Great Yarmouth Third River Crossing

OUTLINE BUSINESS CASE

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Norfolk County Council

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New Anglia Local Enterprise Partnership for Norfolk and Suffolk

Great Yarmouth Third River Crossing

Variable Demand Model Report

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1 Introduction

1.1 Background

Mouchel have been commissioned to evaluate the impact of construction of a new crossing of the River Yare downstream of the two existing crossings in Great Yarmouth. A series of traffic and transportation models have been developed to assist in these objectives.

1.2 Great Yarmouth Variable Demand Model

The Great Yarmouth Variable Demand Model (GYVDM) is designed to respond to policy changes in the Greater Yarmouth Transport 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.

1.3 Structure of the Report

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

2 The Need for Variable Demand Modelling

2.1 Background

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.

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

WebTAG [1] 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.

WebTAG [2] 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

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.

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 2-1 below provides the area of influence of the model.

[1] WebTAG M2, paragraphs 1.1.2 and 1.1.3

[2] WebTAG M2, section 2.2

Figure 2-1 Area of Influence

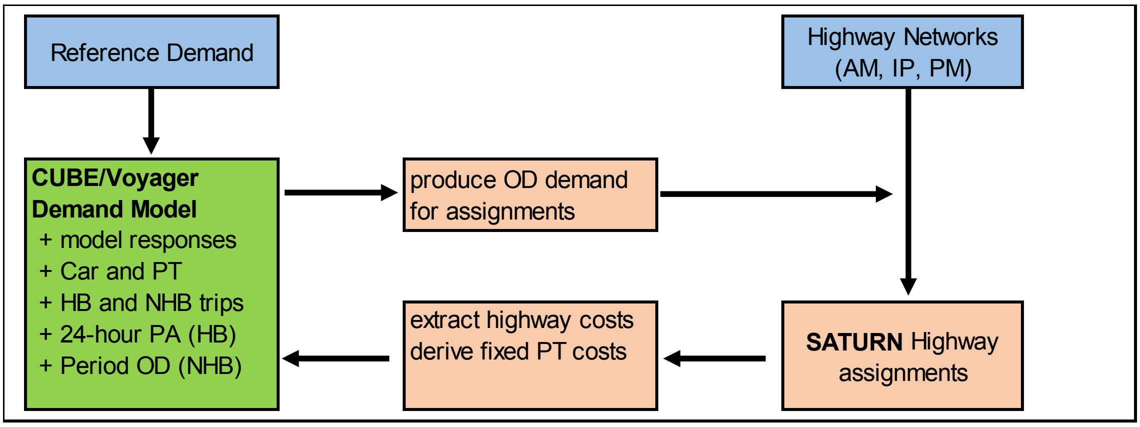
The remainder of the report provides detail on the model developed to address the VDM requirement.

3 Variable Demand Model Structure

3.1 Structure Overview

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 3-1 below.

Figure 3-1 GYVDM Model Structure



The demand model has been 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

According to WebTAG[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.

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).

The change in generalised costs is produced by calculating the difference between the 'Pivot-Point Cost' (from the Base year 2016 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

WebTAG[4] 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)

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

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 3-2 below.

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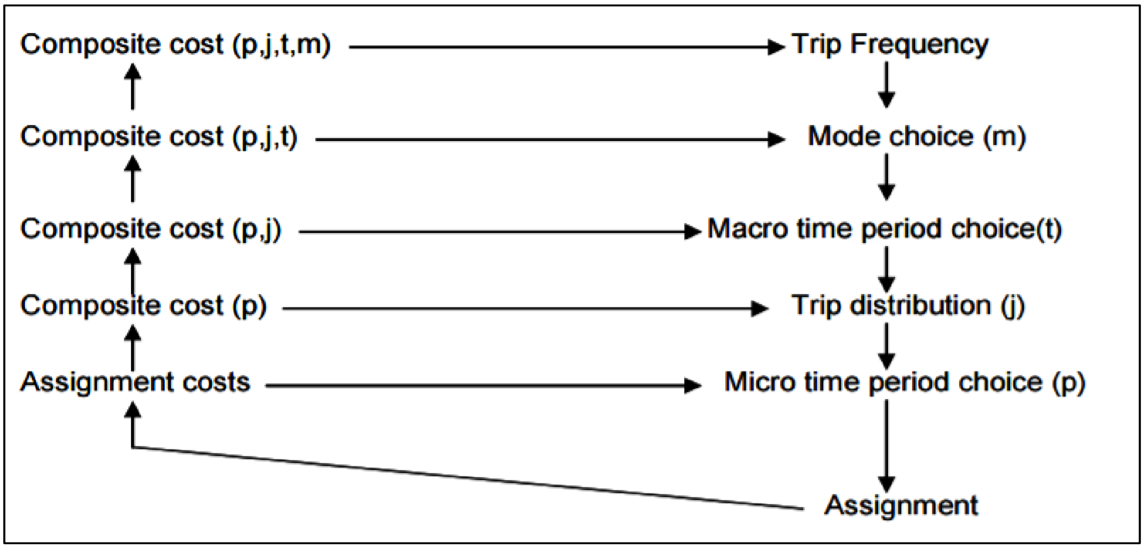
[3] WebTAG M2, section 4.3

[4] WebTAG M2, section 4.5

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

Figure 3-2 Typical Choice Hierarchy with Associated Cost Transfers



3.3.1 *Trip Frequency*

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.

WebTAG [5] 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 be not need to model the response of trip frequency.

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.

3.3.2 *Mode Choice*

WebTAG [6] 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

[5] WebTAG M2 Section 4.6
[6] WebTAG M2 Section 4.7

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.

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.

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

3.3.3 *Time of Day Choice*

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

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.

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.

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.

3.3.4 *Destination Choice*

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.

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.

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

3.3.5 *Route Choice (Assignment)*

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.

3.3.6 *Application of choice responses and hierarchy for GY3VDM*

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.

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[7]. In addition other trip purposes often make greater use of car.

WebTAG [8] 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 Greater Lincoln Transport Model to represent the two model responses, in the order of hierarchy, as below:

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

WebTAG [9] 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

- $\theta_{mode;}$ and
- θ_{freq}

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

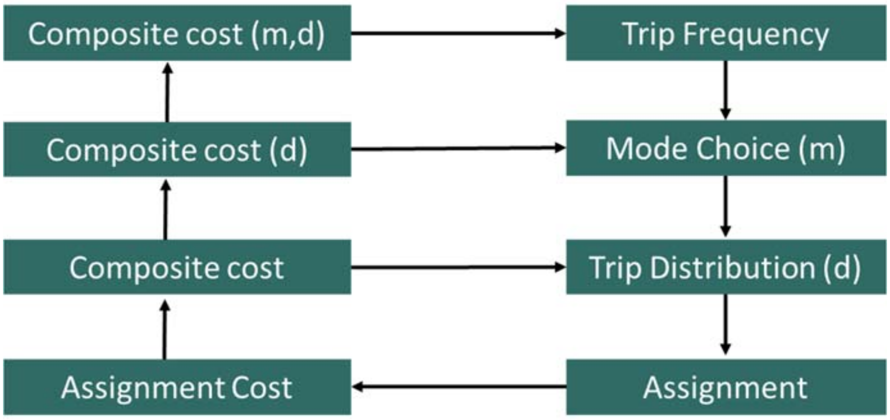
[8] WebTAG M2, section 4.7

[9] WebATG M2 Appendix E Incremental Model Formulation"

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 3-3 below.

Figure 3-3 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

3.4.1 Production Attraction

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.

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).

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.

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.

3.4.2 Demand Segmentation

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).

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 3-1 below.

Table 3-1 GYVDM Purposes to Assignment User Classes

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

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

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)

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

3.6 Singly or Doubly Constrained

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

A 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

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.

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.

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

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 [10], 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.

