adopts two choice responses as mentioned in the previous chapter, that is, in the order of hierarchy:

- Trip frequency choice; and
- Trip destination choice.

The effect of mode choice and time choice were excluded from the demand model on the basis that "passive" mode choice was considered to the study area.

4.4 Conversion of Generalised Costs to P/A Format

Reference cost skims extracted from the highway assignments were converted to 24-hour P/A format for the HB purposes and retained at time period O/D format for the NHB purposes, using the formula below:

- For HB purposes: $\mathrm{GC}^{\mathrm{PA}}_{\mathrm{24h.ij}} = \sum_{\mathrm{p}} \mathrm{GC}^{\mathrm{OD}}_{\mathrm{t.ij}} * \mathrm{SF}^{\mathrm{fH}}_{\mathrm{t.ij}} + \mathrm{GC}^{\mathrm{OD.T}}_{\mathrm{t.ij}} * \mathrm{SF}^{\mathrm{tH}}_{\mathrm{t.ij}}$
- For NHB purposes: $\mathrm{GC}^{\mathrm{OD}}_{\mathrm{t.ij}} = \mathrm{GC}^{\mathrm{OD}}_{\mathrm{t.ij}}$

Where:

[2] It is believed there are no specific criteria in WebTAG for PYV model performance. This section refers to the more onerous base year criteria

- $GC^{OD}_{t.ij}$, $GC^{OD.T}_{t.ij}$ are the generalised costs and transposed generalised costs respectively, extracted from the assignments from zone i to zone j, time period t
- $SF^{fH}_{t.ij}$, $SF^{tH}_{t.ij}$ are the "from Home" and "return Home" splitting factors for each ij pair and by time period t, as calculated from the process described in section 4.2.

4.5 Cost Damping

Initial tests with the LVDM indicates that trips associated with long distance travel resulted in significant change in demand compared to the reference demand. It was understood that the external zones distances from the study area were coded in less detail than those within the study area and therefore changes in travel costs were less accurate under the impact of change in the demand. According to WebTAG M2, Section 3.3, in order to ensure that a model meets the requirement of the realism test, it may be necessary to include the "cost damping" mechanism to achieve this.

A number of cost damping functions were investigated and the "damping generalised cost by a function of distance" as stated in the paragraph. 3.3.5 of this guidance was finally adopted for the purpose of the LVDM demand model, as below:

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

where;

t, c	are the trip time and monetary cost[5], respectively;
VOT	is the value of time;
$(t + c/VOT)$	is generalised cost;
G'	is the damped generalised cost;
d	is the trip length; and
α and k	are parameters that need to be provided or calibrated.

Note (5): monetary cost includes private car fuel, parking, tolls and charges.

The value of **α** adopted was 0.5 and the value of **k** was derived from the average trip length from the base year model. Table 4-1 below summarises the values of average trip-length for each of the time period and purpose.

Table 4-1 – Average Trip Length used for Cost Damping (km)

Purpose	AM Peak	Inter-Peak	PM Peak
Commuting	23.50	20.74	25.17
Other	17.30	21.79	25.73
Business	35.74	28.88	41.27

The average trip length (k) acts as a cut-off point so that if the travelled distance is longer than the average trip length (k) the effect of the cost damping (G') would be present. When the travelled distance (d) is less than the average trip length (k) then it uses directly the generalised costs extracted from the model.

4.6 Calculation of Incremental Change in Demand

The process of modelling trip distribution and frequency choice are provided in number of equations below:

At the bottom level, change in utility is given by the formula:

$$\Delta U_{ijmtpc} = -\lambda_{dest,mc}(GC^1_{ijmtpc} - GC^0_{ijmtpc})$$

Where:

- $-\lambda_{\mathrm{dest,mc}}$ is the destination choice parameters for mode m and person type c;
- $\mathrm{GC}^0_{\mathrm{ijmtpc}}, \mathrm{GC}^1_{\mathrm{ijmtpc}}$ is reference and forecast generalised costs between zone i and zone j for mode m, time period t, purpose p and person c;

Singly and Doubly Constrained Distribution

For employer business, and other purposes, singly-constrained distribution is used by the formula:

- $T_{ijmtpc} = O_{imtpc} \frac{T^0_{ijmtpc} \exp(\Delta U_{ijmtpc})}{\sum_{k=1}^{N} T^0_{ikmtpc} \exp(\Delta U_{ikmtpc})}$

For commuting and education trips, a doubly-constrained distribution was adopted:

- $T_{ijmtpc} = O_{imtpc} \frac{B_{jp}\, T^0_{ijmtpc} \exp(\Delta U_{ijmtpc})}{\sum_{k=1}^{N} B_{kp}\, T^0_{ikmtpc} \exp(\Delta U_{ikmtpc})}$

The balancing factor B_{jp} is required to be calculated so that the destination are met as calculated from the reference demand matrix, as below:

$$\sum_{imtc} T_{ijmtpc} = D_{jp} \text{ with } D_{jp} = \sum_{imtc} T^0_{ijmtpc}$$

The Furnessing procedure was used to calculate distribution demand by running through number of iterative loops until the convergence criteria was met.

Composite Utilities

The change in the composite utility from the destination choice is then calculated:

$$\Delta U^*_{imtpc} = ln \sum_j B_{jp} \frac{T^0_{ijmtpc}}{O^0_{imtpc}} exp(\Delta U_{ijmtpc})$$

Conditional Probabilities

Having calculated the change in the composite utilities it is possible to calculate the conditional utilities for each level of the model, for the LVDM, for destination choice:

$$p_{j/imtpc} = \frac{B_{jp}\, T^{0}_{ijmtpc}\, exp(\Delta U_{ijmtpc})}{\sum_{k=1}^{N} B_{kp}\, T^{0}_{ikmtpc}\, exp(\Delta U_{ikmtpc})}$$

Updated Trip Matrix

The application of the conditional probabilities produce an updated trip matrix:

$$T_{ijmtpc} = T^{0}_{ipc}\, p_{j/imtpc} \text{ (Only destination choice effect)}$$

Application of Frequency Model

The frequency model is only applied after the above process has converged. This gives the final trip matrix from the demand model:

$$T_{ijmtpc} = exp\left(\theta_{c}^{freq}\, \Delta U^{*}_{ipc}\right) T^{0}_{ipc}\, p_{j/imtpc}$$

After the trip frequency model was applied, new demand was produced and was then adjusted depend on the search direction for convergence, and then converted to O/D format by period for the traffic assignment.

