Norfolk County Council

GREAT YARMOUTH THIRD RIVER CROSSING

Variable Demand Model Report

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WSP

8 First Street
Manchester
M15 4RP

Phone: +44 161 200 5000

WSP.com

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Date	21/09/2020			
Prepared by	Colin Wright			
Checked by				
Authorised by	Joanna Lyon			
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1. INTRODUCTION

1.1. BACKGROUND

1.1.1. Mouchel (now part of WSP) was appointed by Norfolk County Council (NCC) to evaluate the impact of construction of a new crossing of the River Yare downstream of the two existing crossings in Great Yarmouth. To inform the Outline Business Case (OBC) a SATURN highway model and CUBE demand model of Great Yarmouth was developed in 2017 with a base year of 2016. The base SATURN model has subsequently been updated to 2018 and the demand model recalibrated for the Development Consent Order (DCO) submission.

1.2. GREAT YARMOUTH VARIABLE DEMAND MODEL

1.2.1. The Great Yarmouth Variable Demand Model (GYVDM) is designed to respond to policy changes in the Great Yarmouth Traffic Model (GYTM) (network distance and time costs, and other external costs i.e. fuel costs). The GYVDM applies a functional algorithm to the generalised costs output from the assignment models. This applies calibrated responses and updates travel demand in balance with supply. The balanced demand is applied for subsequent traffic assignments, including economic evaluation.

1.2.2. The GYVDM needed to be recalibrated following the updates to the base SATURN model and allowing for changes to the value of time. This report supersedes the variable demand model report submitted for the OBC[1].

1.3. STRUCTURE OF THE REPORT

1.3.1. This report describes the development and calibration of the GYVDM 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 GY Base Model
- Chapter 6 – Application of VDM for GY Forecasting; and
- Chapter 7 – Summary

[1] Great Yarmouth Third River Crossing OBC Supporting Document 6 https://www.norfolk.gov.uk/roads-and-transport/major-projects-and-improvement-plans/great-yarmouth/third-river-crossing/further-information-and-documents/outline-business-case-submission

2. THE NEED FOR VARIABLE DEMAND MODELLING

2.1. BACKGROUND

2.1.1. This chapter describes the need for and scope of Variable demand modelling to support the appraisal of the Great Yarmouth Third River Crossing (GYTRC) proposed scheme.

2.1.2. The GYVDM 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 important for producing realistic future forecasts for "with scheme" and "without scheme" which reflect traveller responses to changes in congestion, fuel costs and network availability.

2.2. THE NEED FOR VARIABLE DEMAND MODELLING

2.2.1. WebTAG[2] states that, any change to transport conditions will, in principle, cause a change in the demand for travel. The purpose of variable demand modelling is to predict and quantify these changes. It is of the key importance to establish a realistic scenario in the absence of and with the inclusion of the proposed scheme or strategy.

2.2.2. WebTAG[3] suggests that fixed demand assessments may be acceptable in a limited number of circumstances. However, the context of the GYTRC indicates the need for 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 currently significant traffic congestion in the base year and also in the forecast year networks; however
- The scheme might be expected to have a minor effect on competition between private and public transport in the corridor.

2.3. AREA OF INFLUENCE

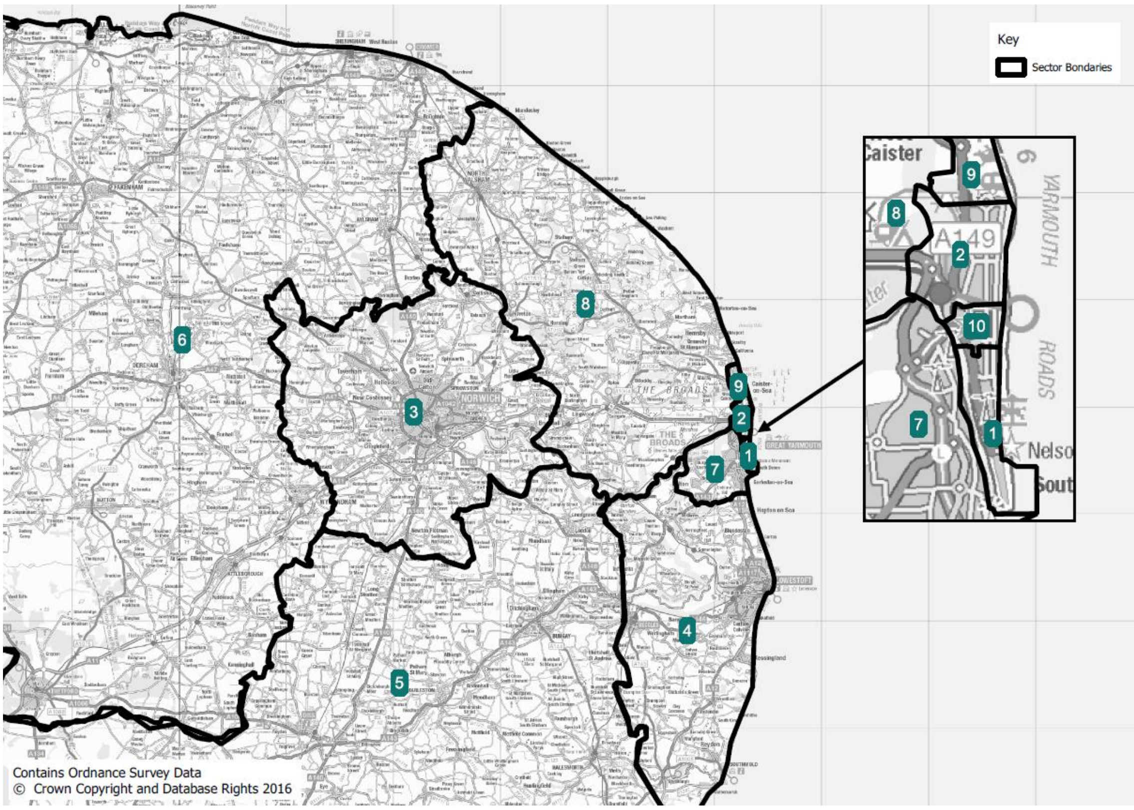
2.3.1. The area of influence was determined using the current version of the SATURN highway assignment models to identify the area over which traffic flows may change when the GYTRC scheme is introduced.

2.3.2. The area of influence is the part of the model for which most attention has been placed on network coding, density and validation. This area includes the Great Yarmouth local authority to Caister-on-Sea to the north, Acle to the west, and Lowestoft to the south. Beyond this area, network coding and demand representation extends with decreasing level of detail. Figure 1 below provides the area of influence of the model.

[2] WebTAG M2 (March 2017), paragraphs 1.1.2 and 1.1.3

[3] WebTAG M2 (March 2017), section 2.2

Figure 1 - Area of Influence



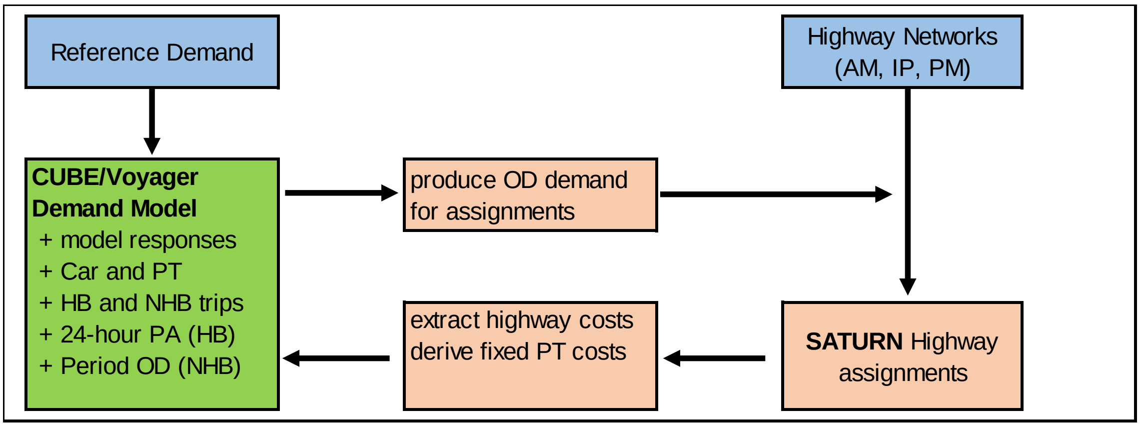
2.3.3. The remainder of this report provides detail on the model developed to address the VDM requirement and details the outputs resulting from the recalibration of the VDM based on the revised 2018 base model and updated VoT.

3. VARIABLE DEMAND MODEL STRUCTURE

3.1. STRUCTURE OVERVIEW

3.1.1. The GYVDM model operates using a bespoke zonal based Variable Demand Model and three peak hour SATURN highway assignment models (AM Peak, Average Inter Peak, PM Peak), aggregated to daily volumes for operation across certain travel responses. The GYVDM model structure is shown in Figure 2 below.

Figure 2 - GYVDM Model Structure



3.1.2. The demand model was developed using a combination of two software platforms, SATURN for the highway assignment models and CUBE VOYAGER for the bespoke demand models. The functions of the respective software platforms are as follows:

- SATURN 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;
- The cost skims from the SATURN highway assignments were also used to derive a fixed cost function to represent public transport costs as per WebTAG M2 guidance;
- 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 SATURN to assign and generate new costs. The process is iterated until stable convergence solution is reached.

3.2. FORM OF MODELS

3.2.1. According to WebTAG[4], 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;

[4] WebTAG M2 (March 2017), section 4.3

- 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.

3.2.2. GYVDM employs a pivot-point model. This employs incremental cost change to derive changes in demand from a reference trip matrix (i.e. forecast demand matrix prior to adjustment by travel cost).

3.2.3. The change in generalised costs is produced by calculating the difference between the 'Pivot-Point Cost' (from the 2018 Base year validated model) and 'reference costs' from assignment of the matrix to be adjusted. The costs are composite (inclusive of all perceived elements) and are calculated for each level of the choice hierarchy to reflect the choice made at a lower level in the hierarchy.

3.3. HIERARCHY OF CHOICE RESPONSES

3.3.1. WebTAG[5] describes the main choice response mechanisms and their hierarchical orders that may be considered in variable demand models as below:

- Trip frequency;
- Mode choice;
- Time of day choice (macro and/or micro time period choice);
- Destination choice (trip distribution); and
- Route choice (assignments)

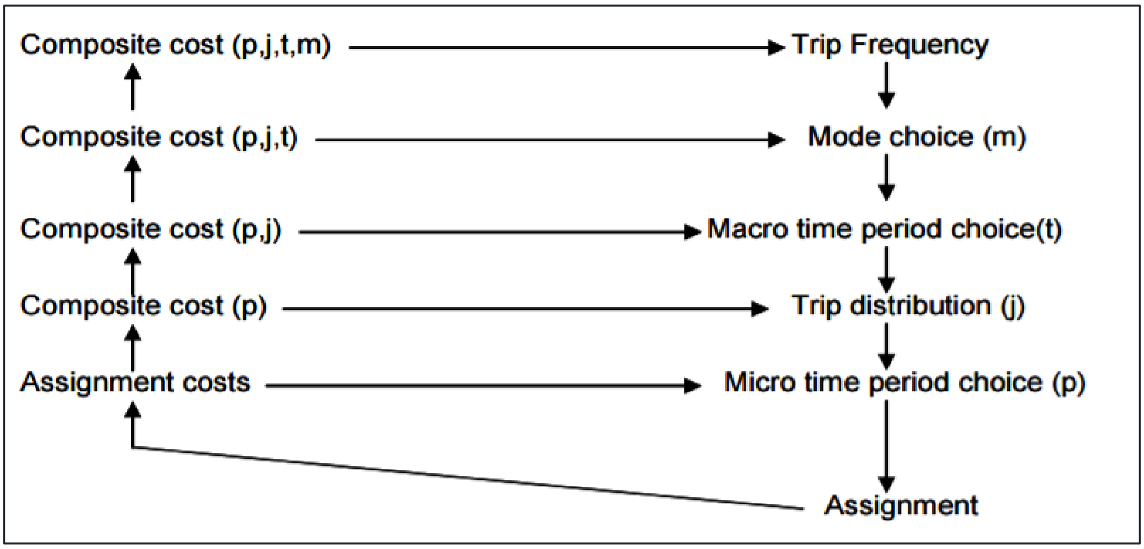
3.3.2. A choice mechanism placed higher in the hierarchy should reflect the composite costs of choices lower in the hierarchy.