4.2.1 Demand Matrices

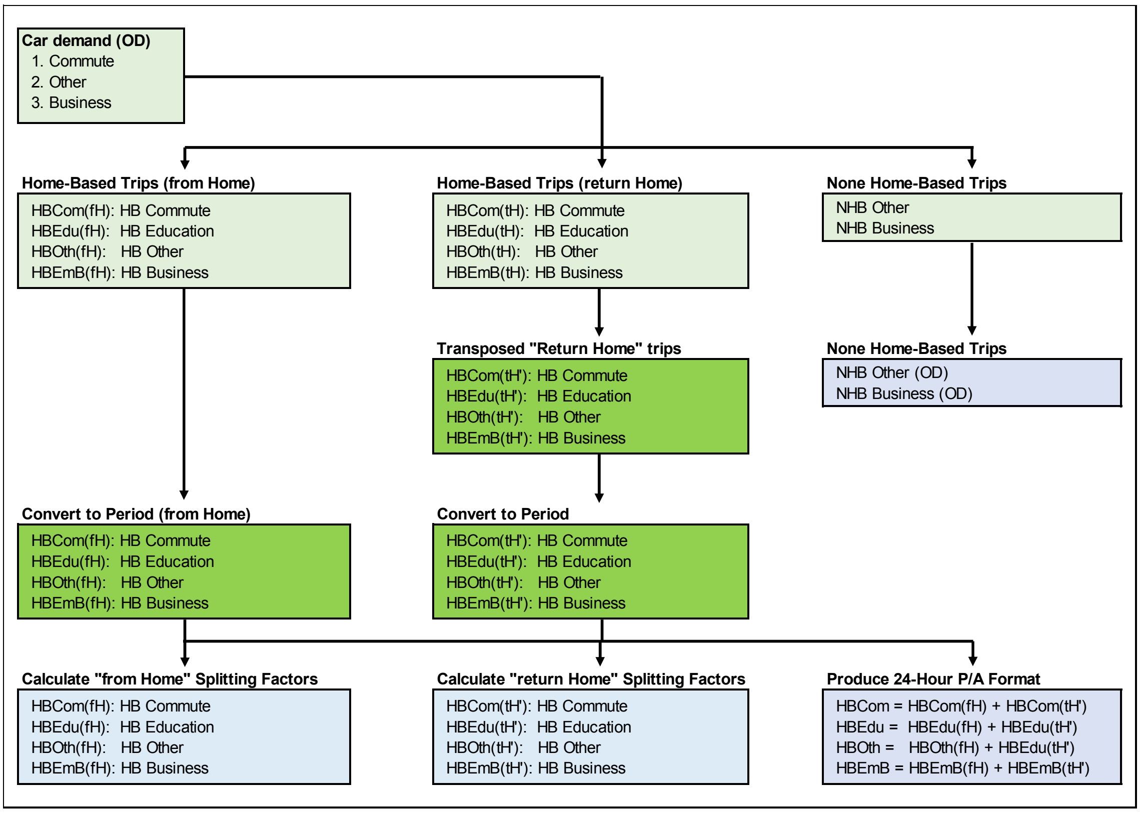
This section describes in more detail the process of constructing the demand matrices in P/A format and conversion from P/A to O/D for the purpose of the assignments. The process involves the following steps:

- 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.

[10] WebTAG M2, para 4.4.1

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 [11], 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.

[11] WebTAG M2, Appendix B.1.8

4.2.2 *Cost Matrices*

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:

- $\mathrm{GC}^{\mathrm{OD}}_{\mathrm{t.ij}}, \mathrm{GC}^{\mathrm{OD.T}}_{\mathrm{t.ij}}$ are the Generalised costs and transposed generalised costs respectively, extracted from the assignments from zone i to zone j, time period t
- $\mathrm{SF}^{\mathrm{fH}}_{\mathrm{t.ij}}, \mathrm{SF}^{\mathrm{tH}}_{\mathrm{t.ij}}$ 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

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.

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

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;

4.4.1 *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.

4.4.2 Composite Utilities

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

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

And for the Mode choice is calculated:

$$\Delta U^*_{itpc} = ln \sum_{m} p^0_{mitpc}\, exp(\theta^{mode}_{c} \Delta U^*_{imtpc})$$

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

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

4.4.3 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 GYVDM:

For destination choice:

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

For mode choice:

$$p_{m/itpc} = \frac{p^0_{mitpc}\,exp(\theta_c^{mode}\Delta U^*_{imtpc})}{\sum_{k=1}^{N} p^0_{kitpc}\,exp(\theta_c^{mode}\Delta U^*_{iktpc})}$$

4.4.4 *Updated Trip Matrix*

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

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

4.4.5 *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:

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

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.

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;

4.4.6 *Singly and Doubly Constrained Model*

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.

4.5 Cost Damping

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

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:

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

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

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:

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

4.7 Base Year Realism Tests

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.

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:

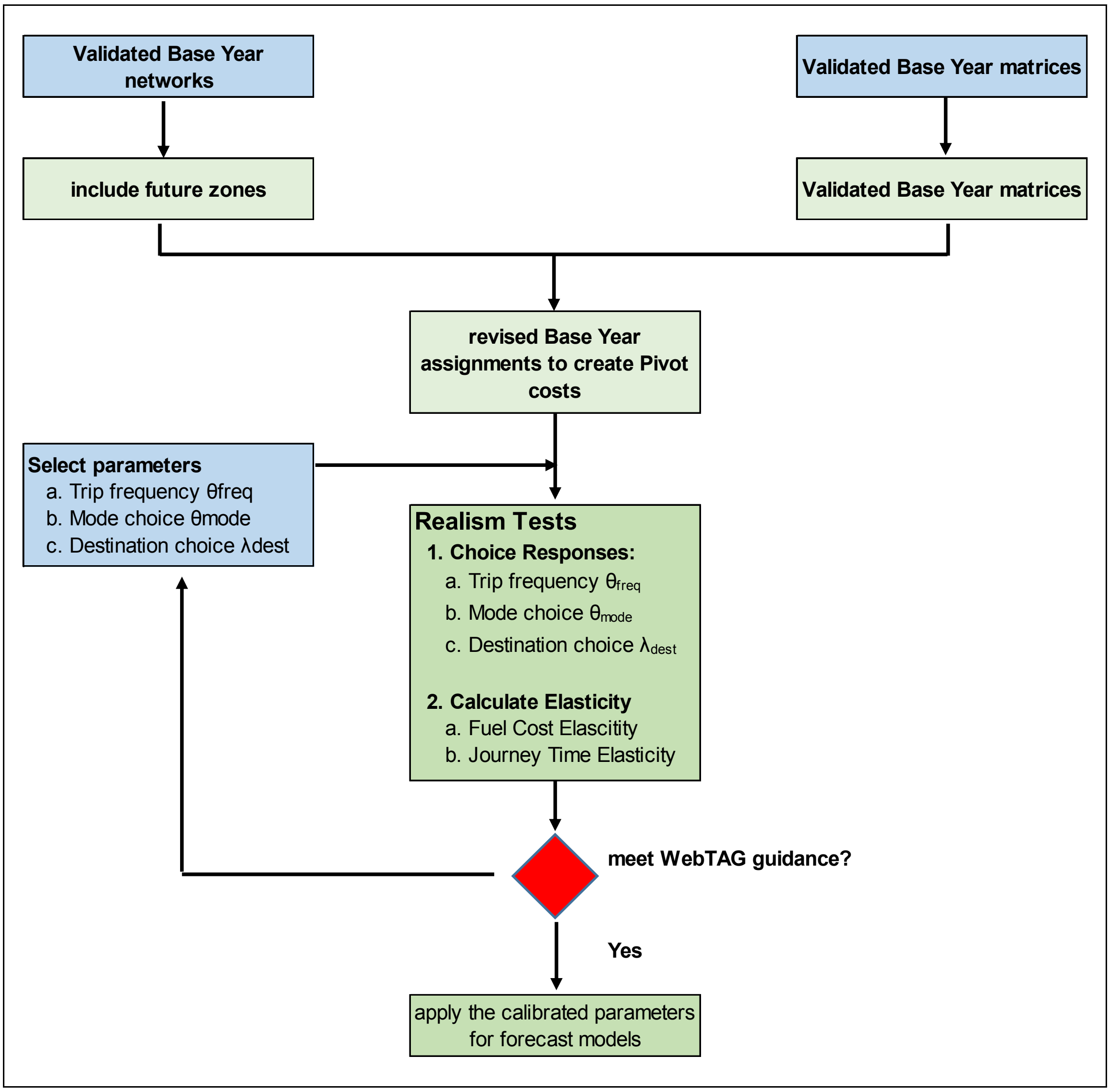
$$E = \frac{log(T^1) - log(T^0)}{log(C^1) - log(C^0)}$$

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

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

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

Figure 4-2 Realism Test Process



4.7.1 *Car Fuel Cost Elasticity*

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

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.