4.7 Convergence of Demand Model

The process described in Section 4.6 was carried out iteratively until a convergence solution was reached, i.e the relative gap between supply and demand is lower than the required values, currently 0.1% as recommended by the WebTAG M2. The convergence gap of the demand model is calculated by the following formula:

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

Where;

X_{ijctm} is the current flow vector or matrix from the model

$C(X_{ijctm})$ is the generalised cost vector or matrix obtained by assigning that matrix

$D(C(X_{ijctm}))$ is the flow vector or matrix output by the demand model, using the costs $C(X_{ijctm})$ as input

$ijctm$ represents origin i, destination j, demand segment/user class c, time period t and mode m

4.8 Search for Convergence Solution

To help searching for convergence solution, number of methods were tested such as conventional method, fixed step length and method of successive averages (MSA). The fixed step length method was adopted, as provided by the formula below:

- $X^N = X^{N-1} + \alpha U(X^{N-1})$,

Where:

- α is the step length, was fixed as 0.5
- X^N, X^{N-1} is the final demand adjusted in searching for convergence solution for this iteration and for the previous iteration, respectively
- $U(X^{N-1})$ is the search direction for convergence solution, search direction is calculated by the formula: $U(X^{N-1}) = D[C(X^{N-1})] - X^{N-1}$

4.9 Base Year Realism Tests

Realism tests were carried out on the base year model to make sure that the models behaved "realistically", by changing the various components of travel costs and time, and checking that the overall demand response accords with general experience. If it does not, the values of the parameters controlling the response demand to costs should be adjusted until an acceptable response is achieved.

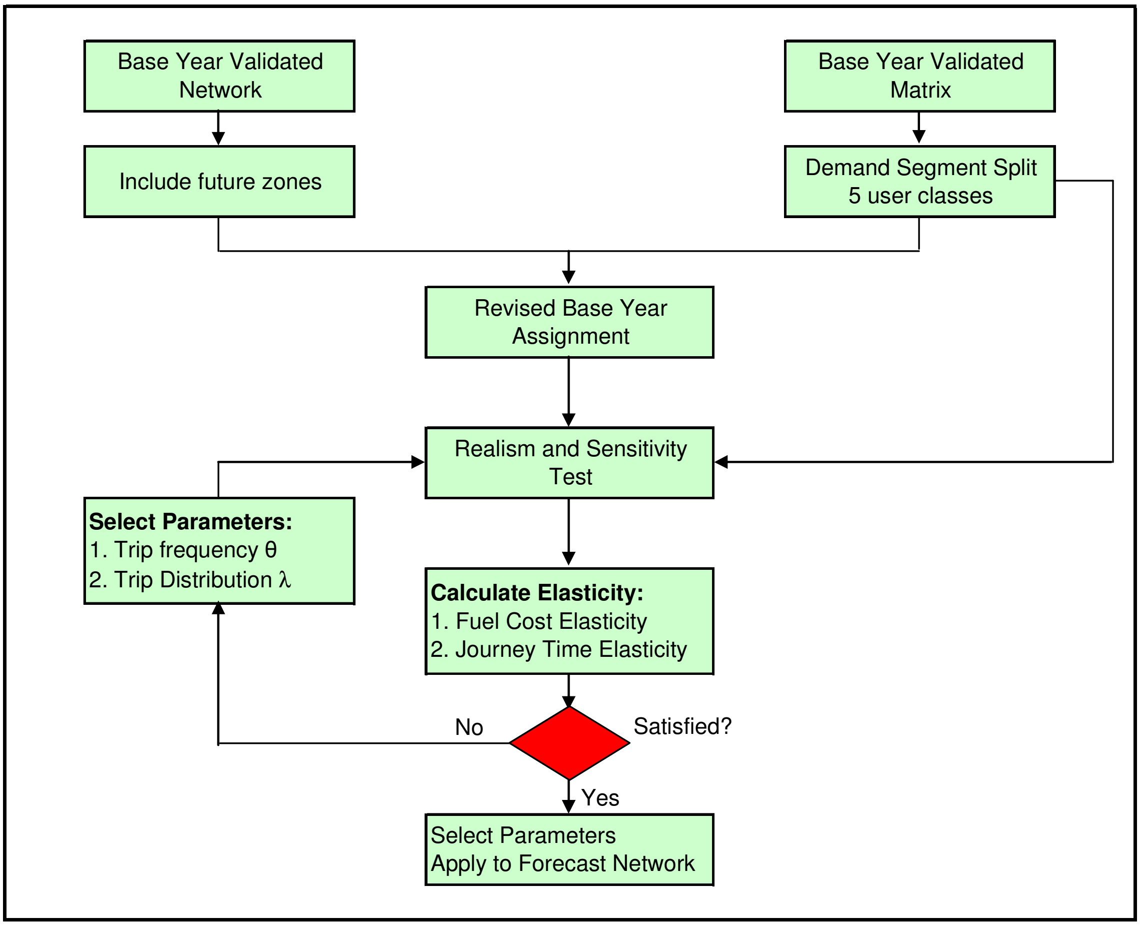
The acceptability of the model's response is determined by the demand elasticity, which is calculated by changes in a cost or time component by a small global proportion and calculating the proportionate change in the trips made. The elasticity recommended is the arc elasticity formula is as follows:

$$E = \frac{log(T^1) - log(T^0)}{log(C^1) - log(C^0)}$$

Where superscript 0 and 1 indicate values of demand 'T' and cost 'C' before and after change in costs, respectively.

The process of carrying out the realism tests for the base year model is provided in the Figure 4-2 below.

Figure 4-2 – Realism Test Process



According to WebTAG M2, three tests are required to ensure that the models behave "realistically"; these are:

4.9.1 *Car Fuel Cost Elasticity*

Car fuel cost elasticity tests the change in car vehicle kilometres travelled when fuel prices change. For the tests, the following was adopted for the LVDM model:

- The calculation of elasticity was carried out with 20% increase in fuel costs;
- The fuel cost elasticity was calculated from a converged run of the supply/demand loop;
- Car fuel cost elasticity was calculated following the matrix-based, i.e. car vehicle kilometres were calculated from the car trip matrices and skimmed distance matrices which relate to the before and after fuel costs change model runs. The movements included in the calculation only relate to movements in which the full range of demand responses applied in the demand model

The elasticity calculated from model runs was approximately -0.3 for cars trips with -0.1 for employer business trips and -0.4 for discretionary trips, and for commuting trips somewhere near the average

4.9.2 *Car Journey Time Elasticity*

Car journey time elasticity tests the change in car trips with respect to a change in journey time. For the LVDM, the following was adopted:

- Journey time elasticity was calculated using a single run of the model due to the target elasticity in this case being derived from stated preference data;
- Journey time tested $\mathrm{GC}^{\mathrm{JT}} = 1.2 * \mathrm{Time} + \frac{\mathrm{PPK}}{\mathrm{PPM}} * \mathrm{Distance}$

The output elasticity with respect to car journey time increase should not produce very high values, say not stronger than -2.0

4.9.3 *Sensitivity Testing*

Sensitivity tests are carried out to ensure that the model response to changes in fuel costs increase/decrease proportionately with the increase/decrease of the destination choice lambda values. Tests of ±50% of the calibrated lambda values were recommended to test the robustness of the demand model. If the scheme remains justified against these higher values then a conclusion that the scheme is beneficial will be robust against the effects of the induced traffic.