3.3.3. The model adopts a looping procedure to achieve stability. During each cycle, the composite costs must be calculated for each level in the hierarchy, since each level requires combinations of cost in relation to choices made lower in the hierarchy. In the hierarchy, the composite cost calculation weights costs by choices made according to the parameters used. Choice calculations are then made down the hierarchy and the whole cycle is recalculated until an acceptable degree of convergence is achieved. A typical choice hierarchy with associated cost transfers is illustrated in Figure 3 below.

3.3.4. In the subsequent sections the individual choice mechanisms are considered in turn and relevance to Great Yarmouth are reviewed.

[5] WebTAG M2 (March 2017), section 4.5

Figure 3 - Typical Choice Hierarchy with Associated Cost Transfers



Trip Frequency

3.3.5. Trip frequency models represent the response of trips to changes in generalised costs. This is district from trip generation, which estimates trips based on the demographic and socio-economic characteristics of an area.

3.3.6. WebTAG[6] states that where the active modes of walk and cycle are not explicitly included in the demand model, trips frequency may be thought of as, mainly, the transfer between the active modes and the mechanised modes. Otherwise, overall trip rates will be fairly stable and will often not need to model the response of trip frequency.

3.3.7. There will not normally be a requirement to model trip frequency for doubly-constrained trips such as commuting, since the constraints on total travel are usually assumed to be binding, since employment is assumed to be fixed. This implication however does not hold if active mode has been omitted and they are likely to form a significant percentage of commuting trips, and/or the planned intervention will result in a significant impact on active mode users.

Mode Choice

3.3.8. WebTAG[7] states that it is almost always desirable to include some representation of modal choice in variable demand modelling, but the level of detail depends upon the importance attached to it. It may be acceptable to include the alternative modes merely as a set of fixed costs, but it may be necessary to model the journey components in detail, for example, the effect of changing road conditions of bus travel times.

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[6] WebTAG M2 (March 2017), Section 4.6

[7] WebTAG M2 (March 2017), Section 4.7

3.3.9. If there is little real competition between private and public transport and public transport is not a key focus of the intervention being tested, the public transport generalised costs estimates can be made with limited precision.

3.3.10. Where active modes are omitted, trip frequency elasticities should be stronger, since they have to represent the effect of active modal transfer.

Time of Day Choice

3.3.11. There are two distinctly different aspects of time of day choice; these are a) macro time choice; and b) micro time choice.

3.3.12. Macro time choice involves in the transfer of trips between broad time periods that should only be considered when strong cost differentials between time periods are expected to develop or change. This is obviously the case where different charges are introduced for use of a road, rail or bus services in the peak and inter-peak period.

3.3.13. Micro time period (or peak spreading) involves in reallocation of trips between the peak hour and the shoulders if severe congestion occurs during the peak hour.

3.3.14. Time choice is often relevant for longer journeys (where active mode is not a viable choice) and for journeys involving networks which are significantly over capacity for extended periods.

Destination Choice

3.3.15. Destination choice involves in the transfer of trips between different destinations as a result of change in travel costs and can be applied in terms of zonal production and attraction or origin and destination trip totals.

3.3.16. It is common to use doubly-constrained models for forecasting commuting and education trips, so that each zone attracts and generates a fixed total of work trip ends; and singly-constrained models for other purposes such as business and other, where only the total number of trips generated in each zone is fixed.

3.3.17. The response is modelled to reflect the long-term impact of cost change and is considered critical to the function of most VDM systems.

Route Choice (Assignment)

3.3.18. A variable demand model includes an assignment stage to provide travel cost information to the demand model. The assignment must be adequately converged, particularly since this is necessary to achieve a good level of convergence between the assignment model and the demand model.

Application of choice responses and hierarchy for GY3VDM

3.3.19. Local knowledge shows that the pattern of traffic seems consistent across the day with little or no clear indication of people switching between time periods or between peak and shoulders within neutral traffic periods. Furthermore, currently there is limited evidence on modelling time choice without sufficient local data to calibrate. Therefore, time choice responses (both macro and micro time choice) was excluded from the choice responses for the GY3VDM.

3.3.20. Great Yarmouth is primarily a car based travel market. Of motorised travel bus accounts for around 3.5% of commuter travel, lower than the England average of 4.7%. Whilst peak public transport flows will be higher, PT use has declined since 2011[8]. In addition, other trip purposes often make greater use of car.

3.3.21. WebTAG[9] states that the use of fixed public transport costs will suffice unless public transport alternatives need to be assessed as part of the scheme appraisal. On that basis, an incremental hierarchical logit choice model has been developed for the GYTM to represent the two model responses, in the order of hierarchy, as below:

- Frequency choice (optional);
- Mode choice;
- Destination choice; and
- Traffic assignment.

WebTAG[10] guidance states that when specifying an incremental hierarchical model, scaling parameters (thetas) that refers to the probability of nests of alternatives or composite alternatives, reflect the ratios of the lambdas for different responses 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.

Since the destination choice is at the bottom of the demand hierarchy, sensitivity is provided by the parameters

- λ (lamda) for destination choice:

then via (theta) scaling parameters of

- θmode; and
- θfreq

for mode choice and frequency choice respectively in calculation of composite costs from the lower level of the hierarchy.

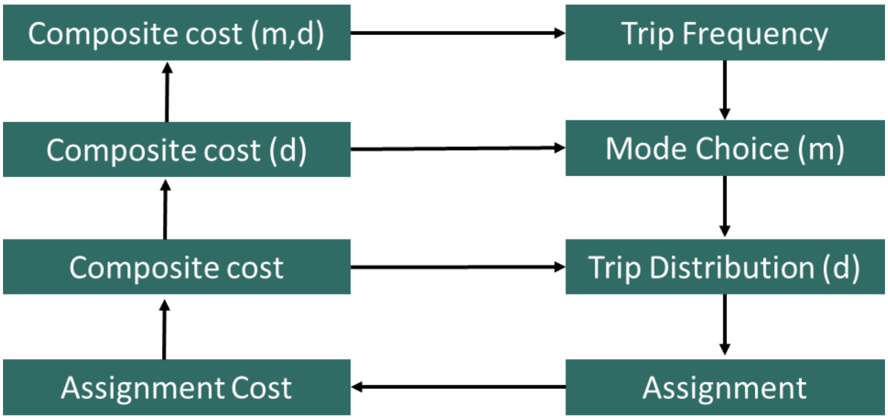
The cost matrices, supplied by the Great Yarmouth SATURN highway models, provide origin/destination generalised costs by time period trip purpose, and mode. The cost matrices and **θ, λ** parameters determine the level of sensitivity in order to forecast a new trip matrix, based on a change in generalised costs. The hierarchy of the demand model is illustrated in the Figure 4 below.

[8] https://www.gov.uk/government/collections/bus-statistics

[9] WebTAG M2 (March 2017), section 4.7

[10] WebATG M2 (March 2017), Appendix E Incremental Model Formulation

Figure 4 - Choice Responses and Hierarchy Adopted for GY3VDM



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:

- 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:

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

Detail of the incremental model formulation that was applied for the GYVDM is provided in Chapter 5.

3.4. MATRIX FORMS AND DEMAND SEGMENTATION

Production Attraction

3.4.1. WebTAG M2 recommends that for variable demand modelling, Production/Attraction (P/A) form of matrices should be used in preference to Origin/Destination (O/D) form and expected to represent an all-day model for Home-Based (HB) trips. For None Home-Based (NHB), it is satisfactory to use O/D based matrices for the purpose of variable demand modelling.

3.4.2. Production attraction format is particularly important as it enables trips to be linked to demand drivers such as population centres and employment centres, and also enables the demand modelling to take account of factors such as “destination choice” (i.e. attraction zone choice). All home-based trips are typically built in production and attraction format which means that individual trips can be identified as “outward” (“from home”: production to attraction) or “return” (“to home”: attraction to production).

3.4.3. The P/A matrices for the base year demand were constructed from the observed travel movements based on road-side interviews (RSI) in 2016 during the development of the GY3 base year model. The RSI data provides information of return trip time by trip purpose. The information obtained from the RSI data was applied to the O/D validated base year matrices to derive a P/A form of demand.

3.4.4. Where no data was available from the RSI database (in the case of infill movements from other sources of movement data), the default purpose split and from Home/to Home proportional split was obtained from the National Transport Survey (NTS), focussed on non-metropolitan areas.

Demand Segmentation

3.4.5. 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 row and column of the base P/A matrices at an all-day level to reflect expected land-use and car ownership changes (travel demand in the absence of cost change).

3.4.6. Six journey purposes were constructed for the GYVDM demand model, in which HB trips operate at 24-hours PA format, and NHB trips operate at time period OD format. Each of 6 journey purposes correspond to the relevant user classes for the SATURN highway assignments, as shown in Table 1 below.

Table 1 - GYVDM Purposes to Assignment User Classes

No	Assignment User Classes	GYVDM Journey Purposes
1	Business	HB Business (24Hr PA)
1	Business	NHB Business (Period OD)
2	Commuting	HB Commuting (24Hr PA)
3	Other	HB Education (24Hr PA)
3	Other	HB Other (24Hr PA)
3	Other	NHB Other (Period OD)
4	LGV	LGV (assignment only)
5	HGV	HGV (assignment only)

3.4.7. During the demand modelling process, trip matrices must be converted from P/A to O/D for the purpose of highway assignment.

3.5. ALLOCATION TO TIME PERIODS

3.5.1. The GYVDM demand model operates at the 24-hours PA level for the HB trips and at hourly OD level for NHB trips. The outward and return proportions of trips are based on the original data in the 2006 model. The SATURN highway assignment models represent 3 individual peak hours with O/D matrices allocated as follows.

- AM Peak Hour (8:00-9:00) representing AM Period (07:00-10:00);
- Inter Peak Average Hour (10:00-15:30); and
- PM Peak Hour (16:30-17:30) representing PM period (15:30-18:30)

3.5.2. To facilitate this P/A to O/D conversion was conducted and is explained in the next chapter.

3.6. SINGLY OR DOUBLY CONSTRAINED

3.6.1. A doubly-constrained choice model, matching both productions and attractions, is applied to HB commuting and HB Education purposes, as per DfT guidance, since confidence can also be placed on the absolute level of attractions.

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

3.6.3. 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

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

4.1.2. CUBE determines the new demand forecast matrix utilising the skim cost matrices provided by SATURN 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.

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

4.2. CONVERSION BETWEEN P/A AND O/D

4.2.1. 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[11] it is essential that the demand and assignment models are correctly integrated, with consistent cost definitions and appropriate conversion between the P/A demand model matrices and the assignment O/D matrices.