4.7.2 Car Journey Time Elasticity

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 $\mathrm{GC}^{\mathrm{JT}} = 1.2 * \mathrm{Time} + \frac{\mathrm{PPK}}{\mathrm{PPM}} * \mathrm{Distance}$

The output elasticity with respect to car journey time increase should not produce high values in excess of -2.0.

4.7.3 Public Transport Fares

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 GY Base Model

5.1 Background

This Chapter presents the results of the calibration of the GYVDM base year demand model. Following the construction of the demand model, a series of tests must 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, 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

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.

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:

- $Time_{walk}$ is total walking time from and to the car;
- $Weight_{walk}$ is the weight to be applied to walking time;
- $Time_{Car}$ is journey time spent in the car;
- VOC is the vehicle operating costs per kilometre of a journey of Dist km;
- $Dist_{Car}$ 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;

- $Time_{PT}$ 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;
- $Fare_{PT}$ 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

The calibration of the GYVDM demand model was tested using 2016 Base year validated demand matrices, with the following parameters, consistent with the WebTAG guidance. Tables 5-1 to 5-5 provide parameters required to carry out Realism tests.

Table 5-1 Highway Generalised Costs – Pivot Point (Base Year 2016)

User Class	Pence Per Minute			Pence Per Kilometre		
	AM	IP	PM	AM	IP	PM
Business	47.46	46.38	45.63	12.16	12.16	12.16
Commute	14.00	13.89	13.70	5.63	5.63	5.63
Other	17.79	18.49	19.04	5.63	5.63	5.63

Table 5-2 Highway Generalised Costs – with 20% Increase in Fuel Costs

User Class	Pence Per Minute			Pence Per Kilometre		
	AM	IP	PM	AM	IP	PM
Business	47.46	46.38	45.63	13.10	13.10	13.10
Commute	14.00	13.89	13.70	6.75	6.75	6.75
Other	17.79	18.49	19.04	6.75	6.75	6.75

Table 5-3 PT Generalised Costs – Pivot Point (Base Year 2016)

User Class	Pence Per Minute		
	AM	IP	PM
Business	25.10	25.10	25.10
Commute	12.24	12.24	12.24
Other	10.86	10.86	10.86

Table 5-4 Car Occupancy - Base Year 2016

User Class	AM Period	Inter-Peak	PM Period	Off-Peak
Business	1.213	1.178	1.154	1.166
Commute	1.144	1.135	1.119	1.121
Other	1.638	1.703	1.753	1.714

Table 5-5 Reference Case Matrix Totals (persons) - Base Year 2016

Purpose	Format	AM period	IP Period	PM Period	OP Period	24hr Total
HB Trips						
HB Commute (PA)	from Home	6,636	2,661	1,096	2,805	**13,198**
	return Home	604	2,472	4,827	1,886	**9,789**
	Total	**7,239**	**5,133**	**5,924**	**4,691**	**22,987**
HB Education (PA)	from Home	828	1,239	731	563	**3,360**
	return Home	325	1,750	4,227	1,419	**7,722**
	Total	**1,153**	**2,989**	**4,958**	**1,982**	**11,082**
HB Other (PA)	from Home	10,849	16,874	5,193	4,567	**37,482**
	return Home	3,254	19,288	11,476	9,915	**43,934**
	Total	**14,104**	**36,162**	**16,669**	**14,482**	**81,416**
HB Business (PA)	from Home	732	496	126	300	**1,654**
	return Home	72	594	554	320	**1,541**
	Total	**804**	**1,089**	**680**	**621**	**3,194**
NHB Trips						
NHB Other (OD)	Total	5,736	21,578	13,557	9,793	**50,663**
NHB Business (OD)	Total	1,067	4,159	1,397	1,566	**8,190**

5.4 Fuel Cost Elasticity

Tests have been 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.

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 5-6 below provides a summary of convergence and elasticity resulted from the three tests with zero trip frequency and minimum, median, and maximum values of destination choice lambda.

Table 5-6 Car Fuel Elasticity without Frequency Choice

Test	Purpose		Choice responses			Outturn Elasticity				Gap (%)
			Freq	Mode	Dest	AM	IP	PM	24-Hour	
no frequency + minimum values										
1	HBEB	Business	0.00	0.36	0.038	-0.108	-0.110	-0.094	-0.105	8/ 0.029
	NHBEB		0.00	0.73	0.069					
	HBW	Commute	0.00	0.50	0.054	-0.036	-0.045	-0.039	-0.039	
	HBED	Other	0.00	0.27	0.074	-0.311	-0.340	-0.260	-0.312	
	HBO		0.00	0.27	0.074					
	NHBED		0.00	0.62	0.073					
	NHBO		0.00	0.62	0.073					
	Car					**-0.152**	**-0.244**	**-0.147**	**-0.190**	
no frequency + median values										
2	HBEB	Business	0.00	0.45	0.067	-0.159	-0.138	-0.132	-0.142	8/ 0.034
	NHBEB		0.00	0.73	0.081					
	HBW	Commute	0.00	0.68	0.065	-0.054	-0.076	-0.057	-0.061	
	HBED	Other	0.00	0.53	0.090	-0.370	-0.399	-0.309	-0.368	
	HBO		0.00	0.53	0.090					
	NHBED		0.00	0.81	0.077					
	NHBO		0.00	0.81	0.077					
	Car					**-0.189**	**-0.292**	**-0.181**	**-0.231**	
no frequency + maximum values										
3	HBEB	Business	0.00	0.65	0.106	-0.230	-0.183	-0.185	-0.195	9/ 0.028
	NHBEB		0.00	0.73	0.107					
	HBW	Commute	0.00	0.83	0.113	-0.113	-0.182	-0.119	-0.133	
	HBED	Other	0.00	1.00	0.160	-0.618	-0.644	-0.511	-0.602	
	HBO		0.00	1.00	0.160					
	NHBED		0.00	1.00	0.105					
	NHBO		0.00	1.00	0.105					
	Car					**-0.322**	**-0.478**	**-0.307**	**-0.383**	

It can be seen that without trip frequency responses, it was not possible to achieve the recommended elasticity set out by the WebTAG guidance, particularly the order of magnitude regarding the outturn elasticity for each purpose as recommended by the DfT. It can be seen that the outturn elasticity for Business is higher than -0.1 as recommended by the DfT. The elasticity for commute, however, is lower than recommended range. This is anticipated given the geographical location and nature of the study area:

- Limited number of employment locations and access routes available. Example is A47 to Norwich, A12, AA143 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.

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 would need 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.

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.

