

NATIONAL TRANSPORT MODEL UPDATE VARIABLE DEMAND MODEL REPORT

NTpM Volume 4
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Table of Contents

1	Introduction	5
1.1	Overview.....	5
1.2	Purpose of Report	5
1.3	NTpM Model Structure.....	5
1.4	Role of the Variable Demand Model Module of the NTpM	6
1.5	Limitations of the Variable Demand Model.....	7
1.6	VDM Overview.....	9
1.7	Incremental Model.....	10
1.8	Overview of the Variable Demand Modelling Process in the NTpM	10
1.9	Structure of report.....	12
2	Variable Demand Model	13
2.1	Overview.....	13
2.2	Demand Model.....	15
2.3	Production-Attraction Matrices.....	15
2.4	Calculating Generalised Cost	16
2.5	Cost Damping	18
2.6	Choice Model (Logit).....	19
2.7	Demand Model Calibration.....	21
3	Reference Scenario	22
3.1	Overview.....	22
3.2	Reference Scenario Inputs.....	22
3.3	Reference Network	23
3.4	Running the Reference Scenario	23
3.5	Public Transport Fares	24
3.6	Reference Scenario Model Outputs	25
3.7	Intra-Zonal Cost	25
4	Test Scenario.....	26
4.1	Overview.....	26
4.2	Test Scenario Inputs.....	26
4.3	Running the Test Scenario.....	26
4.4	VDM Convergence.....	29
4.5	VDM Output Data.....	29
5	VDM Validation	31
5.1	Introduction	31
5.2	Realism Testing.....	31
6	Conclusions	34

1 Introduction

1.1 Overview

In order to provide all the relevant detail of the Transport Infrastructure Ireland (TII) National Transport Model (NTpM) in a clear and concise manner, the documentation for the NTpM is split into four volumes as follows:

- NTpM Volume 1 – **Model Development Report** – Provides the background to the NTpM and outlines the development, calibration and validation of the modules of the NTpM;
- NTpM Volume 2 – **Data Collection Report** – Presents details of the data and data sources used to update and enhance the NTpM;
- NTpM Volume 3 – **Travel Demand Forecasting Report** – A detailed discussion on the background data and methodologies used to inform the estimates of future travel demand in the NTpM is presented in this report; and
- NTpM Volume 4 – **Variable Demand Model Report** – The final report provides the details on the background, development and function of the variable demand model.

This report, which is referred to as the Variable Demand Model Report, forms Volume 4 of the NTpM suite of supporting documentation.

1.2 Purpose of Report

This report details the inputs, outputs and operation of the VDM module of the NTpM. The report outlines the structure of the VDM and how it interfaces with the various elements that make up the NTpM and discusses the calibration of the demand model. A VDM User Manual is also available for request from TII which guides the user step-by-step on how to use the VDM and explains all of the relevant files that are contained within the VDM package.

1.3 NTpM Model Structure

The NTpM is made up of several sub-models, each having its own unique inputs and structure.

- Demographic models are developed to estimate future year population, employment and jobs projections for each zone in the NTpM;
- Car Ownership models forecast future year car ownership and car numbers for each zone in the NTpM based on the future year demographic and economic projections;
- A freight model is used to estimate the increase in freight demand at a national level and then to allocate this growth to zones in the NTpM with specific freight related activity;
- The Trip Attraction Generation Model (TAGM) takes the outputs of the Demographic, Car Ownership and Freight models and converts them into origin and destination zone trip ends for each mode of transport;
- A Trip Distribution Model (TDM) is used to distribute the origin and destination trip ends totals between the various zones in the model. The Freight Model is used to estimate the increase in freight demand at a national level. The TDM outputs demand matrices which present the origin and destination demand (by mode) between each zone in the NTpM.
- Assignment models (Traffic, Rail & Bus) are used to assign the demand for travel represented by the demand matrices to the transport network, generating travel costs (e.g. time, distance, tolls, fares) for each mode; and

- The role of the VDM is to assess, if required, the impact of a change in the transport network or change in the cost of travel (e.g. fuel costs, fares) upon the demand for travel. This is calculated by comparing the zonal travel costs from the assignment models between a Do-Minimum (without change) scenario and a Do-Something scenario (with change).

This structure of the model is shown in the diagram in Figure 1.1.