Demand Matrices

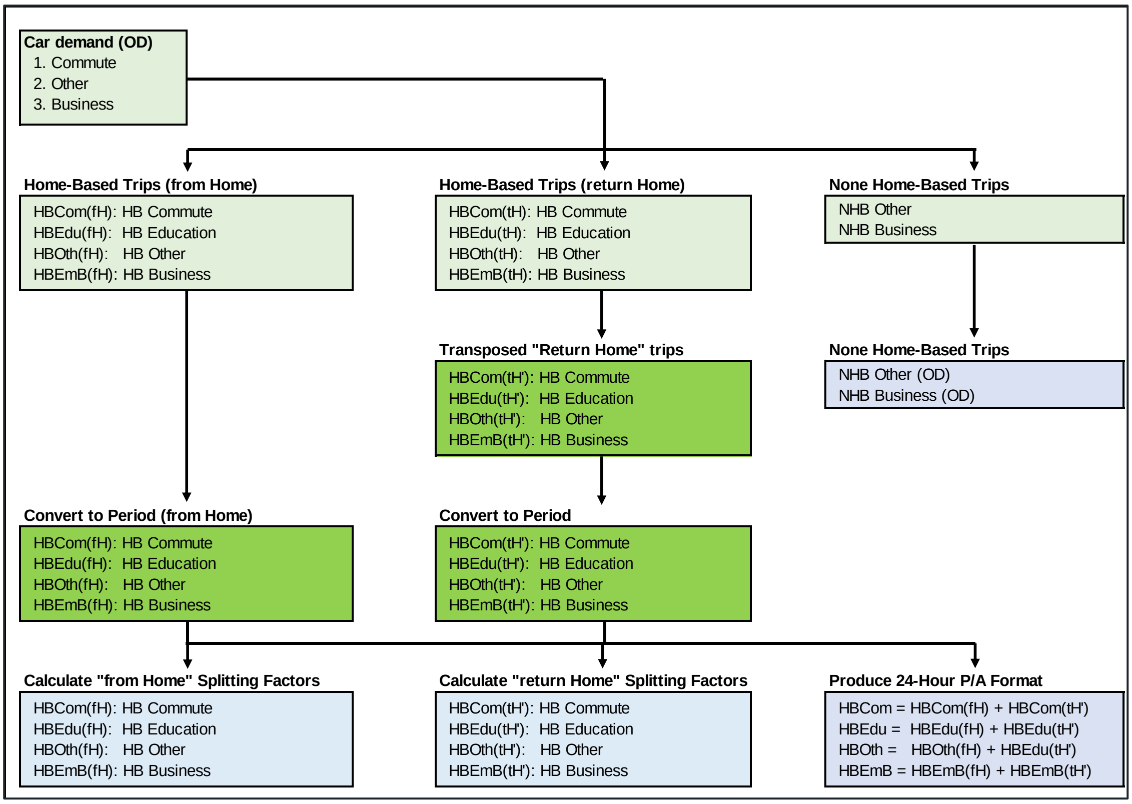
4.2.2. This section describes in more detail the process of constructing the demand matrices in P/A format and conversion from P/A to O/D for the purpose of the assignments. The process involves the following steps:

- 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.

4.2.3. The process of converting O/D period car demand to 24-hour P/A format is provided in Figure 5 below.

[11] WebTAG M2 (March 2017), para 4.4.1

Figure 5 - Conversion of O/D Period Demand to 24-Hour P/A Format



4.2.4. 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.

4.2.5. According to WebTAG[12], if no assignment matrix is in existence, then the first step should be to establish if, on conversion to O/D, the derived base P/A matrices can 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 no change has occurred during the conversion process. This is to minimise the noise during the demand model that would cause the demand model not to produce realistic estimation of forecast demand.

Cost Matrices

4.2.6. 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:

[12] WebTAG M2 (March 2017), Appendix B.1.8

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

Where:

- $GC^{OD}_{t.ij}, GC^{OD.T}_{t.ij}$ 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.

4.3. INCREMENTAL MODELLING

4.3.1. The highway assignment model was calibrated to a base year of 2016 and adheres to the most recent WebTAG calibration criteria. The impact of updated values of time was assessed within the process.

4.3.2. As mentioned in the previous chapter, the GYVDM adopts a Pivot-Point mechanism with incremental cost change from the validated base year model 2016 driving demand choices, with three distinct applications evident:

- 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 external to the area of influence and LGV, HGV.

4.4. CALCULATION OF INCREMENTAL CHANGE IN DEMAND

4.4.1. 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:

- $-\lambda_{dest,mc}$ is the destination choice parameters for mode m and person type c;
- $GC^{0}_{ijmtpc}, GC^{1}_{ijmtpc}$ 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

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

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

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

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

4.4.4. 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:

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

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

Composite Utilities

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

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

4.4.7. And for the Mode choice is calculated:

$$\Delta U^*_{itpc} = ln \sum_m p^0_{mitpc}\ exp\ (\theta^{mode}_c \Delta U^*_{imtpc})$$

4.4.8. With reference case probability is calculated from the input reference demand as follow:

$$\mathrm{p}^0_{\mathrm{mtpc}} = \frac{\sum_{tj} \mathrm{T}^0_{\mathrm{ijmtpc}}}{\sum_{tjm} \mathrm{T}^0_{\mathrm{ijmtpc}}}$$

Conditional Probabilities

4.4.9. Having calculated the change in the composite utilities it is possible to calculate the conditional utilities for each level of the model, for the GYVDM:

4.4.10. For destination choice:

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

4.4.11. For mode choice:

$$p_{m/itpc} = \frac{p^0_{mitpc}\ exp\ (\theta^{mode}_c \Delta U^*_{imtpc})}{\sum^N_{k=1} p^0_{kitpc}\ exp\ (\theta^{mode}_c \Delta U^*_{iktpc})}$$

Updated Trip Matrix

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

$$T_{ijmtpc} = T^0_{ipc} * p_{m/itpc} * \ p_{j/imtpc}$$

Application of Frequency Model

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

$$T_{ijmtpc} = exp\left(\theta^{freq}_c\ \Delta U^*_{ipc}\right) T^0_{ipc} * p_{m/itpc} * p_{j/imtpc}$$

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

4.4.15. 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:

- $-\lambda_{dest,mc}$ is the destination choice parameters for mode m and person type c;
- $GC^0_{ijmtpc}, GC^1_{ijmtpc}$ 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 Model

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

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

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

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

4.4.18. 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:

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

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

4.5. COST DAMPING

4.5.1. Cost damping for longer distance trips within the demand model was tested but rejected on the basis of the following:

- The base year model mainly concentrates on the Great Yarmouth district without expanding to the wider Norwich;
- Initial test without the cost damping shows that the responsiveness to the model choices with regard to change in fuel costs was not sensitive, it was therefore expected that with the cost damping included, the responses to change in travel costs would be even less sensitive in order to achieve the WebTAG elasticities; and
- Initial tests with the GYVDM also indicates that very little trips associated with long distance travelled therefore did not result in significant impact to the demand changes with respect to travel cost change.

4.6. CONVERGENCE OF DEMAND MODEL

4.6.1. The process described in Section 4.5 was carried out iteratively until a convergence solution was reached, i.e 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:

$$\frac{\sum_a C(X_a{}^n)\left|D\left(C(X_a{}^n)\right) - X_a{}^n\right|}{\sum_a C(X_a{}^n) X_a{}^n} * 100$$

Where:

$X_a{}^n$ is cell *a* in the previous assignment matrix for iteration *n*;

$C(X_a{}^n)$ is cell *a* in the generalised costs resulting from assigning that matrix

$D\left(C(X_a{}^n)\right)$ is cell *a* in the matrix output by the demand model based on costs $C(X_a{}^n)$. In models where the matrix output by the demand model is used directly as the assignment matrix (as well usually be the case in variable demand models), this will be equal to $X_a{}^{n+1}$.

a represents every combination of origin, destination, demand segment/user class, time period and mode.

4.6.2. To help searching for convergence solution, number of method were tested such as conventional method, Fixed Step Length and Method of Successive Averages (MSA). The method of Fixed Step Length was finally adopted, as provided by the formula below:

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

Where:

- a 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: $U(X^{N-1}) = D[C(X^{N-1})] - X^{N-1}$

4.7. BASE YEAR REALISM TESTS

4.7.1. Realism tests were carried out on the Base year model to make sure that the models behave “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, then the values of the parameters controlling the response demand to costs should be adjusted until an acceptable response is achieved.

4.7.2. The acceptability of the model’s response is determined by the demand elasticity, which is calculated by changing 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, as below:

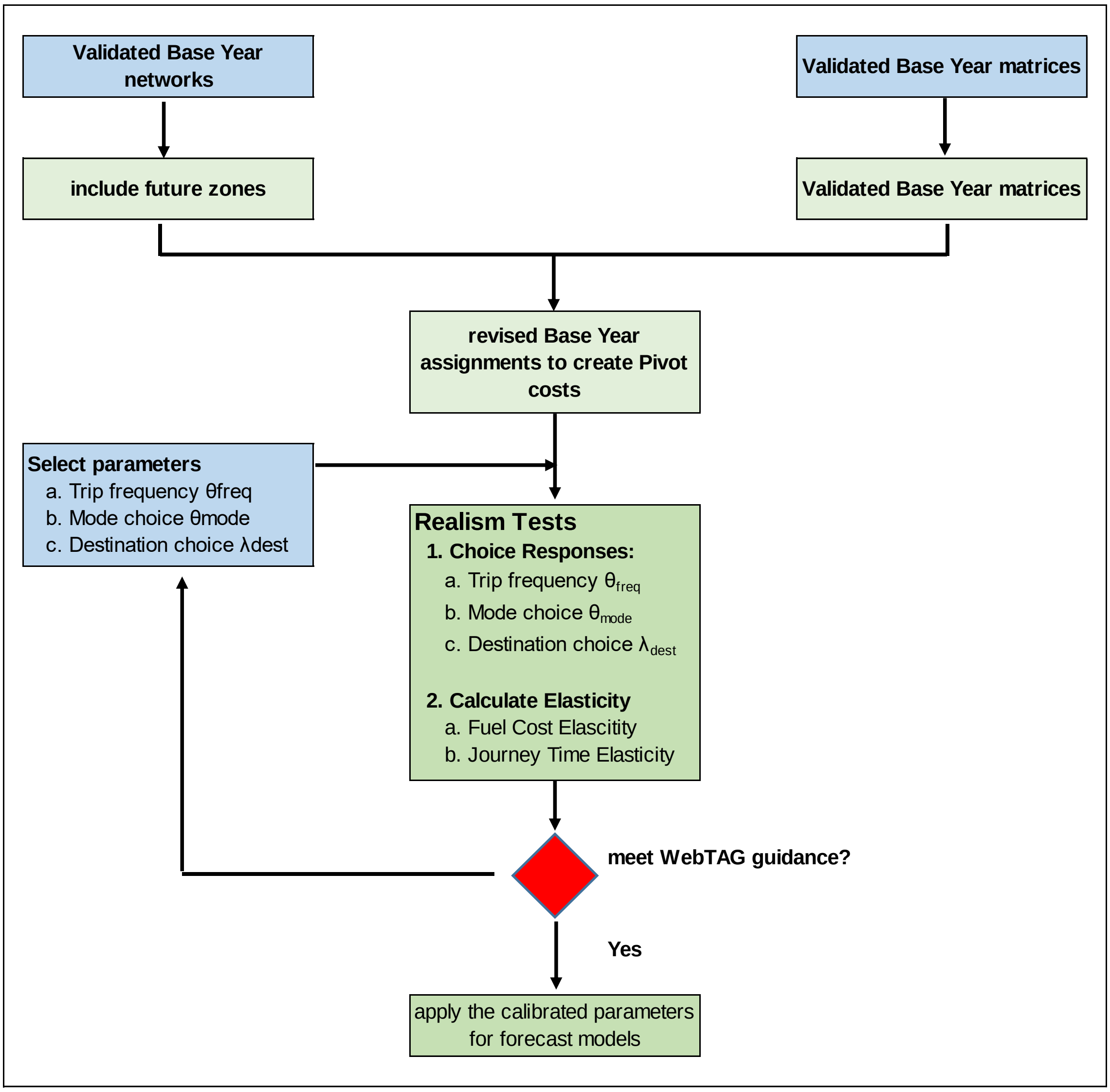
$$E = \frac{\log(T^1) - log\ (T^0)}{\log(C^1) - log\ (C^0)}$$

Where superscript 0 and 1 indicate values of demand T and cost C before and after change in costs, respectively.

4.7.3. The process of carrying out the realism tests for the base year model is provided in the Figure 7 overleaf.

4.7.4. According to WebTAG M2, there are three tests are required to be carried out to ensure that the models behave “realistically”, which is:

Figure 6 - *Realism Test Process*



Car Fuel Cost Elasticity

4.7.5. Car Fuel Cost Elasticity tests the change in car vehicle-kms travelled with respect to change in fuel prices. For the tests, the following was adopted for the GYVDM 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.kms 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

4.7.6. Elasticity calculated from model runs should be on average ≈ -0.3 for car with lower elasticity for employer's business ≈ -0.1 and higher elasticity ≈ -0.4 for discretionary trips. Commuting trips should reflect an intermediate value.