Further tests were therefore carried out 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 5-7 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 5-7 Car Fuel Elasticity with Frequency Choice Included

Test	Purpose		Choice responses			Outturn Elasticity				Gap (%)
			Freq	Mode	Dest	AM	IP	PM	24-Hour	
With frequency included + minimum values										
4	HBEB	Business	0.00	0.36	0.038	-0.108	-0.109	-0.088	-0.103	8/ 0.032
	NHBEB		0.00	0.73	0.069					
	HBW	Commute	0.20	0.50	0.054	-0.103	-0.144	-0.107	-0.116	
	HBED	Other	0.20	0.27	0.074	-0.346	-0.377	-0.304	-0.351	
	HBO		0.20	0.27	0.074					
	NHBED		0.20	0.62	0.073					
	NHBO		0.20	0.62	0.073					
	Car					**-0.200**	**-0.290**	**-0.198**	**-0.238**	
With frequency included + median values										
5	HBEB	Business	0.00	0.45	0.067	-0.157	-0.136	-0.127	-0.139	8/ 0.038
	NHBEB		0.00	0.73	0.081					
	HBW	Commute	0.20	0.68	0.065	-0.161	-0.234	-0.166	-0.182	
	HBED	Other	0.20	0.53	0.090	-0.443	-0.472	-0.387	-0.442	
	HBO		0.20	0.53	0.090					
	NHBED		0.20	0.81	0.077					
	NHBO		0.20	0.81	0.077					
	Car					**-0.272**	**-0.374**	**-0.266**	**-0.313**	
With frequency included + maximum values										
6	HBEB	Business	0.00	0.65	0.106	-0.224	-0.176	-0.175	-0.187	

Test	Purpose		Choice responses			Outturn Elasticity				Gap (%)
			Freq	Mode	Dest	AM	IP	PM	24-Hour	
	NHBEB		0.00	0.73	0.107					9/ 0.031
	HBW	Commute	0.20	0.83	0.113	-0.326	-0.492	-0.335	-0.372	
	HBED	Other	0.20	1.00	0.160	-0.817	-0.835	-0.703	-0.794	
	HBO		0.20	1.00	0.160					
	NHBED		0.20	1.00	0.105					
	NHBO		0.20	1.00	0.105					
	Car					**-0.507**	**-0.668**	**-0.490**	**-0.570**	

Increases in fuel elasticity are only achieved if the effect of trip frequency for Commuting and Discretionary trips is stronger due to the reasoning identified above.

Incorporating this requirement it was possible to derive a set of final destination choice parameters calibrating the base demand model and achieving the recommended target elasticity. Table 5-8 below provides a summary of the test with the final destination choice lambda values.

Table 5-8 Car Fuel Elasticity with Final Set of Values

Test	Purpose		Choice responses			Outturn Elasticity				Gap (%)
			Freq	Mode	Dest	AM	IP	PM	24-Hour	
With frequency included + final values										
7	HBEB	Business	0.00	0.36	0.038	-0.107	-0.108	-0.087	-0.103	8/ 0.043
	NHBEB		0.00	0.73	0.069					
	HBW	Commute	0.20	0.73	0.068	-0.180	-0.264	-0.186	-0.204	
	HBED	Other	0.20	0.41	0.083	-0.397	-0.428	-0.347	-0.399	
	HBO		0.20	0.41	0.083					
	NHBED		0.20	0.72	0.075					
	NHBO		0.20	0.72	0.075					
	Car					**-0.259**	**-0.349**	**-0.252**	**-0.295**	

As can be seen from Table 5-8, the model achieved the overall elasticity of -0.295 with respect to change in fuel costs, within the recommended acceptable range from -0.25 to -0.35 from the WebTAG M2 guidance. The resultant elasticities also shows 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 to the resultant elasticity is weaker for the AM and PM peak and stronger for the Inter-Peak, consistent with WebTAG [12].

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[12] WebTAG M2, para. 6.4.17

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

The car journey time elasticity was carried out on the final set of frequency and destination choice parameters. Table 5-9 below provides a summary of the test with journey time elasticity.

Table 5-9 Journey Time Elasticity with Final Set of Values

Test	Purpose		Choice responses			Outturn Elasticity				Gap (%)
			Freq	Mode	Dest	AM	IP	PM	24-Hour	
With frequency included + final values										
8	HBEB	Business	0.00	0.36	0.038	-0.371	-0.338	-0.301	-0.336	2/ NA
	NHBEB		0.00	0.73	0.069					
	HBW	Commute	0.20	0.73	0.068	-0.199	-0.271	-0.216	-0.224	
	HBED	Other	0.20	0.41	0.083	-0.427	-0.455	-0.421	-0.440	
	HBO		0.20	0.41	0.083					
	NHBED		0.20	0.72	0.075					
	NHBO		0.20	0.72	0.075					
	Car					**-0.306**	**-0.399**	**-0.320**	**-0.350**	

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

The 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 2016 costs;
- Forecast scenario: Core scenario, Core + Harfreys roundabout option, Low growth and High growth scenarios.

This note reports the output from the GYVDM demand model for the Core scenario, the Core sensitivity, 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

Tables 6-1 to 6-5 below summarise the input parameters that were used for the GYVDM forecast models.

Table 6-1 Generalised Cost Parameters – Forecast Years

User Class	Pence Per Minute			Pence Per Kilometre		
	AM	IP	PM	AM	IP	PM
Opening Year 2023						
Business	52.72	51.60	50.70	11.98	11.98	11.98
Commute	15.53	15.42	15.23	5.46	5.46	5.46
Other	19.49	20.26	20.92	5.46	5.46	5.46
Design Year 2038						
Business	70.47	69.12	67.79	11.74	11.74	11.74
Commute	20.72	20.59	20.38	5.30	5.30	5.30
Other	25.44	26.41	27.40	5.30	5.30	5.30
Horizon Year 2051						
Business	89.55	87.84	86.14	11.94	11.94	11.94
Commute	26.33	26.16	25.90	5.54	5.54	5.54
Other	32.33	33.56	34.81	5.54	5.54	5.54

Table 6-2 Car Occupancy – Forecast Years

User Class	AM Period	Inter-Peak	PM Period	Off-Peak
Opening Year 2023				
Business	1.206	1.173	1.147	1.160
Commute	1.137	1.129	1.115	1.117
Other	1.608	1.671	1.726	1.691
Opening Year 2038				
Business	1.193	1.164	1.136	1.150
Commute	1.126	1.119	1.107	1.110
Other	1.557	1.617	1.677	1.650
Horizon Year 2051				
Business	1.193	1.164	1.136	1.150
Commute	1.126	1.119	1.107	1.110
Other	1.557	1.617	1.677	1.650

Table 6-3 Reference Case Matrix Totals – Opening Year 2023

Purpose	Format	AM period	IP Period	PM Period	OP Period	24hr Total
HB Trips						
HB Commute (PA)	from Home	6,928	2,743	1,112	2,929	**13,712**
	return Home	629	2,588	5,071	1,969	**10,257**
	Total	**7,557**	**5,331**	**6,183**	**4,898**	**23,968**
HB Education (PA)	from Home	926	1,370	817	632	**3,745**
	return Home	346	2,026	4,725	1,594	**8,692**
	Total	**1,273**	**3,396**	**5,542**	**2,226**	**12,437**
HB Other (PA)	from Home	11,644	18,265	5,674	4,933	**40,517**
	return Home	3,488	20,781	12,116	10,711	**47,097**
	Total	**15,133**	**39,046**	**17,791**	**15,644**	**87,613**
HB Business (PA)	from Home	778	527	135	319	**1,759**
	return Home	76	633	589	341	**1,638**
	Total	**854**	**1,160**	**724**	**660**	**3,398**
NHB Trips						
NHB Other (OD)	Total	6,084	23,117	14,500	10,516	**54,217**
NHB Business (OD)	Total	1,107	4,357	1,447	1,634	**8,545**