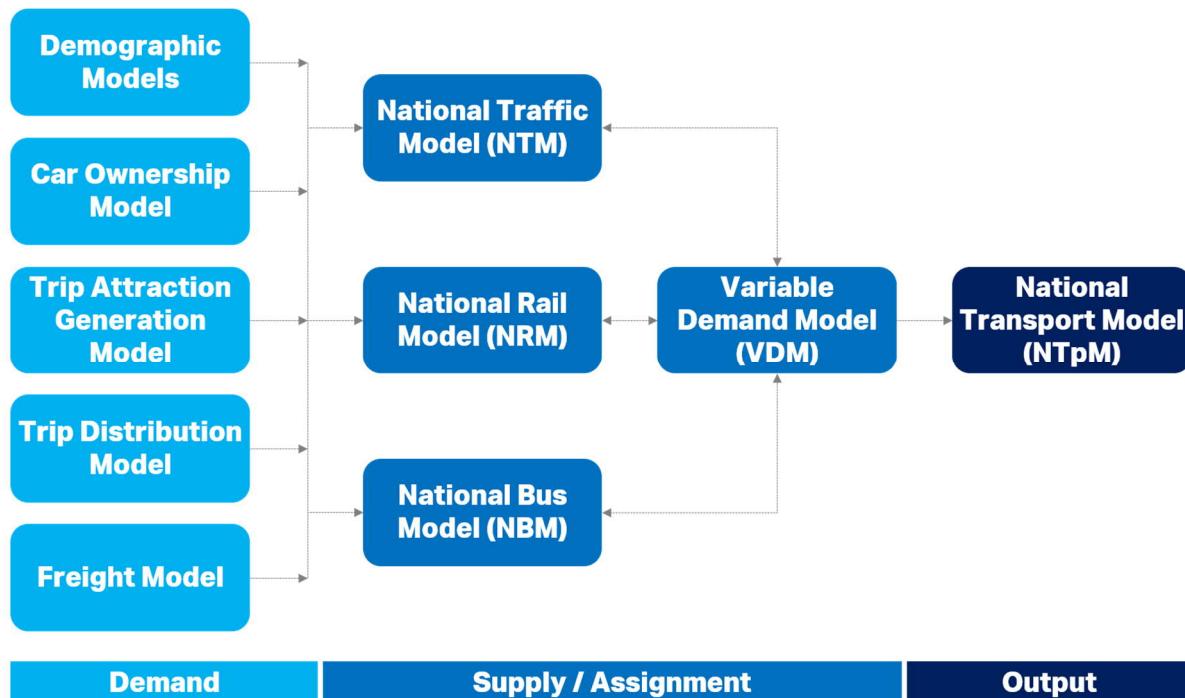


Figure 1.1. NTpM Basic Structure

1.4 Role of the Variable Demand Model Module of the NTpM

The VDM module of the NTpM was developed by TII to help inform, at a strategic level, the potential multi-modal demand responses arising from proposed changes to the National Road Network (NRN) or policy changes at a national level. The NTpM by its very nature is a high level strategic transport modelling tool and is appropriate for assessing impacts on strategic inter-urban demand only (road, heavy rail and inter-urban-bus), particularly along national road corridors. As such, the VDM module should also only be used to inform the high level assessment of potential demand response.

Neither the NTpM or the VDM module should be used at a scheme specific level as a replacement for more detailed and refined modelling tools which are required to inform the appraisal, design of environmental impacts of infrastructure proposals or changes to public transport service provision. The NTpM and its VDM module can however be used at the initial or early stages of a project (prior to the development of scheme specific models/tools) to provide indicative analysis in relation to the potential areas of influence of a scheme or to understand the relative multi-modal demand response of a scheme for information purposes.

It is advised to liaise with TII to agree if the VDM module would be an appropriate tool to use as part of the early appraisal process of a potential scheme.

1.5 Limitations of the Variable Demand Model

As outlined previously the NTpM is a strategic transport modelling tool which is intended to be used for high level analysis only. The following sections outline some of the limitations of the NTpM and VDM module that users should be aware of prior to using the tool.

Spatial Representation of Demand

Given the scale and nature of the NTpM the spatial representation of demand in general is very coarse. There are 1,129 zones in the NTpM in total, representing the entire Island of Ireland. Intra-zonal travel within these NTpM zones is not assigned to the transport network nor is it intended to be represented accurately, as the primary role of NTpM is to represent inter-urban travel only.