5 Realism Tests for LEB Base Model

5.1 Background

This chapter presents the results of the calibration of the LVDM base year demand model. Following the construction of the demand model, a series of tests should be undertaken in order to ensure that it functions realistically. These tests involve changing the components of travel and monitoring the overall demand responses. If the changes in demand are not in line with general experience, the parameter values of the choice model should be adjusted until acceptable responses are achieved.

The guidance suggests that a number of studies in this country using time-series data on car travel, and fuel prices and costs have shown an elasticity of car use with respect to fuel cost of around -0.3 and this value is in line with a review of European research on this topic. These values were used as elasticity targets in the process of the choice model calibration.

In line with earlier finding concerning this version of the model, the mode choice was determined to be of limited value given the scheme focus and local travel market. Therefore the mode nest was removed with a reliance on strengthened responses in respect of frequency and distribution.

5.2 Parameters Used

The calibration of the LVDM demand model was tested using 2015 present year validated demand matrices, with the following parameters, consistent with the WebTAG guidance. Tables 5-1 to 5-4 provide parameters required to carry out Realism tests.

Table 5-1 – Generalised Cost Parameters – Pivot Point (Base Year 2015)

User Class	Pence Per Minute			Pence Per Kilometre		
	AM	IP	PM	AM	IP	PM
Commute	13.54	13.54	13.54	6.51	6.51	6.51
Other	18.25	18.25	18.25	6.51	6.51	6.51
Business	45.76	45.76	45.76	12.91	12.91	12.91

Table 5-2 – Generalised Cost Parameters – Test with 20% Increase in Fuel Costs

User Class	Pence Per Minute			Pence Per Kilometre		
	AM	IP	PM	AM	IP	PM
Commute	13.54	13.54	13.54	7.82	7.82	7.82
Other	18.25	18.25	18.25	7.82	7.82	7.82
Business	45.76	45.76	45.76	13.99	13.99	13.99

Table 5-3 – Car Occupancy – Base Year 2015

User Class	AM Period	Inter-Peak	PM Period	Off-Peak
Commute	1.145	1.136	1.120	1.121
Other	1.642	1.707	1.757	1.717
Business	1.214	1.179	1.155	1.167

Table 5-4 – Reference Matrix Totals – Base Year 2015

Purpose	Format	AM period	IP Period	PM Period	OP Period	24hr Total
HB Trips						
HB Commute (PA)	from Home	59,576	20,868	7,811	868	89,123
	return Home	4,827	24,390	42,366	1,210	72,792
	Total	64,403	45,258	50,177	2,078	161,915
HB Education (PA)	from Home	12,729	9,955	1,324	10	24,018
	return Home	2,668	21,589	7,017	29	31,303
	Total	15,398	31,544	8,341	38	55,321
HB Other (PA)	from Home	20,045	60,213	28,859	999	110,116
	return Home	20,729	19,074	27,664	1,478	68,944
	Total	40,774	79,287	56,523	2,477	179,060
HB Business (PA)	from Home	6,023	5,292	2,245	216	13,776
	return Home	1,771	4,437	7,006	449	13,662
	Total	7,793	9,729	9,251	665	27,438
NHB Trips						
NHB Other (OD)	Total	27,250	261,267	60,453	7,690	356,661
NHB Business (OD)	Total	8,142	25,146	5,045	924	39,256

5.3 Fuel Cost Elasticity

As stated above, since the model is unimodal and the experience of time period choice is insufficiently developed to provide sensible parameterisation, the variable demand only applies two responses, trip frequency and destination choice.

A number of tests have been carried out with different sets of trip frequency and destination choice parameters to achieve the recommended values of elasticity, i.e. -0.3 for car, with -0.1 being closer to employer business, -0.4 being closer to discretionary trips, and average values being closer to commuting trips.

The first three tests were carried out with trip frequency being omitted, for minimum, median, and maximum sets of destination choice lambda values. This was done to observe the model's response by the outturn elasticity with respect to fuel costs. Table 5-5 below provides a summary of convergence and elasticity resulting from the three tests with zero trip frequency and minimum, median, and maximum values of destination choice lambda.

Table 5-5 – Car Fuel Elasticity without Frequency Choice

Test	Purpose	θ	λ	Elasticity AM	Elasticity IP	Elasticity PM	Elasticity 24-Hr	%Gap
Zero Trip Frequency + Minimum Lambda								
1	HB EmB	0.000	0.038	-0.036	-0.033	-0.050	-0.039	0.064%
	NHB EmB	0.000	0.069					
	Commute	0.000	0.054	-0.063	-0.030	-0.082	-0.065	
	HB Edu	0.000	0.074	-0.149	-0.235	-0.206	-0.214	
	HB Other	0.000	0.074					
	NHB Other	0.000	0.073					
	Car			**-0.083**	**-0.167**	**-0.121**	**-0.130**	
Zero Trip Frequency + Median Lambda								
2	HB EmB	0.000	0.067	-0.054	-0.045	-0.067	-0.053	0.099%
	NHB EmB	0.000	0.081					
	Commute	0.000	0.065	-0.072	-0.036	-0.096	-0.075	
	HB Edu	0.000	0.090	-0.168	-0.265	-0.233	-0.241	
	HB Other	0.000	0.090					
	NHB Other	0.000	0.077					
	Car			**-0.096**	**-0.190**	**-0.140**	**-0.149**	
Zero Trip Frequency + Maximum Lambda								
3	HB EmB	0.000	0.106	-0.065	-0.054	-0.074	-0.063	0.098%
	NHB EmB	0.000	0.107					
	Commute	0.000	0.113	-0.108	-0.059	-0.138	-0.112	
	HB Edu	0.000	0.160	-0.240	-0.404	-0.311	-0.355	
	HB Other	0.000	0.160					
	NHB Other	0.000	0.105					
	Car			**-0.139**	**-0.287**	**-0.189**	**-0.216**	

It can be seen that with zero trip frequency included, it was not possible to achieve the recommended elasticity set out by the WebTAG guidance, even with the maximum values of destination choice lambda.

As stated above, since this is a highway-only model, and slow modes were not included, the trip frequency was therefore included with higher responsive value to represent two effects: transfer from car to slow modew and vice versa; and transfer from car to public transport and vice versa.

The further tests were therefore carried out with different sets of trip frequency in combination with median values of destination choice lambda to search for a suitable set of trip frequency theta values. Table 5-6 below summarises the tests that were carried out with a set of trip frequency theta in combination with minimum, median and maximum values of destination choice lambda.