Table 6-4 Reference Matrix Totals – Design Year 2038

Purpose	Format	AM period	IP Period	PM Period	OP Period	24hr Total
HB Trips						
HB Commute (PA)	from Home	7,414	2,905	1,153	3,130	**14,603**
	return Home	655	2,752	5,451	2,104	**10,963**
	Total	**8,068**	**5,657**	**6,605**	**5,235**	**25,565**
HB Education (PA)	from Home	1,089	1,614	937	747	**4,387**
	return Home	385	2,519	5,401	1,884	**10,189**
	Total	**1,474**	**4,132**	**6,338**	**2,631**	**14,575**
HB Other (PA)	from Home	13,046	20,744	6,493	5,534	**45,816**
	return Home	3,757	22,889	13,220	12,015	**51,882**
	Total	**16,804**	**43,633**	**19,713**	**17,549**	**97,698**
HB Business (PA)	from Home	841	580	147	348	**1,916**
	return Home	79	692	644	372	**1,787**
	Total	**920**	**1,272**	**792**	**720**	**3,703**
NHB Trips						
NHB Other (OD)	Total	6,674	25,903	16,132	11,801	**60,511**
NHB Business (OD)	Total	1,194	4,669	1,538	1,750	**9,151**

Table 6-5 Reference Matrix Totals – Horizon Year 2051

Purpose	Format	AM period	IP Period	PM Period	OP Period	24hr Total
HB Trips						
HB Commute (PA)	from Home	7,891	3,070	1,234	3,319	**15,514**
	return Home	702	2,893	5,759	2,231	**11,585**
	Total	**8,594**	**5,963**	**6,993**	**5,550**	**27,100**
HB Education (PA)	from Home	1,203	1,762	1,016	819	**4,801**
	return Home	424	2,744	5,936	2,067	**11,171**
	Total	**1,627**	**4,507**	**6,952**	**2,886**	**15,972**
HB Other (PA)	from Home	14,405	22,651	7,067	6,086	**50,209**
	return Home	4,188	25,305	14,530	13,214	**57,238**
	Total	**18,593**	**47,956**	**21,597**	**19,300**	**107,447**
HB Business (PA)	from Home	902	626	158	374	**2,060**
	return Home	85	745	691	399	**1,921**
	Total	**987**	**1,371**	**849**	**774**	**3,981**
NHB Trips						
NHB Other (OD)	Total	7,306	28,396	17,678	12,933	**66,313**
NHB Business (OD)	Total	1,288	5,002	1,654	1,878	**9,822**

The input parameters were used to carry out GYVDM forecast demand models. Tables 6-6 to 6-8 below provide a high level summary of change in forecast demand from the reference demand as a result from the GYVDM demand model.

Table 6-6 Change in Matrix Totals from GYVDM – Opening Year 2023

Period	Purpose	Matrix Totals (veh)			%Difference	
		Ref.	DM	DS	DM – Ref.	DS - DM
AM Peak	Business	919	918	921	-0.1%	0.3%
	Commute	5,371	5,387	5,439	0.3%	1.0%
	Other	8,652	8,623	8,701	-0.3%	0.9%
	Car	**14,942**	**14,929**	**15,061**	**-0.1%**	**0.9%**
	LGV	2,925	2,925	2,925	0.0%	0.0%
	HGV	1,423	1,423	1,423	0.0%	0.0%
Inter-Peak	Business	1,005	1,006	1,005	0.1%	-0.1%
	Commute	1,574	1,590	1,595	1.0%	0.3%
	Other	10,982	10,984	11,016	0.0%	0.3%
	Car	**13,561**	**13,580**	**13,615**	**0.1%**	**0.3%**
	LGV	2,236	2,236	2,236	0.0%	0.0%
	HGV	1,348	1,348	1,348	0.0%	0.0%
PM Peak	Business	946	946	947	0.0%	0.1%
	Commute	4,823	4,838	4,873	0.3%	0.7%
	Other	10,992	10,956	10,984	-0.3%	0.3%
	Car	**16,761**	**16,740**	**16,803**	**-0.1%**	**0.4%**
	LGV	2,496	2,496	2,496	0.0%	0.0%
	HGV	806	806	806	0.0%	0.0%
24-Hours	Business	13,205	13,207	13,211	0.0%	0.0%
	Commute	45,462	45,680	46,004	0.5%	0.7%
	Other	141,804	141,597	142,174	-0.1%	0.4%
	Car	**200,471**	**200,484**	**201,389**	**0.0%**	**0.5%**
	LGV	33,704	33,704	33,704	0.0%	0.0%
	HGV	16,775	16,775	16,775	0.0%	0.0%

Table 6-7 Change in Matrix Totals from GYVDM – Design Year 2038

Period	Purpose	Matrix Totals (veh)			%Difference	
		Ref.	DM	DS	DM – Ref.	DS - DM
AM Peak	Business	1,001	1,000	1,004	-0.2%	0.4%
	Commute	5,791	5,870	5,961	1.4%	1.5%
	Other	9,973	9,913	10,037	-0.6%	1.3%
	Car	**16,765**	**16,783**	**17,001**	**0.1%**	**1.3%**
	LGV	3,840	3,840	3,840	0.0%	0.0%
	HGV	1,661	1,661	1,661	0.0%	0.0%
Inter-Peak	Business	1,094	1,096	1,094	0.2%	-0.2%
	Commute	1,685	1,742	1,745	3.4%	0.2%
	Other	12,759	12,797	12,827	0.3%	0.2%
	Car	**15,538**	**15,635**	**15,666**	**0.6%**	**0.2%**
	LGV	2,936	2,936	2,936	0.0%	0.0%
	HGV	1,573	1,573	1,573	0.0%	0.0%
PM Peak	Business	1,031	1,030	1,033	0.0%	0.2%
	Commute	5,190	5,257	5,326	1.3%	1.3%
	Other	12,595	12,478	12,591	-0.9%	0.9%
	Car	**18,815**	**18,765**	**18,950**	**-0.3%**	**1.0%**
	LGV	3,277	3,277	3,277	0.0%	0.0%
	HGV	942	942	942	0.0%	0.0%
24-Hours	Business	14,377	14,385	14,394	0.1%	0.1%
	Commute	48,898	49,785	50,352	1.8%	1.1%
	Other	163,883	163,541	164,546	-0.2%	0.6%
	Car	**227,158**	**227,710**	**229,292**	**0.2%**	**0.7%**
	LGV	44,259	44,259	44,259	0.0%	0.0%
	HGV	19,583	19,583	19,583	0.0%	0.0%

Table 6-8 Change in Matrix Totals from GYVDM – Horizon Year 2051

Period	Purpose	Matrix Totals (veh)			%Difference	
		Ref.	DM	DS	DM – Ref.	DS - DM
AM Peak	Business	1,077	1,074	1,079	-0.3%	0.4%
	Commute	6,168	6,257	6,373	1.4%	1.8%
	Other	11,012	10,895	11,046	-1.1%	1.4%
	Car	**18,257**	**18,226**	**18,497**	**-0.2%**	**1.5%**
	LGV	4,592	4,592	4,592	0.0%	0.0%
	HGV	1,892	1,892	1,892	0.0%	0.0%
Inter-Peak	Business	1,174	1,177	1,175	0.2%	-0.2%
	Commute	1,776	1,853	1,861	4.3%	0.4%
	Other	14,008	14,025	14,103	0.1%	0.6%
	Car	**16,958**	**17,054**	**17,138**	**0.6%**	**0.5%**
	LGV	3,511	3,511	3,511	0.0%	0.0%
	HGV	1,791	1,791	1,791	0.0%	0.0%
PM Peak	Business	1,106	1,107	1,109	0.1%	0.2%
	Commute	5,495	5,578	5,662	1.5%	1.5%
	Other	13,802	13,630	13,769	-1.2%	1.0%
	Car	**20,403**	**20,316**	**20,541**	**-0.4%**	**1.1%**
	LGV	3,919	3,919	3,919	0.0%	0.0%
	HGV	1,074	1,074	1,074	0.0%	0.0%
24-Hours	Business	15,441	15,453	15,462	0.1%	0.1%
	Commute	51,842	52,952	53,687	2.1%	1.4%
	Other	180,047	179,178	180,696	-0.5%	0.8%
	Car	**247,330**	**247,584**	**249,845**	**0.1%**	**0.9%**
	LGV	52,926	52,926	52,926	0.0%	0.0%
	HGV	22,302	22,302	22,302	0.0%	0.0%

In general, 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.