The role of the VDM module is to assess, if required, the impact of a change in the transport network or change in the cost of travel (e.g. fuel costs, fares) upon the demand for travel. This is calculated by comparing the NTpM zonal travel costs from the assignment models between a Reference (without change) Scenario and a Test (with change) Scenario. This comparison of the change in travel cost occurs at the NTpM zone level and does not account for changes in travel costs below this spatial level. For context an example of the scale of the NTpM zones in the midlands is illustrated in Figure 1.2 and shows that towns such as Mullingar and Tullamore are simply represented by one large zone.



The National Transport Authority (NTA) Regional Modelling System (RMS) which is centred on the five metropolitan areas of Dublin, Cork, Limerick, Galway and Waterford is the appropriate tool for assessing public transport and urban/local road impacts, as these regional models have been developed to reflect the complexity of the network and transport provision in these urban areas.

The NTpM however is the most appropriate tool for assessing impacts on strategic inter-urban demand, particularly along national road corridors. The NTpM zone structure is compatible with the NTA RMS zone structure. This allows for transfer of information at a zonal level between the NTpM and the five NTA Regional Models.

Representation of Inter-Urban Travel

Outside key urban areas, transport activity in Ireland, as can be observed in Figure 1.3, is strongly focused on roads with some 84% of motorised travel outside urban areas undertaken by private vehicles¹. Furthermore, it accounts for 97% of all person kilometres using the road network (including Bus and Heavy Goods Vehicles).

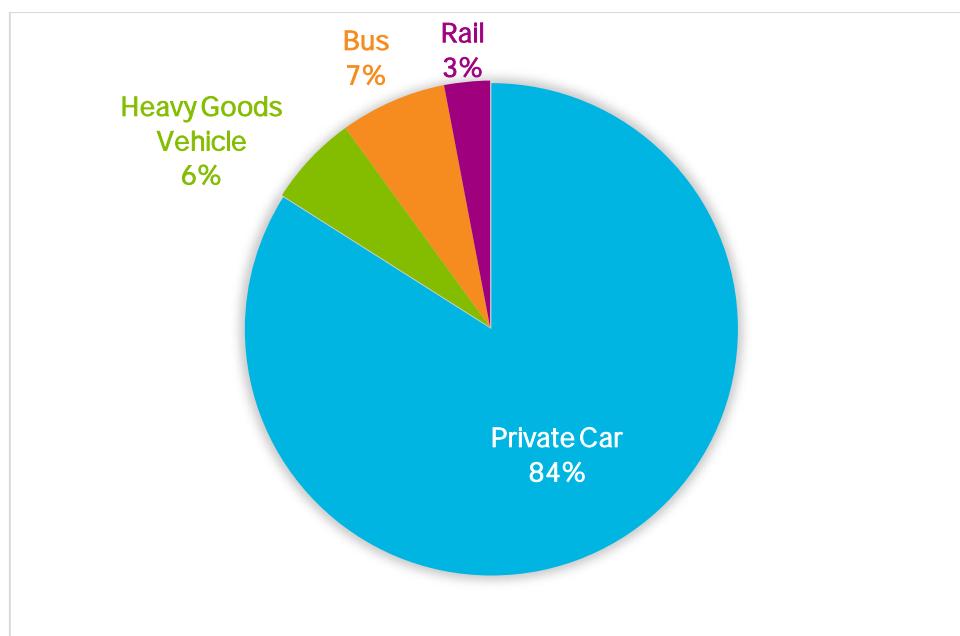


Figure 1.3. 2016 TII National Transport Model Modal Split (Inter Urban Travel Only)

Outside of the urban areas in Ireland there are often limited opportunities for travel by public transport and this is reflected in the very high modal split figures in Figure 1.3. As such, demand responses generated by the VDM module can be limited in certain circumstances when compared to more urban variable demand models. These issues are detailed later in this report.

Time Period Representation in the VDM Module

The inter-urban rail and bus assignment models were constructed for a single 15-hour period using available data. The development of rail and bus matrices for shorter periods would be more complex and less appropriate for an inter-urban national model, due to the long duration of many strategic trips (up to 4 hours). This would require some interpretation of what travel

¹ Source – 2016 National Transport Model Base Year Model outputs person km totals of 84% private car, 6% Heavy Goods Vehicles, 7% bus and 3% rail.

would be considered to occur during that short period and would likely lead to subsequent complications with the annualisation of this data.