Table 5-6 – Car Fuel Elasticity with Frequency Choice Included

Test	Purpose	θ	λ	Elasticity				%Gap
				AM	IP	PM	24-Hr	
With Trip Frequency + Minimum Lambda								
4	HB EmB	0.168	0.038	-0.064	-0.058	-0.068	-0.062	0.086%
	NHB EmB	0.193	0.069					
	Commute	0.163	0.054	-0.132	-0.107	-0.151	-0.135	
	HB Edu	0.225	0.074	-0.225	-0.317	-0.0279	-0.293	
	HB Other	0.225	0.074					
	NHB Other	0.203	0.073					
	Car			**-0.148**	**-0.237**	**-0.183**	**-0.196**	
With Trip Frequency + Median Lambda								
5	HB EmB	0.168	0.067	-0.087	-0.075	-0.091	-0.082	0.084%
	NHB EmB	0.193	0.081					
	Commute	0.163	0.065	-0.152	-0.128	-0.175	-0.157	
	HB Edu	0.225	0.090	-0.248	-0.356	-0.310	-0.327	
	HB Other	0.225	0.090					
	NHB Other	0.203	0.077					
	Car			**-0.169**	**-0.269**	**-0.209**	**-0.223**	
With Trip Frequency + Maximum Lambda								
6	HB EmB	0.168	0.106	-0.110	-0.086	-0.109	-0.098	0.063%
	NHB EmB	0.193	0.107					
	Commute	0.163	0.113	-0.234	-0.200	-0.270	-0.242	
	HB Edu	0.225	0.160	-0.351	-0.533	-0.448	-0.483	
	HB Other	0.225	0.160					
	NHB Other	0.203	0.105					
	Car			**-0.248**	**-0.397**	**-0.305**	**-0.328**	

As can be seen, the fuel cost elasticities are only achieved if the effect of trip frequency for Commuting and Discretionary trips is strengthened by use of a higher lambda value. The stronger requirement for the trip frequency is due to number of reasons:

- No public transport was included, thus the trip frequency has to be stronger so that it can represent the transfer from car to other competitive modes of transport and vice versa

- Slow modes were also not included in the model; therefore trip frequency needs to be included so that the model can represent the transfer to slow modes and vice versa.

From the test results provided in Table 5-6, it was possible to derive the final destination choice parameters in the calibration of the base demand model in order to achieve the recommended elasticity as set out by the DfT. Table 5-7 below provides a summary of the test with the final destination choice lambda values.

Table 5-7 – Car Fuel Elasticity with Final Set of Values

Test	Purpose	θ	λ	Elasticity				%Gap
				AM	IP	PM	24-Hr	
With Trip Frequency + Final Lambda								
7	HB EmB	0.168	0.092	-0.107	-0.084	-0.110	-0.097	0.096%
	NHB EmB	0.193	0.099					
	Commute	0.163	0.084	-0.187	-0.156	-0.215	-0.193	
	HB Edu	0.225	0.126	-0.308	-0.451	-0.384	-0.411	
	HB Other	0.225	0.126					
	NHB Other	0.203	0.092					
	Car			**-0.209**	**-0.337**	**-0.257**	**-0.277**	

As can be seen from Table 5-7, the model achieved the overall elasticity of -0.28 with respect to change in fuel costs, within the recommended acceptable range from -0.25 to -0.35 from the WebTAG Me guidance. The resultant elasticities were also in the correct order of magnitude, with weaker elasticity for business trips of near -0.1 and stronger elasticity for discretionary trips being near to -0.4 and commuting nearer to average.

The results also show that the effect of the fuel cost change on the resultant elasticity is weaker for the AM and PM peak and stronger for the Inter-Peak, consistent with the WebTAG M2, para. 6.4.17.

As mentioned above, the exclusion of mode choice and public transport/slow modes in the LVDM demand model resulted in stronger scaling parameters of trip frequency theta values. This is expected as trip frequency is the least sensitive response within the demand model as it only applies to the top level of the hierarchy, after the destination choice has been implemented.

5.4 Journey Time Elasticity

As described in the previous chapter, the test with car journey time elasticity was carried out on the final set of frequency and destination choice parameters, to ensure that the change in car trips with respect to change in journey time does not produce a very high output elasticity, greater than -2.0. Table 5-8 below provides a summary of the test with journey time elasticity.

Table 5-8 – Journey Time Elasticity with Final Set of Values

<table>
<tr><th rowspan="2">Test</th><th rowspan="2">Purpose</th><th rowspan="2">θ</th><th rowspan="2">λ</th><th colspan="4">Elasticity</th><th rowspan="2">%Gap</th></tr>
<tr><th>AM</th><th>IP</th><th>PM</th><th>24-Hr</th></tr>
<tr><td colspan="9">With Trip Frequency + Final Lambda</td></tr>
<tr><td rowspan="7">8</td><td>HB EmB</td><td>0.168</td><td>0.092</td><td rowspan="2">-0.374</td><td rowspan="2">-0.430</td><td rowspan="2">-0.489</td><td rowspan="2">-0.430</td><td rowspan="7">NA</td></tr>
<tr><td>NHB EmB</td><td>0.193</td><td>0.099</td></tr>
<tr><td>Commute</td><td>0.163</td><td>0.084</td><td>-0.290</td><td>-0.182</td><td>-0.397</td><td>-0.308</td></tr>
<tr><td>HB Edu</td><td>0.225</td><td>0.126</td><td rowspan="3">-0.353</td><td rowspan="3">-0.325</td><td rowspan="3">-0.467</td><td rowspan="3">-0.360</td></tr>
<tr><td>HB Other</td><td>0.225</td><td>0.126</td></tr>
<tr><td>NHB Other</td><td>0.203</td><td>0.092</td></tr>
<tr><td colspan="3">Car</td><td>-0.322</td><td>-0.317</td><td>-0.438</td><td>-0.350</td></tr>
</table>

As can be seen, the outturn elasticities with respect to change in journey time are within the recommended WebTAG value of -2.0.

Details associated with realism testing are included in Appendix A.

6 Application of VDM for LEB Forecasting

6.1 Introduction

The VDM demand model for the LEB forecasting was carried out for the following:

- Forecast years: Opening Year 2018 and Design Year 2033;
- Forecasting case: Do-Minimum and Do-Something cases with pivoting off the Base year 2015 costs;
- Forecast scenario: Core scenario, Low growth and high growth scenarios.

This note only reports the output from the LVDM demand model for the core scenario. Low and high growth scenarios will not be reported in detail.

6.2 Parameters Used

Tables 6-1 to 6-4 below summarise the input time and distance parameters used to derive generalised costs within the LVDM.