It is noteworthy that for the inter-peak period and specifically for Commute trips across the three periods, the GYVDM demand model produces induced traffic for the Do-Minimum demand. This can be explained as the future reduction in generalised costs resultant from increased VoT compared against the slight reduction in VoC relative to the base year 2016 outweighs the increase in delay resultant from the growth in demand between the base year 2016 and the forecast years.

Investigation of the travel costs in the forecast year's reference case Do-Minimum assignments at the 24-hours shows that travel costs per trips for Commuting reduces by

0.2%, 2.5% and 0.3% in the Opening year 2023, design year 2038 and horizon year 2051 respectively relative to the base year 2016, whereas the travel costs per trips for Business and Other show generally increase in the forecast years. This is in line with the outputs from the variable demand, i.e. general induction of traffic for commuting in the Do-minimum and suppression of traffic for business and other purposes.

Table 6-9 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.

Table 6-9 Change in Costs per Trip from Base 2016

	2016				DM2023				DM2038				DM2051			
PPM	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**
Business	47.46	46.38	45.63		52.72	51.60	50.70		70.47	69.12	67.79		89.55	87.84	86.14	
Commute	14.00	13.89	13.70		15.53	15.42	15.23		20.72	20.59	20.38		26.33	26.16	25.90	
Other	17.79	18.49	19.04		19.49	20.26	20.92		25.44	26.41	27.40		32.33	33.56	34.81	
PPK	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**
Business	12.16	12.16	12.16		11.98	11.98	11.98		11.74	11.74	11.74		11.94	11.94	11.94	
Commute	5.63	5.63	5.63		5.46	5.46	5.46		5.30	5.30	5.30		5.54	5.54	5.54	
Other	5.63	5.63	5.63		5.46	5.46	5.46		5.30	5.30	5.30		5.54	5.54	5.54	
Trip (veh)	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**
Business	868	950	895	12,484	919	1,005	946	13,205	1,001	1,094	1,031	14,377	1,077	1,174	1,106	15,441
Commute	5,114	1,507	4,605	43,387	5,371	1,574	4,823	45,462	5,791	1,685	5,190	48,898	6,168	1,776	5,495	51,842
Other	7,895	9,967	10,082	129,208	8,652	10,982	10,992	141,804	9,973	12,759	12,595	163,883	11,012	14,008	13,802	180,047
Time (veh.hr)	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**
Business	306	314	331	4,312	344	344	368	4,768	403	393	436	5,534	466	454	499	6,385
Commute	1,660	534	1,655	14,937	1,855	576	1,836	16,503	2,171	644	2,148	19,109	2,493	724	2,422	21,681
Other	1,558	1,936	2,117	25,720	1,898	2,282	2,520	30,613	2,417	2,828	3,238	38,550	2,924	3,418	3,875	46,468
Dist (veh.kms)	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**
Business	18,763	20,003	20,300	269,449	19,896	21,286	21,495	286,125	21,614	23,013	23,538	310,714	23,329	24,738	25,396	334,646
Commute	94,676	33,885	97,369	885,400	100,026	35,511	102,807	933,246	107,674	37,669	110,238	999,338	115,119	39,755	116,999	########
Other	76,221	100,083	105,362	########	86,931	113,335	117,329	########	99,447	129,985	133,902	########	109,241	141,684	146,584	########
Cost per Trips	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**
Business	26.68	25.36	28.21	359.94	27.34	25.45	28.69	364.41	27.74	25.11	29.33	365.63	28.87	26.09	30.22	379.17
Commute	26.92	30.38	30.25	401.89	27.27	29.95	30.47	400.92	27.25	28.69	30.36	391.86	28.17	29.20	31.00	400.66
Other	14.89	14.71	15.69	204.47	15.98	15.25	16.54	214.74	16.62	15.34	17.48	220.77	17.63	16.31	18.53	234.39
% from Base	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**	**AM**	**IP**	**PM**	**24-Hr**
Business	0.0%	0.0%	0.0%	0.0%	2.5%	0.3%	1.7%	1.2%	3.9%	-1.0%	4.0%	1.6%	8.2%	2.9%	7.1%	5.3%
Commute	0.0%	0.0%	0.0%	0.0%	1.3%	-1.4%	0.7%	-0.2%	1.2%	-5.6%	0.3%	-2.5%	4.7%	-3.9%	2.5%	-0.3%
Other	0.0%	0.0%	0.0%	0.0%	7.3%	3.7%	5.4%	5.0%	11.6%	4.3%	11.4%	8.0%	18.4%	10.9%	18.1%	14.6%

A full report of the forecasting process is included within the forthcoming Great Yarmouth Third River Crossing Forecast Report.

7 Summary

7.1 Overview

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.

7.2 Summary

The GYVDM demand model was calibrated for the base year of 2016. 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.

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.

The outcome of the realism tests show that the GYVDM base demand model behave 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.

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.

A Traffic Forecasting Report will supplement the detail contained herein.

Appendix A – Realism Test Summary

Table A-1 Test 1: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-70.6851	5997.99	177496.7	3227037	4.17203
2	0.5	-34.4896	1417.19	177409.4	3174714	2.05063
3	0.5	-16.8731	336.73	177366.4	3149441	1.00493
4	0.5	-8.25876	79.98	177345.2	3137107	0.49102
5	0.5	-4.0521	19.25	177334.7	3131184	0.24135
6	0.5	-1.97875	4.56	177329.6	3128253	0.1181
7	0.5	-0.97307	1.11	177327	3126877	0.05873
8	0.5	-0.47628	0.27	177325.8	3126186	0.02927

Table A-2 Test 1: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	868.36	867.92	18759.92	18392.81	-0.108
	Commute	5112.82	5101.73	94634.93	94013.37	-0.036
	Other	7894.22	7891.05	76194.98	71988.94	-0.311
	Car	13875.41	13860.7	189589.8	184395.1	-0.152
Inter-Peak	Business	950.06	950.1	19983.74	19586.34	-0.11
	Commute	1507.31	1503.81	33872.94	33594.28	-0.045
	Other	9964.46	9959.29	99951.18	93935.11	-0.34
	Car	12421.82	12413.21	153807.9	147115.7	-0.244
PM Peak	Business	894.56	893.94	20298.69	19954.92	-0.094
	Commute	4603.74	4591.12	97334.99	96653.04	-0.039
	Other	10081.61	10076.72	105331.1	100445.5	-0.26
	Car	15579.91	15561.77	222964.7	217053.4	-0.147
24-Hours	Business	12482.26	12478.95	269302	264171.6	-0.105
	Commute	43378.96	43274.28	885064	878722.3	-0.039
	Other	129185.1	129122.4	1300041	1228054	-0.312
	Car	185046.4	184875.7	2454407	2370948	-0.19

Table A-3 Test 2: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-82.4447	7910.59	177496.7	3227037	4.83743
2	0.5	-40.113	1850.15	177334.8	3164747	2.37177
3	0.5	-19.5711	435.3	177255.4	3134753	1.1562
4	0.5	-9.54852	103.5	177216.4	3120357	0.56723
5	0.5	-4.66432	24.83	177197.3	3113425	0.2791
6	0.5	-2.27661	5.91	177187.8	3110029	0.13706
7	0.5	-1.11213	1.41	177183.1	3108383	0.06747
8	0.5	-0.53826	0.35	177180.8	3107589	0.03365

Table A-4 Test 2: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	868.36	867.48	18759.92	18222.49	-0.159
	Commute	5112.82	5094.02	94634.93	93713.12	-0.054
	Other	7894.22	7884.73	76194.98	71221.8	-0.37
	Car	13875.41	13846.23	189589.8	183157.4	-0.189
Inter-Peak	Business	950.06	950.18	19983.74	19485.84	-0.138
	Commute	1507.31	1500.88	33872.94	33407.96	-0.076
	Other	9964.46	9952.08	99951.18	92938.1	-0.399
	Car	12421.82	12403.13	153807.9	145831.9	-0.292
PM Peak	Business	894.56	893.46	20298.69	19816.84	-0.132
	Commute	4603.74	4583.62	97334.99	96327.32	-0.057
	Other	10081.61	10069.15	105331.1	99563.49	-0.309
	Car	15579.91	15546.22	222964.7	215707.7	-0.181
24-Hours	Business	12482.26	12476.3	269302	262436.1	-0.142
	Commute	43378.96	43202.46	885064	875319.1	-0.061
	Other	129185.1	129026	1300041	1215639	-0.368
	Car	185046.4	184704.7	2454407	2353394	-0.231