To account for this, the demand data used in the VDM module is needed for a consistent time frame between modes. The demand therefore represents the 15 hour weekday period between 7am and 10pm. This period was chosen as the majority of public transport services occur between these hours.

For the purposes of the VDM, an estimate of traffic demand over the 15-hour periods between 07:00 and 22:00 is required. In order to do this, the total 15 hour demand is calculated as a multiple of the assignment for each NTpM peak hour (i.e. AM and Inter Peak) based on regression of national road traffic count information. This generates a consistent time period across all three travel modes.

Public Transport Capacity

In the NTpM there is no capacity restraint in terms of public transport patronage. The demand response in the VDM module in relation to public transport are therefore not influenced by the seating capacity or crush capacity of public transport services.

1.6 VDM Overview

The VDM module of the NTpM consists of two assignment models ('Reference' & 'Test') developed in the software VISUM and a variable demand model developed using a Python script. The purpose of a variable demand model is to calculate the demand response resulting from the change in travel cost associated with a transport intervention. Figure 1.4 provides an overview of the basic structure of the VDM process in the NTpM.

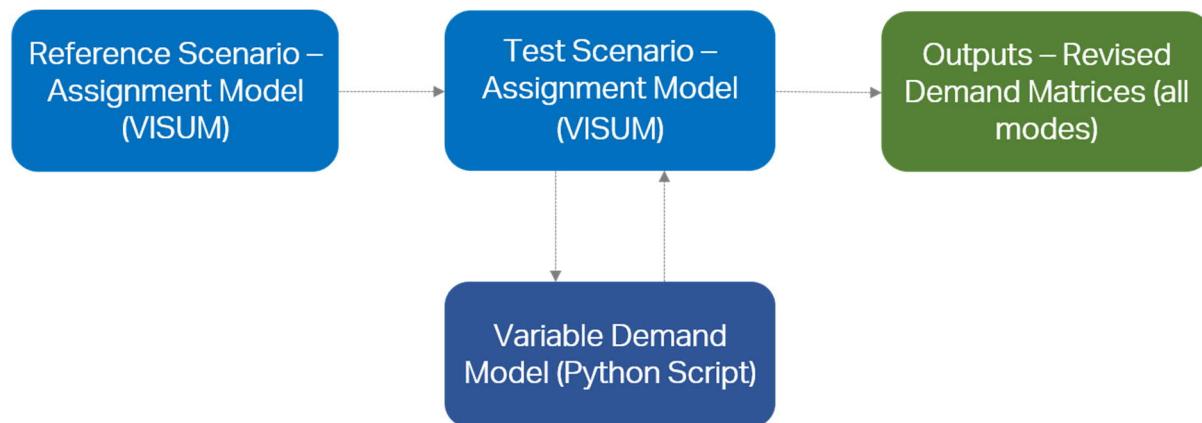


Figure 1.4 Basic NTpM VDM Structure

The reference scenario assignment model is used to calculate the travel costs for all modes in the TII NTpM (highway, heavy rail and inter-urban bus) in the without scheme or reference scenario. The test scenario assignment model is used to calculate the travel costs for all modes in the TII NTpM (highway, heavy rail and inter-urban bus) in the with scheme or test scenario.

The variable demand model then compares the change in travel costs between the reference and test scenarios to generate a set of revised demand matrices for all modes. These revised matrices are then re-assigned in the test scenario assignment model to generate current travel costs.

A convergence check is undertaken comparing the current and previous travel costs, with the loop between the test scenario assignment model and the variable demand model iterating until the convergence criteria is satisfied.

1.7 Incremental Model

The VDM in the NTpM works as an Incremental (or Pivot-Point) model. Incremental models take travel costs (e.g. time, distance, tolls, and fares) from a reference scenario as a starting point, and then forecast the change in demand (e.g. mode share and trip distribution changes) as a function of the changes in travel costs between the reference and test scenarios. Incremental models differ to absolute models in that they rely more heavily on observed data for the base year to produce forecast trip matrices. An absolute model generates forecast trip matrices based more heavily on mathematical methods than observed data.

A summary of the reference and test scenarios is as follows:

- **Reference Scenario** – refers to the baseline or without scheme scenario; and
- **Test Scenario** – refers to the with scheme scenario (i.e. reference scenario plus the proposed transport intervention).