Table 6-1 – Generalised Cost Parameters – Forecast Years

User Class	Pence Per Minute			Pence Per Kilometre		
	AM	IP	PM	AM	IP	PM
Opening Year 2018						
Commute	14.32	14.32	14.32	6.00	6.00	6.00
Other	19.20	19.20	19.20	6.00	6.00	6.00
Business	48.40	48.40	48.40	12.46	12.46	12.46
Design Year 2033						
Commute	18.94	18.94	18.94	5.57	5.57	5.57
Other	24.75	24.75	24.75	5.57	5.57	5.57
Business	64.15	64.15	64.15	11.94	11.94	11.94

Table 6-2 Car Occupancy – Forecast Years

User Class	AM Period	Inter-Peak	PM Period	Off-Peak
Opening Year 2018				
Commute	1.142	1.133	1.118	1.119
Other	1.629	1.694	1.745	1.707
Business	1.211	1.177	1.152	1.164
Opening Year 2018				
Commute	1.128	1.121	1.109	1.111
Other	1.569	1.629	1.688	1.659
Business	1.196	1.166	1.138	1.153

Table 6-3 – Reference Matrix Totals – Opening Year 2018

Purpose	Format	AM period	IP Period	PM Period	OP Period	24hr Total
HB Trips						
HB Commute (PA)	from Home	60,302	21,368	8,186	880	90,736
	return Home	4,903	24,597	42,715	1,227	73,443
	Total	65,205	45,966	50,901	2,107	164,179
HB Education (PA)	from Home	12,779	10,133	1,332	10	24,254
	return Home	2,689	22,161	7,092	29	31,971
	Total	15,468	32,294	8,424	39	56,225
HB Other (PA)	from Home	21,184	65,590	30,191	1,053	118,017
	return Home	21,421	19,537	28,054	1,556	70,568
	Total	42,605	85,127	58,245	2,609	188,585
HB Business (PA)	from Home	6,146	5,563	2,324	221	14,254
	return Home	1,793	4,508	7,076	460	13,837
	Total	7,939	10,071	9,401	681	28,091
NHB Trips						
NHB Other (OD)	Total	27,662	265,442	61,100	7,801	362,004
NHB Business (OD)	Total	8,197	25,395	5,077	931	39,600

Table 6-4 – Reference Matrix Totals – Design Year 2033

Purpose	Format	AM period	IP Period	PM Period	OP Period	24hr Total
HB Trips						
HB Commute (PA)	from Home	61,956	22,578	9,301	909	94,745
	return Home	5,087	25,041	43,503	1,268	74,899
	Total	67,044	47,619	52,805	2,177	169,644
HB Education (PA)	from Home	12,940	10,857	1,381	10	25,188
	return Home	2,791	24,857	7,440	31	35,120
	Total	15,730	35,714	8,822	42	60,308
HB Other (PA)	from Home	24,655	84,961	34,679	1,218	145,513
	return Home	22,315	20,472	28,114	1,801	72,702
	Total	46,970	105,432	62,793	3,019	218,214
HB Business (PA)	from Home	6,494	6,422	2,576	237	15,729
	return Home	1,851	4,725	7,245	492	14,313
	Total	8,345	11,148	9,821	728	30,042
NHB Trips						
NHB Other (OD)	Total	28,303	281,121	62,238	8,131	379,793
NHB Business (OD)	Total	8,213	25,855	5,097	940	40,105

The input parameters were used to carry out LVDM forecast demand models. Tables 6-5 to 6-6 below provide high level summary of change in forecast demand from the reference demand as a result from the LVDM demand model.

Table 6-5 – Change in Matrix Totals as a Result of LVDM – Opening Year 2018

Period	Purpose	Matrix Totals (veh)			%Difference	
		Ref.	DM	DS	DM – Ref.	DS - DM
AM Peak	Business	5,770	5,775	5,798	0.1%	0.4%
	Commute	28,116	28,187	28,306	0.3%	0.4%
	Other	19,788	19,809	20,106	0.1%	1.5%
	Car	**53,674**	**53,771**	**54,210**	**0.2%**	**0.8%**
	LGV	9,818	9,818	9,818	0.0%	0.0%
	HGV	2,611	2,611	2,611	0.0%	0.0%
Inter-Peak	Business	5,022	5,029	5,086	0.1%	1.1%
	Commute	6,762	6,769	6,822	0.1%	0.8%
	Other	37,668	37,739	38,014	0.2%	0.7%
	Car	**49,452**	**49,537**	**49,922**	**0.2%**	**0.8%**
	LGV	9,163	9,163	9,163	0.0%	0.0%
	HGV	3,736	3,736	3,736	0.0%	0.0%
PM Peak	Business	5,606	5,610	5,621	0.1%	0.2%
	Commute	22,987	23,196	23,382	0.9%	0.8%
	Other	24,491	24,732	25,122	1.0%	1.6%
	Car	**53,083**	**53,538**	**54,125**	**0.9%**	**1.1%**
	LGV	9,410	9,410	9,410	0.0%	0.0%
	HGV	1,894	1,894	1,894	0.0%	0.0%
24-Hours	Business	66,651	66,727	67,202	0.1%	0.7%
	Commute	194,827	195,705	196,960	0.5%	0.6%
	Other	379,413	380,661	384,503	0.3%	1.0%
	Car	**640,892**	**643,092**	**648,665**	**0.3%**	**0.9%**
	LGV	117,107	117,107	117,107	0.0%	0.0%
	HGV	37,905	37,905	37,905	0.0%	0.0%

Table 6-6 – Change in Matrix Totals as a Result of LVDM – Design Year 2033

Period	Purpose	Matrix Totals (veh)			%Difference	
		Ref.	DM	DS	DM – Ref.	DS - DM
AM Peak	Business	6,075	6,011	6,030	-1.0%	0.3%
	Commute	29,674	29,597	29,711	-0.3%	0.4%
	Other	22,592	22,023	22,358	-2.5%	1.5%
	Car	**58,340**	**57,632**	**58,099**	**-1.2%**	**0.8%**
	LGV	13,662	13,662	13,662	0.0%	0.0%
	HGV	2,874	2,874	2,874	0.0%	0.0%
Inter-Peak	Business	5,289	5,239	5,308	-0.9%	1.3%
	Commute	7,080	7,052	7,122	-0.4%	1.0%
	Other	43,203	42,977	43,380	-0.5%	0.9%
	Car	**55,572**	**55,268**	**55,810**	**-0.5%**	**1.0%**
	LGV	12,751	12,751	12,751	0.0%	0.0%
	HGV	4,118	4,118	4,118	0.0%	0.0%
PM Peak	Business	5,932	5,873	5,867	-1.0%	-0.1%
	Commute	24,432	24,540	24,663	0.4%	0.5%
	Other	27,510	27,392	27,674	-0.4%	1.0%
	Car	**57,874**	**57,805**	**58,203**	**-0.1%**	**0.7%**
	LGV	13,094	13,094	13,094	0.0%	0.0%
	HGV	2,083	2,083	2,083	0.0%	0.0%
24-Hours	Business	70,276	69,585	70,075	-1.0%	0.7%
	Commute	205,763	205,681	206,841	0.0%	0.6%
	Other	433,125	429,636	434,108	-0.8%	1.0%
	Car	**709,164**	**704,901**	**711,024**	**-0.6%**	**0.9%**
	LGV	162,961	162,961	162,961	0.0%	0.0%
	HGV	41,752	41,752	41,752	0.0%	0.0%

The demand model suppresses demand in the Do-Minimum case and induces demand in the Do-Something cases compared to the reference case demand matrix. It is generally expected as the increase in travel costs in the Do-Minimum forecast network would result in suppressing demand. For the Do-Something, since the additional capacity was added to the network (i.e. the LEB bypass) the demand model would produce additional trips in response to reduction in travel costs across the network.