Table A-5 Test 3: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-121.874	17823.04	177496.7	3227037	7.56311
2	0.5	-58.9201	4027.49	177053.5	3125674	3.66707
3	0.5	-28.6029	928.67	176841	3078109	1.78453
4	0.5	-13.9135	218.59	176738.8	3055810	0.87435
5	0.5	-6.77928	51.3	176688.7	3045028	0.42841
6	0.5	-3.31017	12.25	176664.4	3039901	0.21059
7	0.5	-1.61271	2.91	176652.5	3037446	0.10449
8	0.5	-0.7905	0.69	176646.6	3036244	0.05157
9	0.5	-0.39094	0.24	176643.7	3035665	0.02756

Table A-6 Test 3: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	868.36	866.71	18759.92	17988.6	-0.23
	Commute	5112.82	5071.11	94634.93	92711.1	-0.113
	Other	7894.22	7857.77	76194.98	68079.48	-0.618
	Car	13875.41	13795.58	189589.8	178779.2	-0.322
Inter-Peak	Business	950.06	950.1	19983.74	19328.53	-0.183
	Commute	1507.31	1491.84	33872.94	32770.28	-0.182
	Other	9964.46	9922.13	99951.18	88880.89	-0.644
	Car	12421.82	12364.06	153807.9	140979.7	-0.478
PM Peak	Business	894.56	892.82	20298.69	19625.09	-0.185
	Commute	4603.74	4561.43	97334.99	95251.45	-0.119
	Other	10081.61	10039.12	105331.1	95960.47	-0.511
	Car	15579.91	15493.37	222964.7	210837	-0.307
24-Hours	Business	12482.26	12470.93	269302	259914	-0.195
	Commute	43378.96	42987.19	885064	863891.7	-0.133
	Other	129185.1	128627.6	1300041	1164999	-0.602
	Car	185046.4	184085.7	2454407	2288805	-0.383

Table A-7 Test 4: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-71.3663	5966.54	177496.7	3227037	4.57294
2	0.5	-34.7238	1397.07	177086.9	3162214	2.24637
3	0.5	-16.9362	329.88	176889.4	3130973	1.09735
4	0.5	-8.26004	78.71	176794.2	3116030	0.53857
5	0.5	-4.02278	18.74	176748	3108810	0.26403
6	0.5	-1.9691	4.5	176725.4	3105287	0.12983
7	0.5	-0.96248	1.07	176714.4	3103567	0.06376
8	0.5	-0.47448	0.27	176709.1	3102730	0.03179

Table A-8 Test 4: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	868.36	867.93	18759.92	18395.01	-0.108
	Commute	5112.82	5063.92	94634.93	92869.84	-0.103
	Other	7894.22	7871.06	76194.98	71530.8	-0.346
	Car	13875.41	13802.91	189589.8	182795.7	-0.2
Inter-Peak	Business	950.06	950.09	19983.74	19589.67	-0.109
	Commute	1507.31	1490.91	33872.94	32992.53	-0.144
	Other	9964.46	9931.5	99951.18	93305.79	-0.377
	Car	12421.82	12372.5	153807.9	145888	-0.29
PM Peak	Business	894.56	893.98	20298.69	19975.59	-0.088
	Commute	4603.74	4555.57	97334.99	95446.45	-0.107
	Other	10081.61	10048.15	105331.1	99652.49	-0.304
	Car	15579.91	15497.69	222964.7	215074.5	-0.198
24-Hours	Business	12482.26	12479	269302	264272.4	-0.103
	Commute	43378.96	42936.39	885064	866612.1	-0.116
	Other	129185.1	128767.5	1300041	1219499	-0.351
	Car	185046.4	184182.9	2454407	2350383	-0.238

Table A-9 Test 5: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-83.8824	7912.29	177496.7	3227037	5.63152
2	0.5	-40.6205	1821.8	176768.4	3142915	2.74946
3	0.5	-19.7118	425.42	176423.7	3103044	1.34
4	0.5	-9.59301	101.38	176259.9	3084293	0.65748
5	0.5	-4.67663	24	176180.4	3074986	0.32286
6	0.5	-2.27961	5.68	176143.1	3070625	0.15751
7	0.5	-1.11434	1.37	176125.2	3068567	0.0773
8	0.5	-0.54325	0.33	176116.3	3067533	0.0383

Table A-10 Test 5: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	868.36	867.51	18759.92	18229.58	-0.157
	Commute	5112.82	5033.62	94634.93	91896.08	-0.161
	Other	7894.22	7844.36	76194.98	70284.71	-0.443
	Car	13875.41	13745.49	189589.8	180410.4	-0.272
Inter-Peak	Business	950.06	950.12	19983.74	19493	-0.136
	Commute	1507.31	1480.26	33872.94	32456.69	-0.234
	Other	9964.46	9897.97	99951.18	91713.06	-0.472
	Car	12421.82	12328.36	153807.9	143662.8	-0.374
PM Peak	Business	894.56	893.61	20298.69	19835.46	-0.127
	Commute	4603.74	4527.17	97334.99	94432.25	-0.166
	Other	10081.61	10017.04	105331.1	98157.12	-0.387
	Car	15579.91	15437.82	222964.7	212424.8	-0.266
24-Hours	Business	12482.26	12476.55	269302	262572.6	-0.139
	Commute	43378.96	42663.81	885064	856185.5	-0.182
	Other	129185.1	128342	1300041	1199300	-0.442
	Car	185046.4	183482.3	2454407	2318058	-0.313

Table A-11 Test 6: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-124.697	18605.22	177496.7	3227037	9.52904
2	0.5	-59.8051	4086.62	175695.7	3076498	4.58809
3	0.5	-28.8421	936.65	174890.9	3008444	2.22201
4	0.5	-13.9165	218.3	174522.4	2977055	1.08275
5	0.5	-6.74167	51.59	174350.4	2962284	0.52954
6	0.5	-3.24979	12.11	174269.6	2955237	0.25858
7	0.5	-1.58743	2.94	174231.9	2952001	0.12795
8	0.5	-0.76568	0.7	174213.3	2950347	0.06295
9	0.5	-0.37783	0.17	174205	2949639	0.03099

Table A-12 Test 6: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	868.36	866.77	18759.92	18009.37	-0.224
	Commute	5112.82	4952.1	94634.93	89179.4	-0.326
	Other	7894.22	7747.89	76194.98	65655.1	-0.817
	Car	13875.41	13566.76	189589.8	172843.9	-0.507
Inter-Peak	Business	950.06	950.01	19983.74	19352.45	-0.176
	Commute	1507.31	1451.69	33872.94	30969.4	-0.492
	Other	9964.46	9781.16	99951.18	85842.58	-0.835
	Car	12421.82	12182.86	153807.9	136164.4	-0.668
PM Peak	Business	894.56	893.16	20298.69	19659.69	-0.175
	Commute	4603.74	4450.84	97334.99	91563.84	-0.335
	Other	10081.61	9906.09	105331.1	92667.87	-0.703
	Car	15579.91	15250.09	222964.7	203891.4	-0.49
24-Hours	Business	12482.26	12471.73	269302	260265.9	-0.187
	Commute	43378.96	41931.25	885064	827015.5	-0.372
	Other	129185.1	126838.9	1300041	1124803	-0.794
	Car	185046.4	181241.9	2454407	2212084	-0.57