1.8 Overview of the Variable Demand Modelling Process in the NTpM

Figure 1.5 provides an overview of VDM process in the NTpM. The key steps in the process are as follows:

1. Travel costs skims are calculated for the reference scenario by assigning the demand matrices for the relevant year to the reference scenario transport network. This process is carried out in an assignment model (VISUM) for all modes (highway, heavy rail and inter-urban bus) and then the demand and cost skims are saved for use in the test scenario assignment model;
2. The proposed transport intervention is coded into a separate assignment model (i.e. the test scenario) which is then used to calculate the travel costs in the test scenario. The initial assignment in the test scenario utilises the same demand matrices as the reference scenario;
3. The reference and test scenario demand and travel costs skims are then used as inputs to the VDM (Python Script). The VDM compares the change in travel costs between the reference and test scenarios and generates revised demand matrices. The test scenario assignment model is used as the interface for the VDM, whereby travel demand and cost are looped between the VDM and the test scenario assignment model; and
4. The revised demand matrices generated by the VDM are then re-assigned in the test scenario assignment model to generate new travel cost skims. A convergence check is then undertaken which compares the 'current' cost skims against the 'previous' cost skims. If the convergence criteria are met, then the process is complete and the final demand matrices are produced. If the convergence criteria are not met, then the 'current' and 'previous' demand and cost skims are fed back into the VDM and an iterative process is undertaken until the convergence criteria is met.

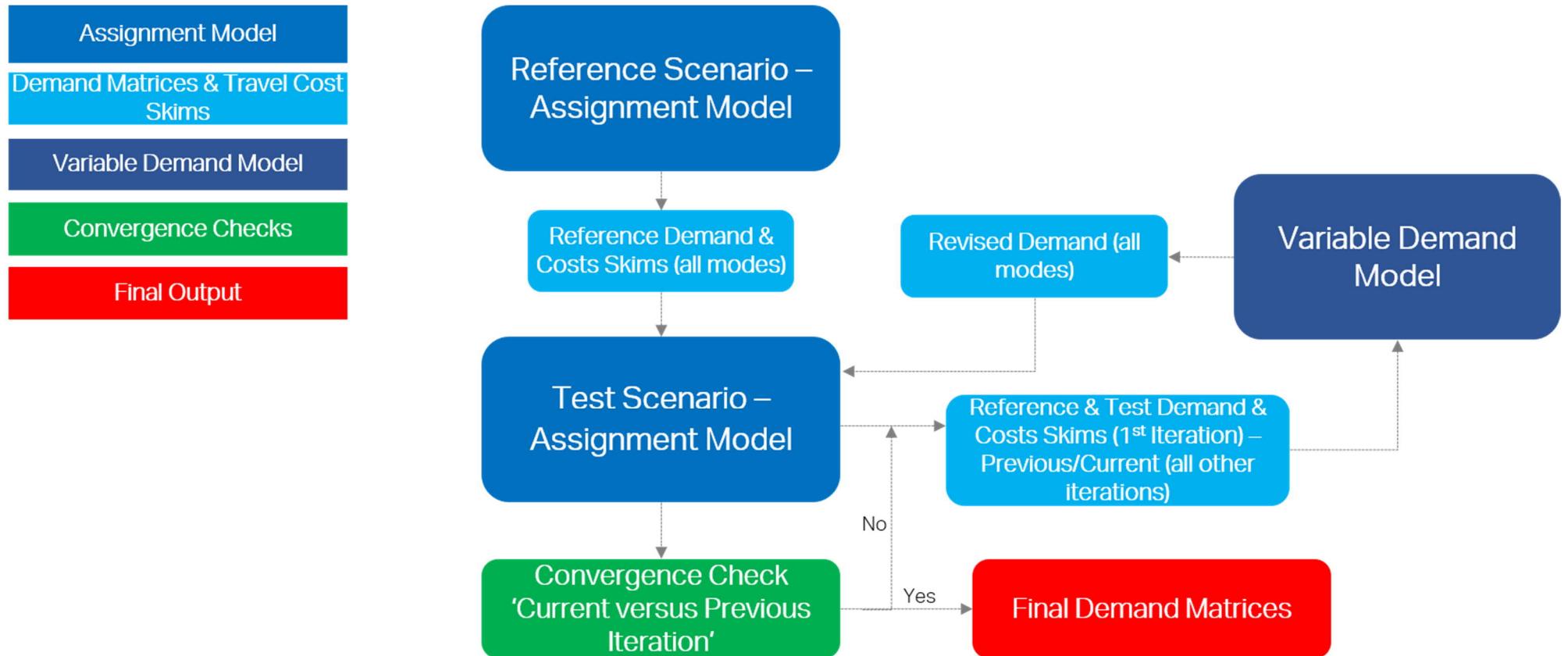


Figure 1.5 Overview of the VDM Process

1.9 Structure of report

The report is divided into a number of key chapters which discuss a core element of the VDM as follows:

- Section 2 - presents the structure of the VDM and the discuss each of the choice models and formulae inherent in the VDM;
- Section 3 - outlines the Reference Scenario for input into the VDM process;
- Section 4 - outlines the Test Scenario to run the VDM, including the economic parameters and modelling parameters; and
- Section 5 - illustrates the calibration of the VDM based on 'Realism' testing.

2 Variable Demand Model

2.1 Overview

As mentioned in the previous section, the VDM compares the change in travel costs between the reference and test scenarios and generates revised demand matrices. This section of the report explains the process of the VDM, and how the revised demand is generated.

The 'reference' and 'test' demand and travel cost skim data is passed from VISUM to the VDM module in the first iteration; in subsequent iterations the output of the VDM from the previous iteration is passed back to VISUM. The same process applies to the travel cost skims.

The demand model which is a function called by VISUM, takes the matrices and performs the necessary demand model calculations on them, before passing them back to VISUM. It also calculates demand / supply convergence, so that VISUM can determine when to stop iterating between demand and supply.

The flow of information that passes between VISUM and the demand model is illustrated in Figure 2.1. Note that the public transport costs are independent of both public transport demand (no crowding) and highway congestion (runs to timetable), so therefore the bus and rail assignments are not included in the demand/supply loop.

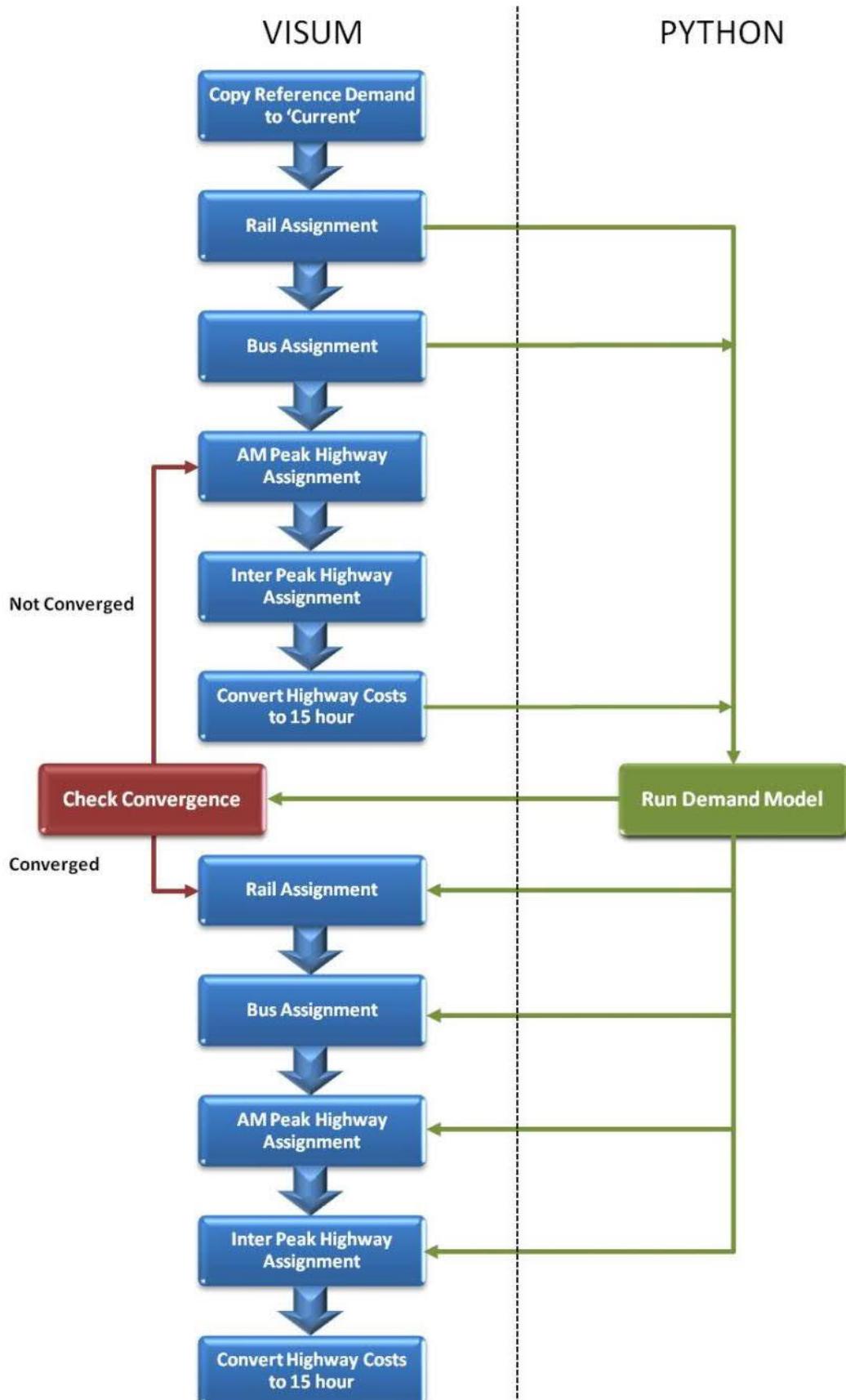


Figure 2.1 VISUM/Demand Model Process

2.2 Demand Model

The VDM performs the following processes outlined in Table 2.1 using the 'reference' and 'test' demand and skims from VISUM.

Table 2.1 Demand Process

Steps	Process
1	Converts highway vehicle demand from AM Peak and Inter Peak origin-destination (O-D) matrices to 15hr production-attraction (P-A) people matrices
2	Converts rail and bus O-D demand to P-A format
3	Calculates logit composite costs for public transport using the costs from the rail and bus assignments and converts into generalised costs
4	Calculates generalised cost for highway
5	Calculate logit composite costs across attractions for highway and public transport for the mode choice model
6*	Applies an incremental logit mode-choice model to create output origin (vector) matrices by mode.
7	Applies an incremental logit distribution model to create output full matrices by mode
8	Calculates the convergence gap numerators and denominators
9	Converts the highway matrices from 15hr P-A people matrices back to AM Peak and Inter Peak O-D vehicle matrices