Car Journey Time Elasticity

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

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

4.7.8. The output elasticity with respect to car journey time increase should not produce high values more than -2.0.

Public Transport Fares

4.7.9. The GYVDM is primarily a highway models without an active public transport assignment model. The element of the public transport mode choice was mainly derived from the highway costs to reflect the impact of potential diversion to and from highway. Given the lack of full sensitivity the realism tests for public transport fares were excluded.

5. REALISM TESTS FOR 2018 GY BASE MODEL

5.1. BACKGROUND

5.1.1. This chapter presents the results of the recalibration of the GYVDM base year demand model following the updates to 2018 SATURN base highway model and changes in the value of time. Following the construction of the original demand model, a series of tests were undertaken to ensure that it functions realistically. These tests involve changing the components of travel and monitoring the overall demand responses, and where repeated for the updated demand model. 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.

5.1.2. 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, in line with a review of European metadata on this topic. These values were used as elasticity targets in the process of the choice model calibration.

5.2. GENERALISED COSTS

5.2.1. Generalised costs determine travel choices based on a combination of travel time and operating costs, generalised to a unit of time for the purpose of demand modelling.

5.2.2. For car, generalised cost per vehicle is calculated using the formula:

$$GCost_{car} = Time_{Walk} * Weight_{Walk} + Time_{Car} + \frac{Dist_{Car} * VOC}{Occ * VoT} + \frac{Parking\ Cost}{Occ * VoT}$$

Where:

- Timewalk is total walking time from and to the car;
- Weightwalk is the weight to be applied to walking time;
- TimeCar is journey time spent in the car;
- VOC is the vehicle operating costs per kilometre of a journey of Dist km;
- DistCar is the travel distance by car;
- Occ is the number of people in the car (varied by purpose); and
- VOT is the value of time (varied by purpose).

The model also includes fixed costs for public transport in order to represent “passive” mode choice responses within the demand model. The generalised costs adopted for the public transport is calculated using the formula below:

$$GCost_{PT} = Time_{Walk} * Weight_{Walk} + Time_{wait} * Weight_{wait} + Time_{PT} + \frac{Fare_{PT}}{VoT}$$

Where:

- $Time_{walk/wait}$ is total walking time from and to the service or waiting time;
- $Weight_{walk/wait}$ is the weight to be applied to walking/waiting time;
- TimePT is journey time spent in public transport service. For the purpose of the PT modelling, it is assumed that Time spent in the public transport is the same as travel time made by car;

- FarePT is the public transport fare. For the purpose of deriving the fixed costs for the PT model, Fare is assumed to increase over distance travel using the formula $Fare = Boarding\ charge + Fare\ per\ Km * Distance\ travelled$
- VOT is the value of time (varied by purpose).

5.3. GENERALISED COST PARAMETERS

5.3.1. The recalibration of the GYVDM demand model was tested using the updated 2018 Base year validated demand matrices, with the following parameters, consistent with the WebTAG guidance. Tables 2 to 7 provide parameters required to carry out Realism tests. While the highway generalised cost for distance travelled remains consistent with 2016 values, the value of time has changed considerably with a significant reduction in the cost for the business user class and increase for the commute user class. Similarly, the PT generalised cost for time has reduced significantly for the business user class but increased for the commute user class.

Table 2 - Highway Generalised Costs – Pivot Point (Base Year 2018)

	Pence Per Minute	Pence Per Minute	Pence Per Minute	Pence Per Kilometre	Pence Per Kilometre	Pence Per Kilometre
User Class	**AM**	**IP**	**PM**	**AM**	**IP**	**PM**
Business	30.72	31.48	31.17	12.26	12.26	12.26
Commute	20.60	20.94	20.68	5.75	5.75	5.75
Other	14.22	15.14	14.89	5.75	5.75	5.75

Table 3 - Highway Generalised Costs – with 20% Increase in Fuel Costs

	Pence Per Minute	Pence Per Minute	Pence Per Minute	Pence Per Kilometre	Pence Per Kilometre	Pence Per Kilometre
User Class	**AM**	**IP**	**PM**	**AM**	**IP**	**PM**
Business	30.72	31.48	31.17	13.21	13.21	13.21
Commute	20.60	20.94	20.68	6.90	6.90	6.90
Other	14.22	15.14	14.89	6.90	6.90	6.90

Table 4 - PT Generalised Costs – Pivot Point (Base Year 2018)

	Pence Per Minute	Pence Per Minute	Pence Per Minute
User Class	**AM**	**IP**	**PM**
Business	15.40	15.40	15.40
Commute	18.19	18.19	18.19
Other	8.30	8.30	8.30

Table 5 - Car Occupancy - Base Year 2018

User Class	AM Period	Inter-Peak	PM Period	Off-Peak
Business	1.131	1.159	1.147	1.169
Commute	1.132	1.151	1.136	1.153
Other	1.712	1.823	1.793	1.786

Table 6 - Reference Case Matrix Totals (persons) - Base Year 2018

PURPOSE	FORMAT	AM PERIOD	IP PERIOD	PM PERIOD	OP PERIOD	24HR TOTAL
HB Commute (PA)	from Home	6,566	2,698	1,113	2,885	**13,262**
HB Commute (PA)	return Home	597	2,507	4,901	1,940	**9,945**
HB Commute (PA)	**Total**	**7,163**	**5,205**	**6,014**	**4,825**	**23,207**
HB Education (PA)	from Home	866	1,326	747	586	**3,525**
HB Education (PA)	return Home	340	1,874	4,324	1,478	**8,016**
HB Education (PA)	**Total**	**1,206**	**3,200**	**5,071**	**2,065**	**11,541**
HB Other (PA)	from Home	11,340	18,063	5,311	4,758	**39,472**
HB Other (PA)	return Home	3,401	20,647	11,738	10,332	**46,118**
HB Other (PA)	**Total**	**14,741**	**38,710**	**17,049**	**15,090**	**85,590**
HB Business (PA)	from Home	683	488	125	301	**1,596**
HB Business (PA)	return Home	68	584	551	321	**1,524**
HB Business (PA)	**Total**	**750**	**1,072**	**676**	**622**	**3,120**
NHB Other (OD)	Total	5,995	23,099	13,866	10,204	**53,164**
NHB Business (OD)	Total	995	4,092	1,388	1,570	**8,046**

5.4. FUEL COST ELASTICITY

5.4.1. For the 2016 GYVDM calibration, tests were carried out with differing 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. These tests were run again for the recalibration of the 2018 GYVDM.

5.4.2. The first three tests were carried out with trip frequency response omitted, for minimum, median, and maximum sets of destination choice lambda values. This was to define the model's elasticity response to fuel costs. Table 7 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.

5.4.3. The results from the updated tests show that as was the case previously, it was not possible to achieve the recommended elasticity set out by the WebTAG guidance without trip frequency responses. Table 7 shows that the outturn elasticity for Business is higher than -0.1 (for the median and maximum values) as recommended by the DfT, while the elasticity for commute is lower than recommended range. This is expected given the geographical location and nature of the study area:

- Limited number of employment locations and access routes available. Example is A47 to Norwich, A47, A143 to the south and A149 to the north. This results in less sensitivity to change in fuel costs for commuting;
- The relative proportions of other trip purposes (for example tourism) are somewhat higher than average, and commuting is somewhat lower. As a smaller segment this make commuting potentially less sensitive to costs driven demand change.

5.4.4. In order to meet the overall elasticity for car of between -0.25 to -0.35 as recommended by the DfT, either the destination choice λ parameters needs to be increased significantly to outside the minimum-maximum range, or the order of magnitude of the outturn elasticity for business and commuting would not be in line with the DfT guidance.

5.4.5. Since the model is the highway-only model with a form of fixed costs for public transport, and slow mode was not explicitly included in the demand model, the trip frequency was therefore included to represent the transfer from car to slow mode and vice versa within the study area.

Table 7 - Car Fuel Elasticity without Frequency Choice

Test	Purpose	Purpose	Freq	Mode	Dest	AM	IP	PM	24-Hour	Gap (%)
1 - min	HBEB	Business	0.00	0.36	0.038	-0.088	-0.091	-0.076	-0.086	
1 - min	NHBEB	Business	0.00	0.73	0.069	-0.088	-0.091	-0.076	-0.086	
1 - min	HBW	Commute	0.00	0.5	0.054	-0.025	-0.03	-0.027	-0.027	
1 - min	HBED	Other	0.00	0.27	0.074	-0.231	-0.252	-0.205	-0.235	
1 - min	HBO	Other	0.00	0.27	0.074	-0.231	-0.252	-0.205	-0.235	
1 - min	NHBED	Other	0.00	0.62	0.073	-0.231	-0.252	-0.205	-0.235	
1 - min	NHBO	Other	0.00	0.62	0.073	-0.231	-0.252	-0.205	-0.235	
1 - min	**All**	**All**				**-0.113**	**-0.181**	**-0.114**	**-0.142**	**8/ 0.026**
2 - med	HBEB	Business	0.00	0.45	0.067	-0.134	-0.117	-0.112	-0.12	
2 - med	NHBEB	Business	0.00	0.73	0.081	-0.134	-0.117	-0.112	-0.12	
2 - med	HBW	Commute	0.00	0.68	0.065	-0.036	-0.049	-0.038	-0.04	
2 - med	HBED	Other	0.00	0.53	0.09	-0.277	-0.298	-0.245	-0.279	
2 - med	HBO	Other	0.00	0.53	0.09	-0.277	-0.298	-0.245	-0.279	
2 - med	NHBED	Other	0.00	0.81	0.077	-0.277	-0.298	-0.245	-0.279	
2 - med	NHBO	Other	0.00	0.81	0.077	-0.277	-0.298	-0.245	-0.279	
2 - med	**All**	**All**				**-0.141**	**-0.219**	**-0.141**	**-0.174**	**8/ 0.031**
3- max	HBEB	Business	0.00	0.65	0.106	-0.204	-0.163	-0.166	-0.174	
3- max	NHBEB	Business	0.00	0.73	0.107	-0.204	-0.163	-0.166	-0.174	
3- max	HBW	Commute	0.00	0.83	0.113	-0.073	-0.111	-0.075	-0.084	
3- max	HBED	Other	0.00	1.00	0.16	-0.473	-0.496	-0.414	-0.469	
3- max	HBO	Other	0.00	1.00	0.16	-0.473	-0.496	-0.414	-0.469	
3- max	NHBED	Other	0.00	1.00	0.105	-0.473	-0.496	-0.414	-0.469	

3- max	NHBO	Other	0.00	1.00	0.105	-0.473	-0.496	-0.414	-0.469	
3- max	**All**	**All**				**-0.243**	**-0.365**	**-0.241**	**-0.294**	**8/0.048**

5.4.6. Further tests were therefore carried out using 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. The same trip frequency value of 0.2 for other trips was used for the updated GYVDM while an adjusted value of 0.25 was used for HBW Commute trips. Table 8 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 8 - Car Fuel Elasticity with Frequency Choice Included

Test	Purpose	Purpose	Freq	Mode	Dest	AM	IP	PM	24-Hour	Gap (%)
4 - min	HBEB	Business	0.00	0.36	0.038	-0.088	-0.091	-0.076	-0.086	
4 - min	NHBEB	Business	0.00	0.73	0.069	-0.088	-0.091	-0.076	-0.086	
4 - min	HBW	Commute	0.25	0.5	0.054	-0.082	-0.115	-0.084	-0.091	
4 - min	HBED	Other	0.20	0.27	0.074	-0.261	-0.284	-0.242	-0.268	
4 - min	HBO	Other	0.20	0.27	0.074	-0.261	-0.284	-0.242	-0.268	
4 - min	NHBED	Other	0.20	0.62	0.073	-0.261	-0.284	-0.242	-0.268	
4 - min	NHBO	Other	0.20	0.62	0.073	-0.261	-0.284	-0.242	-0.268	
4 - min	**All**	**All**				**-0.153**	**-0.221**	**-0.157**	**-0.183**	**8/ 0.028**
5 - med	HBEB	Business	0.00	0.45	0.067	-0.135	-0.117	-0.111	-0.12	
5 - med	NHBEB	Business	0.00	0.73	0.081	-0.135	-0.117	-0.111	-0.12	
5 - med	HBW	Commute	0.25	0.68	0.065	-0.127	-0.185	-0.131	-0.144	
5 - med	HBED	Other	0.20	0.53	0.09	-0.339	-0.362	-0.314	-0.344	
5 - med	HBO	Other	0.20	0.53	0.09	-0.339	-0.362	-0.314	-0.344	
5 - med	NHBED	Other	0.20	0.81	0.077	-0.339	-0.362	-0.314	-0.344	
5 - med	NHBO	Other	0.20	0.81	0.077	-0.339	-0.362	-0.314	-0.344	
5 - med	**All**	**All**				**-0.212**	**-0.29**	**-0.215**	**-0.246**	**8/ 0.035**
6 - max	HBEB	Business	0.00	0.65	0.106	-0.207	-0.165	-0.167	-0.175	
6 - max	NHBEB	Business	0.00	0.73	0.107	-0.207	-0.165	-0.167	-0.175	
6 - max	HBW	Commute	0.25	0.83	0.113	-0.253	-0.38	-0.256	-0.287	
6 - max	HBED	Other	0.20	1.00	0.16	-0.657	-0.676	-0.596	-0.65	
6 - max	HBO	Other	0.20	1.00	0.16	-0.657	-0.676	-0.596	-0.65	
6 - max	NHBED	Other	0.20	1.00	0.105	-0.657	-0.676	-0.596	-0.65	
6 - max	NHBO	Other	0.20	1.00	0.105	-0.657	-0.676	-0.596	-0.65	
6 - max	**All**	**All**				**-0.407**	**-0.541**	**-0.406**	**-0.463**	**9/0.031**

5.4.7. The increases in fuel elasticity are achieved if the effect of trip frequency for Commuting and Discretionary (Other) trips is stronger. By incorporating this adjustment, it was possible to derive a set of final destination choice parameters calibrating the base demand model and achieving the recommended target elasticity. Table 9 below provides a summary of the test with the final destination choice lambda values.