It is noted that for the Opening Year 2018, the LVDM demand model produces induced traffic for the Do-Minimum demand, it is anticipated as the reduction in generalised costs associated with the change in VoT and VoC in 2018 from 2015 outweighs the growth in demand between 2015 and 2018.

For completeness demand model convergence is included in Appendix B.

7 Summary

7.1 Overview

The Lincoln Variable Demand Model (LVDM) is designed to respond to policy changes in the Greater Lincoln Transport Model (network distance and time costs, and other external costs i.e. fuel costs). The LVDM applies a functional algorithm to the generalised costs output from the assignment models as inputs to the demand model to adjust travel demand matrices, reflecting in traffic induction or suppression dependent upon cost changes.

7.2 Summary

The LVDM demand model was calibrated for the present year 2015 to realism test the impact of change in generalised costs on the change in demand in response to those changes.

The realism tests were carried out with a 20% change in fuel cost price and a 20% change in car journey time to ensure the models behave realistically in accordance with the WebTAG M2 guidance.

The outcome of the realism tests show that the LVDM base demand model behaves realistically in response to changes in fuel price and car journey times with the outturn elasticities with respect to fuel cost and journey time changes being in accordance with the WebTAG M2 guidance.

Upon completion of the calibration of the base year LVDM demand model, the LVDM demand model was used to produce the variable demand forecasts to test the impact of land-use changes and also the impact of the proposed LEB scheme on network performance, travel patterns and subsequently used for economic appraisal of the scheme.

Appendix A – Realism Test Summary

Table 0-1 – Test 1: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-70	27,064	509,023	10,029,069	2.32
2	0.5	-54	10,174	509,023	9,930,092	1.22
3	0.5	97	12,259	509,023	9,897,810	0.76
4	0.5	-14	772	509,023	9,892,370	0.37
5	0.5	-76	3,482	509,023	9,887,194	0.26
6	0.5	-68	2,539	509,023	9,885,735	0.18
7	0.5	-50	1,667	509,023	9,885,257	0.15
8	0.5	-35	1,031	509,023	9,884,662	0.12
9	0.5	-27	853	509,023	9,885,277	0.11
10	0.5	-17	235	509,023	9,883,894	0.06

Table 0-2 – Test 1: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	3,024	3,025	69,093	68,635	-0.036
	Commute	17,134	17,115	278,020	274,851	-0.063
	Other	13,261	13,263	134,844	131,227	-0.149
	Car	**33,420**	**33,403**	**481,957**	**474,713**	**-0.083**
Inter-Peak	Business	2,556	2,555	62,810	62,429	-0.033
	Commute	3,004	3,011	41,801	41,573	-0.030
	Other	16,326	16,289	212,922	203,991	-0.235
	Car	**21,886**	**21,855**	**317,532**	**307,994**	**-0.167**
PM Peak	Business	2,848	2,849	85,601	84,817	-0.050
	Commute	13,018	12,973	224,750	221,399	-0.082
	Other	12,992	12,999	177,761	171,210	-0.206
	Car	**28,859**	**28,821**	**488,112**	**477,426**	**-0.121**
24-Hours	Business	34,162	34,162	871,111	864,930	-0.039
	Commute	108,385	108,242	1,753,326	1,732,617	-0.065
	Other	185,116	184,894	2,328,917	2,239,843	-0.214
	Car	**327,664**	**327,297**	**4,953,354**	**4,837,389**	**-0.130**

Table 0-3 – Test 2: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-83	39,150	509,023	10,029,069	2.78
2	0.5	-65	12,347	509,023	9,917,619	1.33
3	0.5	124	18,496	509,023	9,879,728	0.86
4	0.5	-127	12,661	509,023	9,871,286	0.52
5	0.5	-95	6,225	509,023	9,868,704	0.32
6	0.5	-60	2,959	509,023	9,865,634	0.22
7	0.5	-36	982	509,023	9,863,270	0.15
8	0.5	-20	406	509,023	9,861,930	0.10

Table 0-4 – Test 2: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	3,024	3,026	69,093	68,419	-0.054
	Commute	17,134	17,111	278,020	274,396	-0.072
	Other	13,261	13,262	134,844	130,781	-0.168
	Car	**33,420**	**33,399**	**481,957**	**473,596**	**-0.096**
Inter-Peak	Business	2,556	2,555	62,810	62,302	-0.045
	Commute	3,004	3,012	41,801	41,527	-0.036
	Other	16,326	16,280	212,922	202,892	-0.265
	Car	**21,886**	**21,846**	**317,532**	**306,720**	**-0.190**
PM Peak	Business	2,848	2,849	85,601	84,568	-0.067
	Commute	13,018	12,967	224,750	220,861	-0.096
	Other	12,992	12,999	177,761	170,373	-0.233
	Car	**28,859**	**28,816**	**488,112**	**475,802**	**-0.140**
24-Hours	Business	34,162	34,162	871,111	862,713	-0.053
	Commute	108,385	108,219	1,753,326	1,729,385	-0.075
	Other	185,116	184,830	2,328,917	2,228,784	-0.241
	Car	**327,664**	**327,212**	**4,953,354**	**4,820,882**	**-0.149**

Table 0-5 – Test 3: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	143	113,456	509,023	10,029,069	4.59
2	0.5	-292	92,975	509,023	9,854,993	2.53
3	0.5	-291	66,788	509,023	9,815,375	1.79
4	0.5	-149	22,627	509,023	9,802,318	0.98
5	0.5	-73	4,221	509,023	9,791,158	0.52
6	0.5	-36	1,851	509,023	9,786,453	0.35
7	0.5	22	987	509,023	9,783,855	0.23
8	0.5	17	497	509,023	9,782,695	0.17
9	0.5	17	375	509,023	9,781,731	0.15
10	0.5	9	149	509,023	9,781,669	0.10