10	Performs an incremental logit sub-mode choice between rail and bus demand using the new public transport demand and converts from P-A to O-D format

**The mode choice model may be absent or restricted for certain segments, for example, non-car-available trips will be unable to select highway as a mode, and freight traffic will not use the mode choice model at all.*

2.3 Production-Attraction Matrices

The highway module of the NTpM outputs origin-destination (O-D) demand in terms of vehicles for the AM and Inter Peak Hours. This demand needs to be converted to 15 hour production-attraction (P-A) demand, in terms of people rather than vehicles, for use in the VDM.

The rail and bus demand outputs of the NTpM are 15 hour O-D demand (people). These demand matrices need to be converted to P-A format for use in the VDM. The process is summarised as follows:

- Highway demand from the AM Peak and Inter Peak is converted from O-D format to 15-hour P-A people matrices; and
- Rail and bus O-D demand is converted to P-A format to establish public transport matrices by rail and bus.

The process uses 'Proportion of Travel from Home' factors outlined in Table 2.2 and 'Vehicle Occupancy' factors from the TII (reference *PAG Unit 6.11: National Parameter Values Sheet*) which are presented in Table 2.3 to generate P-A people matrices.

Table 2.2 Proportion of Travel from Home Factors (TII PAG)²

FromHomeFac*	Commuting	Business	Other	HGV
AMFromHome	0.9637	0.8708	0.7518	1.0
IPFromHome	0.4306	0.4413	0.4556	1.0
PMFromHome	0.0630	0.2920	0.4046	1.0
OPFromHome	0.4895	0.3452	0.3788	1.0
AllFromHome	0.5000	0.5000	0.5000	1.0

Table 2.3 TII Vehicle Occupancy Factors (TII PAG)

Vehicle Occupancy*	Text Name	Commuting	Business	Other	HGV
AM Peak	AMVehOcc	1.23	1.26	1.66	1.0
Inter Peak	IPVehOcc	1.22	1.25	1.65	1.0

2.4 Calculating Generalised Cost

The skim matrices calculated by the highway module (time, distance & toll), and the public transport modules (time, distance & fare) are used to calculate generalised costs for each mode for use in the VDM. The process is summarised below

- Generalised costs are calculated for road travel using the time, distance and toll skims from the NTpM highway module and TII economic parameters (reference PAG Unit 6.11: National Parameter Values Sheet).
- Logit composite costs³ are calculated for public transport using the costs from the rail and bus assignments and converting into generalised costs using standard economic parameter values; and
- Logit composite costs are calculated across attractions separately for road and public transport for input to the mode choice model.