Table 9 - Car Fuel Elasticity with Final Set of Values

Test	Purpose		Freq	Mode	Dest	AM	IP	PM	24-Hour	Gap (%)
7 - final	HBEB	Business	0.00	0.46	0.056	-0.112	-0.098	-0.093	-0.1	
7 - final	NHBEB	Business	0.00	0.68	0.068	-0.112	-0.098	-0.093	-0.1	
7 - final	HBW	Commute	0.25	0.75	0.095	-0.199	-0.295	-0.204	-0.226	
7 - final	HBED	Other	0.20	0.61	0.098	-0.381	-0.408	-0.355	-0.388	
7 - final	HBO	Other	0.20	0.61	0.098	-0.381	-0.408	-0.355	-0.388	
7 - final	NHBED	Other	0.20	0.81	0.090	-0.381	-0.408	-0.355	-0.388	
7 - final	NHBO	Other	0.20	0.81	0.090	-0.381	-0.408	-0.355	-0.388	
7 - final	**All**					**-0.263**	**-0.342**	**-0.264**	**-0.297**	**8/0.040**

5.4.8. As can be seen from Table 9, the updated model achieved an overall elasticity of -0.297 with respect to change in fuel costs, which is within the recommended acceptable range from -0.25 to -0.35 from the WebTAG M2 guidance. The resultant elasticities are 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.

5.4.9. The results also show that the effect of the fuel cost change on to the resultant elasticity is weaker for the AM and PM peak and stronger for the Inter-Peak, consistent with WebTAG[13].

5.4.10. As mentioned above, the inclusion of fixed costs for PT elements and exclusion of slow modes in the GYVDM demand model resulted in relatively strong scaling parameters (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.

5.5. JOURNEY TIME ELASTICITY

5.5.1. The car journey time elasticity was carried out on the final set of frequency and destination choice parameters derived during the Car Fuel Elasticity calibration process. Table 10 below provides a summary of the test with journey time elasticity.

Table 10 - Journey Time Elasticity with Final Set of Values

Test	Purpose		Freq	Mode	Dest	AM	IP	PM	24-Hour	Gap (%)

[13] WebTAG M2 (March 2017), para. 6.4.17

7 - final	HBEB	Business	0.00	0.46	0.056	-0.24	-0.202	-0.208	-0.213	
7 - final	NHBEB	Business	0.00	0.68	0.068	-0.24	-0.202	-0.208	-0.213	
7 - final	HBW	Commute	0.25	0.75	0.095	-0.337	-0.445	-0.352	-0.371	
7 - final	HBED	Other	0.20	0.61	0.098	-0.356	-0.377	-0.364	-0.369	
7 - final	HBO	Other	0.20	0.61	0.098	-0.356	-0.377	-0.364	-0.369	
7 - final	NHBED	Other	0.20	0.81	0.090	-0.356	-0.377	-0.364	-0.369	
7 - final	NHBO	Other	0.20	0.81	0.090	-0.356	-0.377	-0.364	-0.369	
7 - final	**All**					**-0.335**	**-0.369**	**-0.344**	**-0.352**	**2/NA**

5.5.2. The outturn elasticity with respect to change in journey time are within the recommended WebTAG value of -2.0.

6. APPLICATION OF VDM FOR GYTRC FORECASTING

6.1. INTRODUCTION

6.1.1. The updated VDM demand model for the Great Yarmouth forecasting was carried out for the following:

- Forecast years: Opening Year 2023, Design Year 2038 and a Horizon Year 2051;
- Forecasting case: Do-Minimum and Do-Something cases with pivoting off the Base year 2018 costs;
- Forecast scenario: Core scenario, Low growth and High growth scenarios.

6.1.2. This note reports the output from the GYVDM demand model for the Core scenario, low growth and high growth scenarios will not be reported in detail but only a high level output such as TUBA.

6.2. FUTURE YEAR GENERALISED COST PARAMETERS

6.2.1. Tables 11 to 14 below summarise the input parameters that were used for the GYVDM forecast models.

Table 11 - Generalised Cost Parameters – Forecast Years

	Pence Per Minute	Pence Per Minute	Pence Per Minute	Pence Per Kilometre	Pence Per Kilometre	Pence Per Kilometre
	AM	**IP**	**PM**	**AM**	**IP**	**PM**
2023 Business	32.29	33.09	32.76	12.14	12.14	12.14
2023 Commute	21.65	22.01	21.73	5.67	5.67	5.67
2023 Other	14.94	15.91	15.65	5.67	5.67	5.67
2038 Business	42.28	43.33	42.89	11.54	11.54	11.54
2038 Commute	28.36	28.82	28.45	5.43	5.43	5.43
2038 Other	19.56	20.84	20.49	5.43	5.43	5.43
2051 Business	55.54	55.89	55.33	11.76	11.76	11.76
2051 Commute	36.58	37.17	36.70	5.70	5.70	5.70
2051 Other	25.24	26.88	26.43	5.70	5.70	5.70

Table 12 - Reference Case Matrix Totals (persons) - Base Year 2023

PURPOSE	FORMAT	AM PERIOD	IP PERIOD	PM PERIOD	OP PERIOD	24HR TOTAL
HB Commute (PA)	from Home	6,830	2,771	1,121	2,994	**13,716**
HB Commute (PA)	return Home	619	2,616	5,117	2,013	**10,364**
HB Commute (PA)	**Total**	**7,449**	**5,387**	**6,238**	**5,007**	**24,081**
HB Education (PA)	from Home	964	1,456	830	651	**3,900**
HB Education (PA)	return Home	360	2,149	4,783	1,641	**8,933**
HB Education (PA)	**Total**	**1,323**	**3,605**	**5,613**	**2,292**	**12,834**

PURPOSE	FORMAT	AM PERIOD	IP PERIOD	PM PERIOD	OP PERIOD	24HR TOTAL
HB Other (PA)	from Home	12,128	19,488	5,766	5,089	**42,471**
HB Other (PA)	return Home	3,623	22,105	12,291	11,050	**49,069**
HB Other (PA)	**Total**	**15,751**	**41,592**	**18,057**	**16,139**	**91,540**
HB Business (PA)	from Home	719	511	134	317	**1,680**
HB Business (PA)	return Home	70	613	581	338	**1,603**
HB Business (PA)	**Total**	**789**	**1,124**	**715**	**655**	**3,283**
NHB Other (OD)	Total	6,348	24,597	14,707	10,843	**56,496**
NHB Business (OD)	Total	1,021	4,244	1,428	1,623	**8,317**

Table 13 - Reference Case Matrix Totals (persons) - Base Year 2038

PURPOSE	FORMAT	AM PERIOD	IP PERIOD	PM PERIOD	OP PERIOD	24HR TOTAL
HB Commute (PA)	from Home	7,473	2,994	1,183	3,258	**14,909**
HB Commute (PA)	return Home	660	2,839	5,602	2,190	**11,291**
HB Commute (PA)	**Total**	**8,133**	**5,833**	**6,785**	**5,449**	**26,200**
HB Education (PA)	from Home	1,189	1,800	994	801	**4,784**
HB Education (PA)	return Home	420	2,811	5,708	2,020	**10,958**
HB Education (PA)	**Total**	**1,609**	**4,611**	**6,702**	**2,821**	**15,742**
HB Other (PA)	from Home	14,259	23,200	6,870	5,939	**50,269**
HB Other (PA)	return Home	4,101	25,584	13,975	12,895	**56,555**
HB Other (PA)	**Total**	**18,360**	**48,784**	**20,845**	**18,834**	**106,823**
HB Business (PA)	from Home	790	570	148	350	**1,858**
HB Business (PA)	return Home	74	680	646	374	**1,774**
HB Business (PA)	**Total**	**865**	**1,250**	**794**	**724**	**3,633**
NHB Other (OD)	Total	7,304	28,951	17,070	12,664	**65,989**
NHB Business (OD)	Total	1,121	4,597	1,541	1,761	**9,020**

Table 14 - Reference Case Matrix Totals (persons) - Base Year 2051

PURPOSE	FORMAT	AM PERIOD	IP PERIOD	PM PERIOD	OP PERIOD	24HR TOTAL
HB Commute (PA)	from Home	8,053	3,195	1,282	3,497	**16,027**
HB Commute (PA)	return Home	721	3,025	5,986	2,351	**12,083**

PURPOSE	FORMAT	AM PERIOD	IP PERIOD	PM PERIOD	OP PERIOD	24HR TOTAL
HB Commute (PA)	**Total**	**8,774**	**6,220**	**7,268**	**5,847**	**28,109**
HB Education (PA)	from Home	1,324	1,987	1,084	886	**5,280**
HB Education (PA)	return Home	466	3,094	6,321	2,235	**12,116**
HB Education (PA)	**Total**	**1,790**	**5,081**	**7,405**	**3,121**	**17,396**
HB Other (PA)	from Home	15,848	25,599	7,529	6,595	**55,571**
HB Other (PA)	return Home	4,601	28,634	15,493	14,319	**63,047**
HB Other (PA)	**Total**	**20,449**	**54,234**	**23,022**	**20,913**	**118,618**
HB Business (PA)	from Home	855	618	160	379	**2,012**
HB Business (PA)	return Home	81	737	699	405	**1,922**
HB Business (PA)	**Total**	**936**	**1,355**	**858**	**784**	**3,933**
NHB Other (OD)	Total	8,043	32,102	18,867	14,014	**73,026**
NHB Business (OD)	Total	1,220	4,949	1,671	1,901	**9,741**

6.2.2. The input parameters were used to run the GYVDM forecast demand models. Tables 15 to 17 below provide a high level summary of change in forecast demand from the reference demand resulting from the GYVDM demand model.