Table 0-6 – Test 3: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	3,024	3,027	69,093	68,276	-0.065
	Commute	17,134	17,085	278,020	272,598	-0.108
	Other	13,261	13,274	134,844	129,062	-0.240
	Car	**33,420**	**33,386**	**481,957**	**469,936**	**-0.139**
Inter-Peak	Business	2,556	2,555	62,810	62,193	-0.054
	Commute	3,004	3,017	41,801	41,352	-0.059
	Other	16,326	16,240	212,922	197,817	-0.404
	Car	**21,886**	**21,812**	**317,532**	**301,362**	**-0.287**
PM Peak	Business	2,848	2,850	85,601	84,448	-0.074
	Commute	13,018	12,945	224,750	219,171	-0.138
	Other	12,992	13,043	177,761	167,973	-0.311
	Car	**28,859**	**28,839**	**488,112**	**471,592**	**-0.189**
24-Hours	Business	34,162	34,166	871,111	861,218	-0.063
	Commute	108,385	108,113	1,753,326	1,717,971	-0.112
	Other	185,116	184,735	2,328,917	2,183,103	-0.355
	Car	**327,664**	**327,014**	**4,953,354**	**4,762,292**	**-0.216**

Table 0-7 – Test 4: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-74	24,074	509,023	10,029,069	2.63
2	0.5	-47	6,511	507,242	9,870,274	1.17
3	0.5	102	12,882	506,669	9,820,065	0.77
4	0.5	-112	7,286	506,492	9,815,463	0.40
5	0.5	-82	7,087	506,346	9,807,802	0.33
6	0.5	-73	4,841	506,270	9,804,406	0.27
7	0.5	-55	2,308	506,230	9,803,854	0.19
8	0.5	-39	1,305	506,198	9,803,237	0.15
9	0.5	-27	501	506,176	9,801,851	0.10
10	0.5	-19	301	506,168	9,800,761	0.09

Table 0-8 – Test 4: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	3,024	3,013	69,093	68,297	-0.064
	Commute	17,134	16,940	278,020	271,431	-0.132
	Other	13,261	13,158	134,844	129,424	-0.225
	Car	**33,420**	**33,112**	**481,957**	**469,152**	**-0.148**
Inter-Peak	Business	2,556	2,546	62,810	62,151	-0.058
	Commute	3,004	2,980	41,801	40,996	-0.107
	Other	16,326	16,128	212,922	200,981	-0.317
	Car	**21,886**	**21,654**	**317,532**	**304,127**	**-0.237**
PM Peak	Business	2,848	2,841	85,601	84,552	-0.068
	Commute	13,018	12,852	224,750	218,640	-0.151
	Other	12,992	12,873	177,761	168,937	-0.279
	Car	**28,859**	**28,566**	**488,112**	**472,130**	**-0.183**
24-Hours	Business	34,162	34,043	871,111	861,315	-0.062
	Commute	108,385	107,172	1,753,326	1,710,651	-0.135
	Other	185,116	183,149	2,328,917	2,207,934	-0.293
	Car	**327,664**	**324,364**	**4,953,354**	**4,779,899**	**-0.196**

Table 0-9 – Test 5: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-88	34,604	509,023	10,029,069	3.14
2	0.5	98	16,400	506,897	9,836,737	1.44
3	0.5	-222	54,076	506,329	9,808,170	1.24
4	0.5	-110	13,543	506,013	9,788,623	0.65
5	0.5	-48	2,603	505,843	9,776,637	0.28
6	0.5	-22	876	505,767	9,772,533	0.18
7	0.5	-17	531	505,726	9,771,443	0.15
8	0.5	-13	281	505,695	9,770,227	0.11
9	0.5	-9	122	505,678	9,769,337	0.08

Table 0-10 – Test 5: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	3,024	3,011	69,093	68,009	-0.087
	Commute	17,134	16,904	278,020	270,419	-0.152
	Other	13,261	13,148	134,844	128,893	-0.248
	Car	**33,420**	**33,063**	**481,957**	**467,322**	**-0.169**
Inter-Peak	Business	2,556	2,544	62,810	61,961	-0.075
	Commute	3,004	2,976	41,801	40,837	-0.128
	Other	16,326	16,104	212,922	199,549	-0.356
	Car	**21,886**	**21,623**	**317,532**	**302,347**	**-0.269**
PM Peak	Business	2,848	2,838	85,601	84,199	-0.091
	Commute	13,018	12,824	224,750	217,679	-0.175
	Other	12,992	12,868	177,761	167,997	-0.310
	Car	**28,859**	**28,531**	**488,112**	**469,875**	**-0.209**
24-Hours	Business	34,162	34,013	871,111	858,174	-0.082
	Commute	108,385	106,953	1,753,326	1,703,798	-0.157
	Other	185,116	182,947	2,328,917	2,194,127	-0.327
	Car	**327,664**	**323,913**	**4,953,354**	**4,756,099**	**-0.223**

Table 0-11 – Test 6: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-135	97,507	509,023	10,029,069	5.16
2	0.5	-291	99,300	505,527	9,739,049	2.67
3	0.5	-139	22,373	504,844	9,683,300	1.44
4	0.5	-205	37,253	504,569	9,671,504	1.01
5	0.5	-143	11,706	504,315	9,657,409	0.60
6	0.5	-47	3,117	504,206	9,650,926	0.29
7	0.5	-48	2,828	504,147	9,647,573	0.22
8	0.5	-21	409	504,115	9,645,723	0.15
9	0.5	25	770	504,105	9,644,170	0.12
10	0.5	28	1,064	504,118	9,644,935	0.14
11	0.5	-22	427	504,122	9,646,349	0.13
12	0.5	9	113	504,108	9,645,151	0.06

Table 0-12 – Test 6: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	3,024	3,012	69,093	67,727	-0.110
	Commute	17,134	16,782	278,020	266,420	-0.234
	Other	13,261	13,111	134,844	126,481	-0.351
	Car	**33,420**	**32,906**	**481,957**	**460,628**	**-0.248**
Inter-Peak	Business	2,556	2,543	62,810	61,837	-0.086
	Commute	3,004	2,958	41,801	40,302	-0.200
	Other	16,326	15,992	212,922	193,212	-0.533
	Car	**21,886**	**21,494**	**317,532**	**295,352**	**-0.397**
PM Peak	Business	2,848	2,839	85,601	83,912	-0.109
	Commute	13,018	12,718	224,750	213,971	-0.270
	Other	12,992	12,831	177,761	163,820	-0.448
	Car	**28,859**	**28,387**	**488,112**	**461,703**	**-0.305**
24-Hours	Business	34,162	34,016	871,111	855,679	-0.098
	Commute	108,385	106,168	1,753,326	1,677,591	-0.242
	Other	185,116	181,992	2,328,917	2,132,781	-0.483
	Car	**327,664**	**322,177**	**4,953,354**	**4,666,051**	**-0.328**