Table A-13 Test 7: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-78.5137	7108.46	177496.7	3227037	5.29243
2	0.5	-38.0786	1645.36	176863.9	3148931	2.58908
3	0.5	-18.4918	385.07	176562.6	3111686	1.26374
4	0.5	-9.00348	91.81	176418.9	3094109	0.61991
5	0.5	-4.39211	21.74	176349.2	3085408	0.30442
6	0.5	-2.14	5.41	176316.3	3081473	0.15168
7	0.5	-1.04821	1.43	176299.7	3079288	0.07844
8	0.5	-0.51375	0.49	176292.5	3078529	0.04259

Table A-14 Test 7: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	868.36	867.88	18759.92	18396.45	-0.107
	Commute	5112.82	5024.03	94634.93	91586.14	-0.18
	Other	7894.22	7857.74	76194.98	70872.07	-0.397
	Car	13875.41	13749.65	189589.8	180854.7	-0.259
Inter-Peak	Business	950.06	950.03	19983.74	19592.49	-0.108
	Commute	1507.31	1476.85	33872.94	32284.06	-0.264
	Other	9964.46	9914.15	99951.18	92451.94	-0.428
	Car	12421.82	12341.03	153807.9	144328.5	-0.349
PM Peak	Business	894.56	893.98	20298.69	19979.53	-0.087
	Commute	4603.74	4517.88	97334.99	94096.51	-0.186
	Other	10081.61	10033.22	105331.1	98877.13	-0.347
	Car	15579.91	15445.08	222964.7	212953.2	-0.252
24-Hours	Business	12482.26	12478.46	269302	264310	-0.103
	Commute	43378.96	42576.21	885064	852808.4	-0.204
	Other	129185.1	128552.9	1300041	1208792	-0.399
	Car	185046.4	183607.6	2454407	2325910	-0.295

Table A-15 Test 8: Convergence Summary

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	-130.949	30926.88	177496.7	3097071	12.86163

Table A-16 Test 8: Elasticity Summary

Period	Purpose	Total Trips (vehs)		Total Costs (veh.km)		Elasticity
		Ref.	Forecast	Ref.	Forecast	
AM Peak	Business	868.36	865.81	18759.92	17534.44	-0.371
	Commute	5112.82	4996.62	94634.93	91267.6	-0.199
	Other	7894.22	7815.53	76194.98	70484.62	-0.427
	Car	13875.41	13677.96	189589.8	179286.7	-0.306
Inter-Peak	Business	950.06	949.75	19983.74	18789.65	-0.338
	Commute	1507.31	1471.3	33872.94	32239.74	-0.271
	Other	9964.46	9872.62	99951.18	91999.8	-0.455
	Car	12421.82	12293.67	153807.9	143029.2	-0.399
PM Peak	Business	894.56	891.27	20298.69	19215.02	-0.301
	Commute	4603.74	4491.08	97334.99	93578.65	-0.216
	Other	10081.61	9962.67	105331.1	97547.59	-0.421
	Car	15579.91	15345.03	222964.7	210341.3	-0.32
24-Hours	Business	12482.26	12460.26	269302	253297.1	-0.336
	Commute	43378.96	42353.71	885064	849654	-0.224
	Other	129185.1	127885.4	1300041	1199849	-0.44
	Car	185046.4	182699.4	2454407	2302801	-0.35

Appendix B - Forecasting Convergence

Table B-1 Convergence Summary – Core Scenario - DM2023

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	56.57609	7771.66	190036.5	3413875	5.56431
2	0.5	26.97074	1306.77	189913.4	3421830	2.23894
3	0.5	12.75974	258.17	189908.2	3432163	0.98555
4	0.5	6.06221	56.39	189921.9	3439083	0.45989
5	0.5	2.89696	12.42	189932.8	3442663	0.22045
6	0.5	1.38363	2.79	189940	3444555	0.10443
7	0.5	0.6778	0.7	189944.2	3445564	0.05158
8	0.5	0.32276	0.22	189946.3	3446050	0.03235

Table B-2 Convergence Summary – Core Scenario - DS2023

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	164.7319	29431.99	190036.5	3302049	5.19409
2	0.5	79.51798	6865.16	190418.2	3348032	2.48111
3	0.5	38.55182	1613.69	190598.2	3369914	1.1954
4	0.5	18.84697	384.25	190682.8	3380313	0.58274
5	0.5	9.19853	91.29	190722.5	3385189	0.2859
6	0.5	4.55333	22.28	190741.5	3387456	0.13947
7	0.5	1.9591	4.56	190750.7	3388708	0.06977
8	0.5	1.1405	1.45	190754.6	3389062	0.03627

Table B-3 Convergence Summary – Core Scenario - DM2038

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	243.1703	88732.25	210846	3827925	16.69884
2	0.5	104.9066	12469.59	210584.6	3826287	6.05055
3	0.5	47.71228	2503.98	210752.2	3872384	2.67121
4	0.5	21.83235	519.89	210876.1	3898855	1.20957
5	0.5	9.98247	112.11	210949.4	3913014	0.57278
6	0.5	4.48879	23.87	210988	3919821	0.26874
7	0.5	2.06747	5.33	211009	3923564	0.1304
8	0.5	0.98303	1.48	211018.7	3925372	0.07137
9	0.5	0.44992	0.6	211022.8	3925888	0.04211

Table B-4 Convergence Summary – Core Scenario - DS2038

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	248.0693	81550.4	210846	3577323	12.80533
2	0.5	112.0502	17788.09	211631.2	3721767	5.83103
3	0.5	50.93807	3931.47	212012.2	3789157	2.72649
4	0.5	22.8339	853.8	212199.6	3821561	1.28903
5	0.5	10.57978	195.03	212289.6	3836247	0.61635
6	0.5	4.99318	44.21	212335.3	3843309	0.29443
7	0.5	1.86113	10.02	212358.4	3847369	0.14919
8	0.5	1.58362	6.14	212367.3	3848211	0.09307
9	0.5	0.83166	1.58	212374.4	3849369	0.0521
10	0.5	-0.63678	1.34	212377	3850279	0.04371

Table B-5 Convergence Summary – Core Scenario - DM2051

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	433.7323	271812.6	230152.2	4391983	26.9267
2	0.5	168.2718	29626.28	229118.3	4237129	8.5313
3	0.5	69.88005	5330.63	229401.1	4294993	3.58566
4	0.5	29.33359	1026.64	229639.6	4336193	1.60736
5	0.5	12.50592	202.07	229775	4358726	0.74166
6	0.5	5.34627	45.88	229842.1	4370755	0.39052
7	0.5	2.26699	10.4	229868.7	4373311	0.20481
8	0.5	0.98841	4.42	229888.8	4377430	0.13719
9	0.5	-0.43093	2.38	229893.2	4376777	0.09785
10	0.5	-2.42015	23.34	229900.9	4378944	0.11854
11	0.5	1.35302	6.97	229898.4	4378558	0.06972
12	0.5	0.70403	5.56	229901.9	4379611	0.11964
13	0.5	-0.40971	1.97	229899.7	4377690	0.08053
14	0.5	0.17411	0.97	229904.2	4378753	0.05529

Table B-6 Convergence Summary – Core Scenario - DS2051

Loop	Step Length	Max Change	Obj. Function	Total Trips (vehs)	Total Costs (veh.kms)	Rel. Gap (%)
1	0.5	399.0534	163342.3	230152.2	3898020	18.13348
2	0.5	173.0385	32309.2	231016.3	4095410	7.87916
3	0.5	74.46282	6458.39	231471.5	4189892	3.55586
4	0.5	32.11456	1307.18	231702.8	4234742	1.64316
5	0.5	13.69433	261.91	231816.1	4254592	0.76916
6	0.5	5.58668	56.38	231875.2	4265299	0.37332
7	0.5	2.52942	14.1	231901	4269461	0.17866
8	0.5	1.15594	5.47	231914.2	4270686	0.10951
9	0.5	0.62402	1.38	231924	4272490	0.05845
10	0.5	0.47125	1.11	231926.8	4272786	0.04152