Table 15 - Change in Matrix Totals from GYVDM – Opening Year 2023

Period	Purpose	Ref. Total Veh	DM Total Veh	DS Total Veh	% Diff DM – Ref.	% Diff DS - DM
AM Peak	Business	905	904	907	-0.1%	0.3%
AM Peak	Commute	5,318	5,293	5,368	-0.5%	1.4%
AM Peak	Other	8,461	8,377	8,438	-1.0%	0.7%
AM Peak	**Car**	**14,683**	**14,574**	**14,712**	**-0.7%**	**1.0%**
AM Peak	LGV	2,767	2,767	2,767	0.0%	0.0%
AM Peak	HGV	1,382	1,382	1,382	0.0%	0.0%
Inter-Peak	Business	989	989	988	0.0%	-0.1%
Inter-Peak	Commute	1,560	1,558	1,565	-0.1%	0.5%
Inter-Peak	Other	10,717	10,669	10,703	-0.5%	0.3%
Inter-Peak	**Car**	**13,267**	**13,216**	**13,257**	**-0.4%**	**0.3%**
Inter-Peak	LGV	2,115	2,115	2,115	0.0%	0.0%
Inter-Peak	HGV	1,310	1,310	1,310	0.0%	0.0%
PM Peak	Business	934	934	934	0.0%	0.0%

PM Peak	Commute	4,776	4,736	4,785	-0.8%	1.0%
PM Peak	Other	10,735	10,682	10,715	-0.5%	0.3%
PM Peak	**Car**	**16,445**	**16,352**	**16,435**	**-0.6%**	**0.5%**
PM Peak	LGV	2,361	2,361	2,361	0.0%	0.0%
PM Peak	HGV	782	782	782	0.0%	0.0%
24-Hours	Business	13,008	13,006	13,011	0.0%	0.0%
24-Hours	Commute	45,025	44,788	45,262	-0.5%	1.1%
24-Hours	Other	138,474	137,677	138,232	-0.6%	0.4%
24-Hours	**Car**	**196,507**	**195,471**	**196,505**	**-0.5%**	**0.5%**
24-Hours	LGV	31,887	31,887	31,887	0.0%	0.0%
24-Hours	HGV	16,294	16,294	16,294	0.0%	0.0%

Table 16 - Change in Matrix Totals from GYVDM – Opening Year 2038

Period	Purpose	Ref. Total Veh	DM Total Veh	DS Total Veh	% Diff DM – Ref.	% Diff DS - DM
AM Peak	Business	993	993	996	0.0%	0.3%
AM Peak	Commute	5,806	5,854	5,949	0.8%	1.6%
AM Peak	Other	9,911	9,831	9,905	-0.8%	0.8%
AM Peak	**Car**	**16,710**	**16,677**	**16,851**	**-0.2%**	**1.0%**
AM Peak	LGV	3,619	3,619	3,619	0.0%	0.0%
AM Peak	HGV	1,588	1,588	1,588	0.0%	0.0%
Inter-Peak	Business	1,081	1,081	1,080	0.0%	-0.1%
Inter-Peak	Commute	1,689	1,728	1,736	2.3%	0.5%
Inter-Peak	Other	12,651	12,673	12,713	0.2%	0.3%
Inter-Peak	**Car**	**15,420**	**15,482**	**15,530**	**0.4%**	**0.3%**
Inter-Peak	LGV	2,767	2,767	2,767	0.0%	0.0%
Inter-Peak	HGV	1,504	1,504	1,504	0.0%	0.0%
PM Peak	Business	1,023	1,024	1,026	0.2%	0.1%
PM Peak	Commute	5,196	5,201	5,277	0.1%	1.5%
PM Peak	Other	12,459	12,394	12,474	-0.5%	0.6%
PM Peak	**Car**	**18,677**	**18,620**	**18,777**	**-0.3%**	**0.8%**
PM Peak	LGV	3,088	3,088	3,088	0.0%	0.0%
PM Peak	HGV	900	900	900	0.0%	0.0%
24-Hours	Business	14,232	14,242	14,250	0.1%	0.1%

24-Hours	Commute	48,997	49,445	50,084	0.9%	1.3%
24-Hours	Other	162,468	162,124	162,928	-0.2%	0.5%
24-Hours	**Car**	**225,698**	**225,811**	**227,262**	**0.1%**	**0.6%**
24-Hours	LGV	41,706	41,706	41,706	0.0%	0.0%
24-Hours	HGV	18,716	18,716	18,716	0.0%	0.0%

Table 17 - Change in Matrix Totals from GYVDM – Horizon Year 2051

Period	Purpose	Ref. Total Veh	DM Total Veh	DS Total Veh	% Diff DM – Ref.	% Diff DS - DM
AM Peak	Business	1,076	1,077	1,082	0.1%	0.4%
AM Peak	Commute	6,264	6,304	6,444	0.6%	2.2%
AM Peak	Other	11,016	10,917	11,031	-0.9%	1.1%
AM Peak	**Car**	**18,356**	**18,298**	**18,557**	**-0.3%**	**1.4%**
AM Peak	LGV	4,318	4,318	4,318	0.0%	0.0%
AM Peak	HGV	1,783	1,783	1,783	0.0%	0.0%
Inter-Peak	Business	1,166	1,166	1,165	0.0%	-0.1%
Inter-Peak	Commute	1,801	1,860	1,872	3.3%	0.7%
Inter-Peak	Other	14,047	14,090	14,166	0.3%	0.5%
Inter-Peak	**Car**	**17,015**	**17,117**	**17,203**	**0.6%**	**0.5%**
Inter-Peak	LGV	3,301	3,301	3,301	0.0%	0.0%
Inter-Peak	HGV	1,688	1,688	1,688	0.0%	0.0%
PM Peak	Business	1,107	1,109	1,112	0.2%	0.2%
PM Peak	Commute	5,565	5,565	5,684	0.0%	2.1%
PM Peak	Other	13,764	13,675	13,811	-0.6%	1.0%
PM Peak	**Car**	**20,436**	**20,350**	**20,607**	**-0.4%**	**1.3%**
PM Peak	LGV	3,685	3,685	3,685	0.0%	0.0%
PM Peak	HGV	1,012	1,012	1,012	0.0%	0.0%
24-Hours	Business	15,389	15,401	15,415	0.1%	0.1%
24-Hours	Commute	52,580	53,115	54,080	1.0%	1.8%
24-Hours	Other	180,201	179,854	181,220	-0.2%	0.8%
24-Hours	**Car**	**248,169**	**248,370**	**250,716**	**0.1%**	**0.9%**
24-Hours	LGV	49,764	49,764	49,764	0.0%	0.0%
24-Hours	HGV	21,019	21,019	21,019	0.0%	0.0%

6.2.3. In general, similar to the 2017 GYVDM, the updated 2018 GYVDM suppresses demand in the Do-Minimum case and induces demand in the Do-Something cases compared to the reference case demand matrix. This can be explained by increasing congestion costs in the Do-Minimum whereas in the Do-Something additional capacity is added and the demand model reacts to a reduction in travel costs.

6.2.4. Analysis of the travel costs for Commuting in the forecast year's reference case Do-Minimum assignments at the 24-hour level, shows that travel costs per trip for Commuting increase slightly relative to the base year 2018, whereas the travel costs per trips for Business and Other generally show a greater increase in the forecast years. This is broadly in line with the outputs from the variable demand.

6.2.5. Table 18 below provides a summary of change in average costs per trips in the forecast years against the base year 2016 for each of the three purposes.

6.2.6. A full report of the forecasting process is included in the Great Yarmouth Third River Crossing Forecast Report[14].

Table 18 - Change in Costs per Trip from Base 2018

PPM	2018 AM	2018 IP	2018 PM	2018 24-HR	2023 DM AM	2023 DM IP	2023 DM PM	2023 DM 24-HR	2038 DM AM	2038 DM IP	2038 DM PM	2038 DM 24-HR	2051 DM AM	2051 DM IP	2051 DM PM	2051 DM 24-HR
Business	30.72	31.48	31.17		32.29	33.09	32.76		42.28	43.33	42.89		55.54	55.89	55.33	
Commute	20.6	20.94	20.68		21.65	22.01	21.73		28.36	28.82	28.45		36.58	37.17	36.7	
Other	14.22	15.14	14.89		14.94	15.91	15.65		19.56	20.84	20.49		25.24	26.88	26.43	
PPK	**2018 AM**	**2018 IP**	**2018 PM**	**2018 24-HR**	**2023 DM AM**	**2023 DM IP**	**2023 DM PM**	**2023 DM 24-HR**	**2038 DM AM**	**2038 DM IP**	**2038 DM PM**	**2038 DM 24-HR**	**2051 DM AM**	**2051 DM IP**	**2051 DM PM**	**2051 DM 24-HR**
Business	12.26	12.26	12.26		12.14	12.14	12.14		11.54	11.54	11.54		11.76	11.76	11.76	
Commute	5.75	5.75	5.75		5.67	5.67	5.67		5.43	5.43	5.43		5.7	5.7	5.7	
Other	5.75	5.75	5.75		5.67	5.67	5.67		5.43	5.43	5.43		5.7	5.7	5.7	
Trip (veh)	**2018 AM**	**2018 IP**	**2018 PM**	**2018 24-HR**	**2023 DM AM**	**2023 DM IP**	**2023 DM PM**	**2023 DM 24-HR**	**2038 DM AM**	**2038 DM IP**	**2038 DM PM**	**2038 DM 24-HR**	**2051 DM AM**	**2051 DM IP**	**2051 DM PM**	**2051 DM 24-HR**
Business	868	950	895	11,532	905	989	934	12,015	993	1,081	1,023	13,145	1,076	1,166	1,107	14,212
Commute	5,114	1,507	4,605	39,163	5,318	1,560	4,776	40,641	5,806	1,689	5,196	44,225	6,264	1,801	5,565	47,458
Other	7,895	9,967	10,082	119,134	8,461	10,717	10,735	127,708	9,911	12,651	12,459	149,898	11,016	14,047	13,764	166,280
Time (veh.hr)	**2018 AM**	**2018 IP**	**2018 PM**	**2018 24-HR**	**2023 DM AM**	**2023 DM IP**	**2023 DM PM**	**2023 DM 24-HR**	**2038 DM AM**	**2038 DM IP**	**2038 DM PM**	**2038 DM 24-HR**	**2051 DM AM**	**2051 DM IP**	**2051 DM PM**	**2051 DM 24-HR**
Business	311	317	336	4,020	336	341	361	4,330	401	400	434	5,131	471	459	503	5,937
Commute	1,683	538	1,679	13,633	1,780	566	1,763	14,362	2,037	652	2,029	16,496	2,278	722	2,251	18,346
Other	1,591	1,962	2,173	24,105	1,793	2,199	2,403	26,953	2,289	2,838	3,077	34,643	2,738	3,361	3,661	41,155
Dist (veh.kms)	**2018 AM**	**2018 IP**	**2018 PM**	**2018 24-HR**	**2023 DM AM**	**2023 DM IP**	**2023 DM PM**	**2023 DM 24-HR**	**2038 DM AM**	**2038 DM IP**	**2038 DM PM**	**2038 DM 24-HR**	**2051 DM AM**	**2051 DM IP**	**2051 DM PM**	**2051 DM 24-HR**
Business	18,354	19,626	19,903	243,568	20,009	21,263	21,491	264,067	23,672	24,786	25,091	309,027	27,173	28,024	28,439	350,887
Commute	91,544	32,153	93,924	767,861	98,900	35,324	101,215	832,689	109,897	40,049	111,930	928,968	118,051	43,373	119,319	997,594

[14] Great Yarmouth Third River Crossing DCO Document 7.6 Economic Appraisal Report Appendix B https://www.norfolk.gov.uk/roads-and-transport/major-projects-and-improvement-plans/great-yarmouth/third-river-crossing/further-information-and-documents/development-consent-application

Other	71,036	92,857	98,738	1,115,726	85,004	111,317	115,274	1,328,202	107,590	143,472	142,926	1,689,518	124,996	166,969	164,002	1,958,883
Cost per Trips	**2018 AM**	**2018 IP**	**2018 PM**	**2018 24-HR**	**2023 DM AM**	**2023 DM IP**	**2023 DM PM**	**2023 DM 24-HR**	**2038 DM AM**	**2038 DM IP**	**2038 DM PM**	**2038 DM 24-HR**	**2051 DM AM**	**2051 DM IP**	**2051 DM PM**	**2051 DM 24-HR**
Business	29.91	28.05	31.29	367.82	30.6	28.56	31.73	374.63	30.78	28.33	32.03	374.5	31.62	28.67	32.74	381.43
Commute	24.74	27.28	27.55	335.8	24.96	27.61	27.67	339	24.68	27.62	27.54	337.82	24.76	27.73	27.6	338.96
Other	15.73	15.35	16.71	198.09	16.53	16.01	17.32	206.69	16.87	16.42	17.86	221.98	17.47	16.87	18.53	218.8
% from Base	**2018 AM**	**2018 IP**	**2018 PM**	**2018 24-HR**	**2023 DM AM**	**2023 DM IP**	**2023 DM PM**	**2023 DM 24-HR**	**2038 DM AM**	**2038 DM IP**	**2038 DM PM**	**2038 DM 24-HR**	**2051 DM AM**	**2051 DM IP**	**2051 DM PM**	**2051 DM 24-HR**
Business	0.0%	0.0%	0.0%	0.0%	2.3%	1.8%	1.4%	1.9%	2.9%	1.0%	2.4%	1.8%	5.7%	2.2%	4.6%	3.7%
Commute	0.0%	0.0%	0.0%	0.0%	0.9%	1.2%	0.4%	1.0%	-0.3%	1.3%	0.0%	0.6%	0.1%	1.7%	0.2%	0.9%
Other	0.0%	0.0%	0.0%	0.0%	5.1%	4.3%	3.6%	4.3%	7.3%	7.0%	6.9%	7.0%	11.1%	10.0%	10.9%	10.5%

7. SUMMARY

7.1. OVERVIEW

7.1.1. The Great Yarmouth Variable Demand Model (GYVDM) is designed to respond to policy changes in the Greater Yarmouth Transport Model (network distance and time costs, and other external costs). The GYVDM applies a functional algorithm to the generalised costs output from the assignment models within the demand model to adjust travel demand matrices in line with network supply changes.