Table 0-13 – Test 7: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-114	62,463	509,023	10,029,069	4.14
2	0.5	139	32,464	506,203	9,785,433	1.94
3	0.5	-264	79,790	505,561	9,755,306	1.37
4	0.5	-127	11,237	505,112	9,724,431	0.66
5	0.5	-109	11,454	504,928	9,709,954	0.50
6	0.5	-104	10,802	504,868	9,705,172	0.40
7	0.5	-82	6,761	504,854	9,702,866	0.31
8	0.5	-58	3,659	504,861	9,702,725	0.24
9	0.5	-39	1,793	504,868	9,702,767	0.18
10	0.5	-25	555	504,874	9,704,171	0.14
11	0.5	-23	789	504,863	9,704,649	0.12
12	0.5	-27	896	504,847	9,704,879	0.11
13	0.5	-22	604	504,829	9,704,704	0.10

Table 0-14 – Test 7: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	3,024	3,010	69,093	67,764	-0.107
	Commute	17,134	16,852	278,020	268,698	-0.187
	Other	13,261	13,124	134,844	127,483	-0.308
	Car	**33,420**	**32,986**	**481,957**	**463,946**	**-0.209**
Inter-Peak	Business	2,556	2,543	62,810	61,851	-0.084
	Commute	3,004	2,969	41,801	40,632	-0.156
	Other	16,326	16,043	212,922	196,114	-0.451
	Car	**21,886**	**21,555**	**317,532**	**298,597**	**-0.337**
PM Peak	Business	2,848	2,838	85,601	83,905	-0.110
	Commute	13,018	12,779	224,750	216,107	-0.215
	Other	12,992	12,846	177,761	165,749	-0.384
	Car	**28,859**	**28,462**	**488,112**	**465,761**	**-0.257**
24-Hours	Business	34,162	34,003	871,111	855,857	-0.097
	Commute	108,385	106,623	1,753,326	1,692,757	-0.193
	Other	185,116	182,409	2,328,917	2,160,622	-0.411
	Car	**327,664**	**323,035**	**4,953,354**	**4,709,236**	**-0.277**

Table 0-15 – Test 8: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	317	419,661	509,023	10,935,023	10.84
2	0.5	535	611,935	490,660	9,480,067	0

Table 0-16 – Test 8: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	3,024	2,825	69,093	56,721	-0.374
	Commute	17,134	16,253	278,020	250,982	-0.290
	Other	13,261	12,435	134,844	110,059	-0.353
	Car	**33,420**	**31,513**	**481,957**	**417,761**	**-0.322**
Inter-Peak	Business	2,556	2,363	62,810	51,608	-0.430
	Commute	3,004	2,905	41,801	39,275	-0.182
	Other	16,326	15,387	212,922	172,706	-0.325
	Car	**21,886**	**20,656**	**317,532**	**263,589**	**-0.317**
PM Peak	Business	2,848	2,605	85,601	68,959	-0.489
	Commute	13,018	12,109	224,750	198,568	-0.397
	Other	12,992	11,931	177,761	134,613	-0.467
	Car	**28,859**	**26,646**	**488,112**	**402,141**	**-0.438**
24-Hours	Business	34,162	31,585	871,111	711,492	-0.430
	Commute	108,385	102,466	1,753,326	1,580,031	-0.308
	Other	185,116	173,345	2,328,917	1,862,350	-0.360
	Car	**327,664**	**307,396**	**4,953,354**	**4,153,873**	**-0.350**

Appendix B – Forecasting Convergence

Table 0-1 – Convergence Summary – Core Scenario – DM2018

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	1,085	989,120	523,532	9,788,037	7.44
2	0.5	567	491,656	524,920	9,875,662	3.89
3	0.5	279	108,024	525,144	9,860,637	1.91
4	0.5	142	26,273	525,496	9,865,092	0.94
5	0.5	74	5,833	525,669	9,865,055	0.48
6	0.5	36	2,008	525,786	9,866,363	0.31
7	0.5	-34	1,014	525,864	9,870,263	0.20
8	0.5	-82	3,586	525,890	9,871,785	0.15
9	0.5	-10	183	525,897	9,872,158	0.11
10	0.5	11	201	525,905	9,872,400	0.10
11	0.5	11	127	525,908	9,872,742	0.07

Table 0-2 – Convergence Summary – Core Scenario – DM2033

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	965	2,049,203	568,027	12,136,455	15.81
2	0.5	517	494,603	563,464	11,547,542	6.50
3	0.5	274	118,279	563,247	11,452,779	3.27
4	0.5	143	31,435	563,466	11,443,808	1.59
5	0.5	-37	5,430	563,569	11,438,204	0.78
6	0.5	-26	2,949	563,631	11,437,168	0.49
7	0.5	-48	1,924	563,650	11,435,673	0.32
8	0.5	-16	646	563,654	11,433,921	0.21
9	0.5	-34	1,617	563,663	11,436,737	0.27
10	0.5	-21	501	563,628	11,435,159	0.19
11	0.5	-13	226	563,616	11,434,461	0.12
12	0.5	-8	140	563,618	11,433,852	0.11
13	0.5	-11	187	563,626	11,433,801	0.10
14	0.5	9	158	563,634	11,432,705	0.09

Table 0-3 – Convergence Summary – Core Scenario – DS2018

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	1,244	1,703,039	523,532	9,519,127	12.18
2	0.5	603	407,012	528,520	9,834,838	5.30
3	0.5	298	112,127	529,755	9,911,636	2.64
4	0.5	145	23,669	530,034	9,914,155	1.29
5	0.5	70	6,051	530,207	9,915,047	0.68
6	0.5	34	1,713	530,324	9,917,772	0.37
7	0.5	22	905	530,388	9,920,135	0.27
8	0.5	17	441	530,416	9,921,053	0.23
9	0.5	13	349	530,426	9,920,929	0.18
10	0.5	10	256	530,431	9,920,723	0.15
11	0.5	8	116	530,431	9,920,303	0.12
12	0.5	-11	154	530,430	9,920,643	0.11
13	0.5	-7	102	530,422	9,920,102	0.09

Table 0-4 – Convergence Summary – Core Scenario – DS2033

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	1,177	2,900,515	568,027	11,731,025	16.74
2	0.5	523	567,223	567,985	11,585,508	7.11
3	0.5	301	176,422	567,827	11,496,596	3.54
4	0.5	149	35,968	568,052	11,499,379	1.68
5	0.5	74	12,793	568,078	11,495,919	1.01
6	0.5	-58	5,851	568,050	11,490,176	0.66
7	0.5	24	1,892	568,030	11,486,377	0.36
8	0.5	35	1,192	568,025	11,482,405	0.23
9	0.5	26	673	568,042	11,482,003	0.17
10	0.5	16	432	568,057	11,481,417	0.15
11	0.5	7	181	568,072	11,481,421	0.12
12	0.5	9	155	568,082	11,481,841	0.11
13	0.5	11	240	568,085	11,481,910	0.10