7.1.2. The original GYVDM needed to be recalibrated following the updates to the base SATURN model and changes to the value of time, and this report supersedes the variable demand model report submitted for the OBC[15].

7.2. SUMMARY

7.2.1. The updated GYVDM demand model was calibrated for the base year of 2018. Appropriate demand choices were implemented using a recommended functional model form. The model was applied with choice parameters taken from within the recommended range. The parameters were verified by realism tests gauging impact of change in generalised costs on the change in travel demand.

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

7.2.3. The outcome of the realism tests show that the GYVDM base demand model behaves realistically in response to change in fuel price and car journey time with the outturn elasticity with respect to fuel cost and journey time changes are met in accordance with the WebTAG M2 guidance.

7.2.4. Upon completion of the calibration of the base year GYVDM demand model, the GYVDM demand model was applied in forecast mode. The forecast model tested the impact of land-use change and also the impact of the proposed Third River Crossing scheme on the network performance. High level travel patterns were found to be appropriate and within expectations.

7.2.5. A Traffic Forecasting Report[16] supplements the detail contained herein.

[15] Great Yarmouth Third River Crossing OBC Supporting Document 6 https://www.norfolk.gov.uk/roads-and-transport/major-projects-and-improvement-plans/great-yarmouth/third-river-crossing/further-information-and-documents/outline-business-case-submission

[16] Great Yarmouth Third River Crossing DCO Document 7.6 Economic Appraisal Report Appendix B https://www.norfolk.gov.uk/roads-and-transport/major-projects-and-improvement-plans/great-yarmouth/third-river-crossing/further-information-and-documents/development-consent-application

Appendix A

REALISM TEST SUMMARY

Test 1: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-47.76123	3476.07	184679.59	3488098.48	3.24739
2	0.5	-23.68402	851.89	184599.18	3443597.68	1.62158
3	0.5	-11.75304	208.76	184559.55	3421642.03	0.80663
4	0.5	-5.83468	51.34	184539.99	3410774	0.4003
5	0.5	-2.90097	12.62	184530.36	3405407.3	0.19887
6	0.5	-1.43804	3.11	184525.6	3402802.45	0.09927
7	0.5	-0.71206	0.8	184523.24	3401521.14	0.05053
8	0.5	-0.35373	0.21	184522.06	3400885.59	0.02619

Test 1: Elasticity Summary

Period	Purpose	Total Trips (vehs) Ref.	Total Trips (vehs) Forecast	Total Costs (veh.km) Ref.	Total Costs (veh.km) Forecast	Elasticity
AM Peak	Business	868.36	867.93	18731.73	18433.68	-0.088
AM Peak	Commute	5112.82	5105.19	94931.41	94499.27	-0.025
AM Peak	Other	7894.22	7891.4	76146.19	73011.37	-0.231
AM Peak	**Car**	13875.41	13864.52	189809.3	185944.3	-0.113
Inter-Peak	Business	950.06	950.04	19981.55	19652.75	-0.091
Inter-Peak	Commute	1507.31	1504.91	33928.33	33744.37	-0.03
Inter-Peak	Other	9964.46	9960.59	100019.2	95529.47	-0.252
Inter-Peak	**Car**	12421.82	12415.54	153929	148926.6	-0.181
PM Peak	Business	894.56	893.94	20243.26	19966.45	-0.076
PM Peak	Commute	4603.74	4595.12	97484.57	97012.16	-0.027
PM Peak	Other	10081.61	10074.13	105333.5	101475.9	-0.205
PM Peak	**Car**	15579.91	15563.19	223061.3	218454.5	-0.114
24-Hours	Business	12482.26	12478.59	269001.9	264802.4	-0.086
24-Hours	Commute	43378.96	43307.26	886960.1	882623.4	-0.027
24-Hours	Other	129185.1	129123.6	1300347	1245915	-0.235

24-Hours	**Car**	185046.4	184909.4	2456309	2393341	-0.142

Test 2: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-56.8181	4674.2	184679.6	3488098	3.78645
2	0.5	-28.1429	1138.9	184529.1	3434780	1.88926
3	0.5	-13.962	278.7	184455.1	3408491	0.93969
4	0.5	-6.92338	68.4	184418.8	3395601	0.46645
5	0.5	-3.43496	16.87	184401	3389303	0.23241
6	0.5	-1.70926	4.24	184392.1	3386153	0.11774
7	0.5	-0.84451	1.03	184387.8	3384570	0.05836
8	0.5	-0.42035	0.27	184385.6	3383891	0.03073

Test 2: Elasticity Summary

Period	Purpose	Total Trips (vehs) Ref.	Total Trips (vehs) Forecast	Total Costs (veh.km) Ref.	Total Costs (veh.km) Forecast	Elasticity
AM Peak	Business	868.36	867.52	18731.73	18279.32	-0.134
AM Peak	Commute	5112.82	5100.11	94931.41	94311.71	-0.036
AM Peak	Other	7894.22	7885.38	76146.19	72396.78	-0.277
AM Peak	**Car**	13875.41	13853.02	189809.3	184987.8	-0.141
Inter-Peak	Business	950.06	950.08	19981.55	19560.12	-0.117
Inter-Peak	Commute	1507.31	1502.91	33928.33	33625.95	-0.049
Inter-Peak	Other	9964.46	9953.63	100019.2	94723.09	-0.298
Inter-Peak	**Car**	12421.82	12406.62	153929	147909.2	-0.219
PM Peak	Business	894.56	893.44	20243.26	19835	-0.112
PM Peak	Commute	4603.74	4590.11	97484.57	96808.66	-0.038
PM Peak	Other	10081.61	10066.15	105333.5	100739	-0.245
PM Peak	**Car**	15579.91	15549.7	223061.3	217382.7	-0.141
24-Hours	Business	12482.26	12475.71	269001.9	263197.4	-0.12
24-Hours	Commute	43378.96	43259.26	886960.1	880483.6	-0.04
24-Hours	Other	129185.1	129028.4	1300347	1235813	-0.279

24-Hours	**Car**	185046.4	184763.4	2456309	2379494	-0.174

Test 3: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-90.727	11679.05	184679.6	3488098	6.02594
2	0.5	-44.8214	2798.41	184266.2	3399506	3.00109
3	0.5	-22.2025	678.18	184067.4	3356567	1.49367
4	0.5	-10.9663	166.42	183971.5	3335883	0.74469
5	0.5	-5.43372	40.4	183924.6	3325617	0.37089
6	0.5	-2.68355	9.95	183901.9	3320692	0.18429
7	0.5	-1.33696	2.48	183890.7	3318193	0.09294
8	0.5	-0.66066	0.64	183885.2	3316980	0.04758

Test 3: Elasticity Summary

Period	Purpose	Total Trips (vehs) Ref.	Total Trips (vehs) Forecast	Total Costs (veh.km) Ref.	Total Costs (veh.km) Forecast	Elasticity
AM Peak	Business	868.36	866.85	18731.73	18047.43	-0.204
AM Peak	Commute	5112.82	5085.57	94931.41	93679.54	-0.073
AM Peak	Other	7894.22	7860.52	76146.19	69851.32	-0.473
AM Peak	**Car**	13875.41	13812.94	189809.3	181578.3	-0.243
Inter-Peak	Business	950.06	949.93	19981.55	19395.69	-0.163
Inter-Peak	Commute	1507.31	1496.95	33928.33	33248.58	-0.111
Inter-Peak	Other	9964.46	9925.71	100019.2	91366.34	-0.496
Inter-Peak	**Car**	12421.82	12372.59	153929	144010.6	-0.365
PM Peak	Business	894.56	892.7	20243.26	19638.54	-0.166
PM Peak	Commute	4603.74	4576.19	97484.57	96161.65	-0.075
PM Peak	Other	10081.61	10035.23	105333.5	97675.34	-0.414
PM Peak	**Car**	15579.91	15504.11	223061.3	213475.5	-0.241
24-Hours	Business	12482.26	12469.9	269001.9	260617.6	-0.174
24-Hours	Commute	43378.96	43121.61	886960.1	873552.6	-0.084

24-Hours	Other	129185.1	128648	1300347	1193818	-0.469
24-Hours	**Car**	185046.4	184239.5	2456309	2327988	-0.294

Test 4: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-48.5853	3479.28	184679.6	3488098	3.59877
2	0.5	-24.0904	849.74	184277.4	3431889	1.79849
3	0.5	-11.961	208.38	184081.8	3404331	0.89446
4	0.5	-5.94208	51.21	183986.7	3390837	0.44433
5	0.5	-2.95502	12.55	183940.2	3384112	0.22018
6	0.5	-1.46735	3.11	183917.6	3380867	0.10951
7	0.5	-0.72793	0.82	183906.5	3379259	0.05593
8	0.5	-0.36529	0.21	183901.2	3378453	0.02819

Test 4: Elasticity Summary

Period	Purpose	Total Trips (vehs) Ref.	Total Trips (vehs) Forecast	Total Costs (veh.km) Ref.	Total Costs (veh.km) Forecast	Elasticity
AM Peak	Business	868.36	867.97	18731.73	18433.37	-0.088
AM Peak	Commute	5112.82	5073.25	94931.41	93527.12	-0.082
AM Peak	Other	7894.22	7871.44	76146.19	72610.67	-0.261
AM Peak	**Car**	13875.41	13812.66	189809.3	184571.2	-0.153
Inter-Peak	Business	950.06	950.03	19981.55	19652.18	-0.091
Inter-Peak	Commute	1507.31	1493.74	33928.33	33225.39	-0.115
Inter-Peak	Other	9964.46	9932.52	100019.2	94971.28	-0.284
Inter-Peak	**Car**	12421.82	12376.29	153929	147848.9	-0.221
PM Peak	Business	894.56	893.97	20243.26	19965.27	-0.076
PM Peak	Commute	4603.74	4564.92	97484.57	95997.09	-0.084
PM Peak	Other	10081.61	10044.83	105333.5	100788.3	-0.242
PM Peak	**Car**	15579.91	15503.73	223061.3	216750.7	-0.157
24-Hours	Business	12482.26	12478.72	269001.9	264793.5	-0.086
24-Hours	Commute	43378.96	43019.39	886960.1	872314.2	-0.091
24-Hours	Other	129185.1	128764.4	1300347	1238400	-0.268

24-Hours	**Car**	185046.4	184262.5	2456309	2375507	-0.183

Test 5: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-58.6486	4755.85	184679.6	3488098	4.4781
2	0.5	-29.0469	1153.05	183959.8	3414271	2.23585
3	0.5	-14.4174	282.68	183614.6	3378391	1.11161
4	0.5	-7.1935	70.06	183448.7	3361037	0.553
5	0.5	-3.56774	17.15	183368.2	3352473	0.27379
6	0.5	-1.78645	4.29	183329.3	3348318	0.13666
7	0.5	-0.88034	1.11	183310.3	3346292	0.06869
8	0.5	-0.42829	0.28	183300.9	3345220	0.03532

Test 5: Elasticity Summary

Period	Purpose	Total Trips (vehs) Ref.	Total Trips (vehs) Forecast	Total Costs (veh.km) Ref.	Total Costs (veh.km) Forecast	Elasticity
AM Peak	Business	868.36	867.6	18731.73	18277.4	-0.135
AM Peak	Commute	5112.82	5049.08	94931.41	92752.13	-0.127
AM Peak	Other	7894.22	7844.48	76146.19	71576.01	-0.339
AM Peak	**Car**	13875.41	13761.17	189809.3	182605.5	-0.212
Inter-Peak	Business	950.06	950.04	19981.55	19559.06	-0.117
Inter-Peak	Commute	1507.31	1485.11	33928.33	32802.03	-0.185
Inter-Peak	Other	9964.46	9898.86	100019.2	93627.5	-0.362
Inter-Peak	**Car**	12421.82	12334.01	153929	145988.6	-0.29
PM Peak	Business	894.56	893.54	20243.26	19836.76	-0.111
PM Peak	Commute	4603.74	4542.17	97484.57	95186.32	-0.131
PM Peak	Other	10081.61	10011.26	105333.5	99469.55	-0.314
PM Peak	**Car**	15579.91	15446.98	223061.3	214492.6	-0.215
24-Hours	Business	12482.26	12476.05	269001.9	263189.8	-0.12
24-Hours	Commute	43378.96	42800.68	886960.1	864024.8	-0.144
24-Hours	Other	129185.1	128328.7	1300347	1221219	-0.344

24-Hours	**Car**	185046.4	183605.4	2456309	2348434	-0.246

Test 6: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-95.2119	12876.95	184679.6	3488098	7.83162
2	0.5	-47.2397	3079.83	182868.1	3351564	3.90578
3	0.5	-23.6245	754.6	182038.7	3287346	1.94269
4	0.5	-11.7785	185.23	181652.7	3256652	0.96403
5	0.5	-5.83469	45.4	181471	3241800	0.4787
6	0.5	-2.90519	11.3	181385.5	3234661	0.23816
7	0.5	-1.42268	2.76	181344.7	3231198	0.11924
8	0.5	-0.70891	0.72	181325	3229471	0.05981

Test 6: Elasticity Summary

Period	Purpose	Total Trips (vehs) Ref.	Total Trips (vehs) Forecast	Total Costs (veh.km) Ref.	Total Costs (veh.km) Forecast	Elasticity
AM Peak	Business	868.36	867	18731.73	18037.53	-0.207
AM Peak	Commute	5112.82	4985.88	94931.41	90647.51	-0.253
AM Peak	Other	7894.22	7744.54	76146.19	67554.74	-0.657
AM Peak	**Car**	13875.41	13597.41	189809.3	176239.8	-0.407
Inter-Peak	Business	950.06	949.86	19981.55	19389.95	-0.165
Inter-Peak	Commute	1507.31	1462.19	33928.33	31656.22	-0.38
Inter-Peak	Other	9964.46	9777.14	100019.2	88421.05	-0.676
Inter-Peak	**Car**	12421.82	12189.19	153929	139467.2	-0.541
PM Peak	Business	894.56	893	20243.26	19635.6	-0.167
PM Peak	Commute	4603.74	4483.96	97484.57	93030.89	-0.256
PM Peak	Other	10081.61	9892.85	105333.5	94485.52	-0.596
PM Peak	**Car**	15579.91	15269.81	223061.3	207152	-0.406
24-Hours	Business	12482.26	12470.95	269001.9	260534.7	-0.175
24-Hours	Commute	43378.96	42230.76	886960.1	841698.4	-0.287
24-Hours	Other	129185.1	126754.9	1300347	1155041	-0.65

24-Hours	**Car**	185046.4	181456.6	2456309	2257274	-0.463

Test 7: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-63.3502	5854.71	184679.6	3488098	5.17507
2	0.5	-31.3965	1413.89	183744.2	3401043	2.57618
3	0.5	-15.6431	347.94	183302.7	3359508	1.2803
4	0.5	-7.79778	85.82	183091.6	3339354	0.63535
5	0.5	-3.90278	21.59	182990.1	3329526	0.31648
6	0.5	-1.92105	5.22	182941.3	3324675	0.15661
7	0.5	-0.9591	1.32	182917.8	3322311	0.07819
8	0.5	-0.49846	0.34	182906.6	3321161	0.03976

Test 7: Elasticity Summary

Period	Purpose	Total Trips (vehs) Ref.	Total Trips (vehs) Forecast	Total Costs (veh.km) Ref.	Total Costs (veh.km) Forecast	Elasticity
AM Peak	Business	868.36	867.75	18731.73	18353.92	-0.112
AM Peak	Commute	5112.82	5012.93	94931.41	91543.59	-0.199
AM Peak	Other	7894.22	7832.94	76146.19	71035.59	-0.381
AM Peak	**Car**	13875.41	13713.63	189809.33	180933.1	-0.263
Inter-Peak	Business	950.06	950.04	19981.55	19626.34	-0.098
Inter-Peak	Commute	1507.31	1472.12	33928.33	32153.27	-0.295
Inter-Peak	Other	9964.46	9883.74	100019.15	92857.44	-0.408
Inter-Peak	**Car**	12421.82	12305.91	153929.03	144637.04	-0.342
PM Peak	Business	894.56	893.76	20243.26	19902.88	-0.093
PM Peak	Commute	4603.74	4507.97	97484.57	93923.91	-0.204
PM Peak	Other	10081.61	9996.85	105333.45	98738.32	-0.355
PM Peak	**Car**	15579.91	15398.58	223061.28	212565.12	-0.264
24-Hours	Business	12482.26	12477.32	269001.86	264134.19	-0.1
24-Hours	Commute	43378.96	42472.46	886960.09	851182.53	-0.226
24-Hours	Other	129185.13	128137.17	1300346.8	1211636.11	-0.388

24-Hours	**Car**	185046.35	183086.95	2456308.75	2326952.83	-0.297

Test 8: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-93.8307	23179.11	184679.6	3338341	11.70879
2	0.5	-46.4404	5166.87	181495.3	3142280	0
3						
4						
5						
6						
7						
8						

Test 8: Elasticity Summary

Period	Purpose	Total Trips (vehs) Ref.	Total Trips (vehs) Forecast	Total Costs (veh.km) Ref.	Total Costs (veh.km) Forecast	Elasticity
AM Peak	Business	868.36	865.71	18731.73	17928.46	-0.24
AM Peak	Commute	5112.82	4917.4	94931.41	89276.98	-0.337
AM Peak	Other	7894.22	7779.17	76146.19	71360.83	-0.356
AM Peak	**Car**	13875.41	13562.28	189809.33	178566.27	-0.335
Inter-Peak	Business	950.06	949.77	19981.55	19257.94	-0.202
Inter-Peak	Commute	1507.31	1447.05	33928.33	31285.48	-0.445
Inter-Peak	Other	9964.46	9828.74	100019.15	93371.66	-0.377
Inter-Peak	**Car**	12421.82	12225.56	153929.03	143915.08	-0.369
PM Peak	Business	894.56	891.23	20243.26	19491.38	-0.208
PM Peak	Commute	4603.74	4415.72	97484.57	91423.59	-0.352
PM Peak	Other	10081.61	9920.72	105333.45	98573.42	-0.364
PM Peak	**Car**	15579.91	15227.67	223061.28	209488.39	-0.344
24-Hours	Business	12482.26	12459.88	269001.86	258771.59	-0.213
24-Hours	Commute	43378.96	41661.69	886960.09	829021.47	-0.371
24-Hours	Other	129185.13	127319.45	1300346.8	1215681.56	-0.369

24-Hours	**Car**	185046.35	181441.01	2456308.75	2303474.62	-0.352

Appendix B

FORECASTING CONVERGENCE

Convergence Summary – Core Scenario - DM2023

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-323.95	156782.1	196521.1	3646269	5.71754
2	0.5	-160.313	38057.92	195869.2	3622161	2.59807
3	0.5	-79.6554	9356.19	195616.3	3614337	1.23338
4	0.5	-39.584	2303.71	195515.2	3611547	0.6121
5	0.5	-19.6418	567.97	195474.9	3610533	0.31293
6	0.5	-9.7823	140.8	195459.3	3610279	0.15938
7	0.5	-4.87694	34.92	195453.2	3610222	0.0808
8	0.5	-2.42164	8.65	195450.9	3610163	0.04282

Convergence Summary – Core Scenario - DS2023

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-249.006	117417.1	196521.1	3552292	5.85347
2	0.5	-123.794	28463.19	196388	3551439	2.82695
3	0.5	-61.5605	7027.59	196352.9	3553162	1.40281
4	0.5	-30.536	1731.44	196343.5	3554192	0.70314
5	0.5	-15.1758	428	196343.2	3555133	0.35084
6	0.5	-7.52661	105.63	196343.6	3555447	0.1782
7	0.5	-3.77373	26.38	196345.2	3555898	0.08682
8	0.5	-1.84398	6.47	196345.2	3555867	0.04595

Convergence Summary – Core Scenario - DM2038

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-254.279	288128	227233.6	4110700	15.7852
2	0.5	-123.457	65854.07	226806	4140124	6.7799
3	0.5	-60.6012	15692.04	226869.1	4176572	3.21729
4	0.5	-29.9242	3800.87	226976.3	4201074	1.58706
5	0.5	-14.891	930.26	227046.9	4214241	0.78833
6	0.5	-7.4315	283.87	227087.4	4224129	0.43459
7	0.5	-3.70569	69.86	227091.1	4224388	0.21599
8	0.5	-1.83061	16.76	227111.8	4226235	0.10636
9	0.5	-0.93588	4.13	227121.6	4227076	0.05372
10	0.5	-0.44902	0.99	227126.4	4227516	0.02814

Convergence Summary – Core Scenario - DS2038

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-230.77	238437.9	227233.6	3924630	14.25005
2	0.5	-114.096	58069.61	227756.7	4036701	6.76703
3	0.5	-56.5865	14209.64	228053.3	4093997	3.28098
4	0.5	-28.0438	3479.62	228213.1	4122774	1.60697
5	0.5	-13.8705	850.84	228297.2	4136944	0.79508
6	0.5	-6.88864	209.35	228341.2	4143890	0.39309
7	0.5	-3.44319	51.51	228364.6	4147494	0.19442
8	0.5	-1.71078	13.02	228376.3	4149025	0.10109
9	0.5	-0.84142	3.25	228383.1	4149983	0.05077
10	0.5	-0.41333	0.94	228386	4150539	0.02788

Convergence Summary – Core Scenario - DM2051

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	321.5226	348712.9	250529	4652138	22.98358
2	0.5	142.2068	69755.19	249695.4	4628255	8.97946
3	0.5	65.69532	15970.27	249932	4685698	4.17073
4	0.5	31.00347	3795.45	250199.2	4729922	2.01164
5	0.5	14.65644	912.91	250352.6	4752787	0.987
6	0.5	6.99541	221.54	250435.3	4764773	0.48013
7	0.5	3.31246	54.01	250475.9	4770497	0.23747
8	0.5	-1.57559	13.82	250496.2	4773482	0.12245
9	0.5	-0.83781	3.72	250505.5	4774526	0.06804
10	0.5	-0.46102	1.38	250511	4775107	0.03863

Convergence Summary – Core Scenario - DS2051

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	300.5979	264228.4	250529	4270589	18.81664
2	0.5	143.5957	62768.02	251473	4455282	8.65134
3	0.5	68.20936	15054.96	252015	4550567	4.10512
4	0.5	32.44858	3646.31	252303.7	4598130	1.98064
5	0.5	15.4436	887.37	252453.4	4622064	0.96496
6	0.5	7.44147	212.45	252527.2	4632537	0.47945
7	0.5	3.48987	51.08	252569.1	4638321	0.23632
8	0.5	1.67643	15.05	252589.8	4641842	0.11922
9	0.5	0.86019	3.41	252596.5	4642569	0.06194
10	0.5	0.40294	0.82	252602.3	4643349	0.03002

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