2.4.1 Generalised Costs – Highway

The generalised cost equation for the highway demand is as follows:

- Highway Generalised Cost = Value of Time (Cents/min) * Time (min) + Vehicle Operating Cost (cents/km) * Distance (km) + Tolls (cents)

Values of Time (VOT) which are entered into the demand model in cents per min are applied to the time skims to calculate the cost of travel. An example of the VOT for each trip purpose in demand model are presented in Table 2.4.

² Values in the TII Project Appraisal Guidelines are, in turn, drawn from the Departmental Common Appraisal Framework Guidelines (CAF).

³ An explanation of Composite Costs can be found in Section 3.2 of WebTAG Unit M2.1 Variable Demand Modelling

Table 2.4 Example of Value of Time (€cents/min) (TII PAG)

Year ⁴	Text Name	Commuting	Business	Other	HGV
2016	ValueOfTime	26.5	54.9	24.1	54.9

* Value of Time needs to be calculated for the given forecast year

Vehicle Operating Costs (VOC) are calculated for the highway demand using the distance skims, average speeds (based on the time and distance skims) and economic fuel parameters. The fuel and non-fuel economic parameters for each trip purpose are presented in Table 2.5 and Table 2.6 respectively.

Table 2.5 VOC Economic Fuel Parameters (TII PAG)

Description	Text Name	Commuting	Business	Other	HGV
Fuel Consumption A	FIA	0.92312	0.92312	0.92312	2.48090
Fuel Consumption B	FIB	0.0538	0.0538	0.0538	0.4904
Fuel Consumption C	FIC	-0.0003	-0.0003	-0.0003	-0.0072
Fuel Consumption D	FID	0.000003	0.000003	0.000003	0.00006
Fuel Efficiency	FEff	1	1	1	1

Table 2.6 VOC Economic Non-Fuel Parameters (TII PAG)

Description	Text Name	Commuting	Business	Other	HGV
Non Fuel A	NFA	0	7.218	0	17.0
Non Fuel B	NFB	0	197.557	0	633.950

2.4.2 Generalised Costs – Public Transport

Generalised costs are calculated for public transport using Perceived Journey Time (PJT) costs, in-vehicle distance skims, fares per km travel and economic parameters. The generalised cost equation for the public transport is as follows:

- Public Transport Generalised Cost of Travel = Value of Time (cents/min) * PJT (mins) + In-Vehicle Distance (km) * Fare (cents/km)

The PJT which is a function of a public transport trip, takes into account the weighted journey time elements that make up the total travel time between a trip origin and destination. The elements and the weighting factors applied are presented in Table 2.7.

Table 2.7 Perceived Journey Time – Weighted Factors⁵

PJT Component	Rail	Bus
In-Vehicle Time	1	1
PuT-Aux Ride Time	1	1
Access Time	2	2
Egress Time	2	2

⁴ Value of Time needs to be calculated for the given forecast year

⁵ Guidance on appropriate weighting values is provided in UK WebTAG Unit M3.2 Public Transport Assignment

PJT Component	Rail	Bus
Walk Time	2	2
Origin Wait Time	0	0
Transfer Wait Time	2.5	1.5
No., of Transfers	12 mins	5 mins

It should be noted, that the rail and bus assignment models used to inform the VDM are based on the timetable based assignment procedure in VISUM, as opposed to the headway assignment option. The headway based assignment option is not appropriate for use where public transport service headways exceed 2hrs (as per inter-urban travel in the NTpM) and is more appropriate for urban models where there is a higher frequency of public transport services.

Under the timetable based assignment procedure, the user has full knowledge of the inter-urban public transport timetables and can therefore make informed decisions about their end to end trip and the relevant interchanges/transfers required to complete their trip in the most efficient manner. As such there is no origin wait time associated with the trip to feed into the PJT.

2.5 Cost Damping

There is strong empirical evidence that the sensitivity of demand responses to changes in generalised cost reduces with increasing trip length.⁶ The model therefore applies functions to reduce large cost changes, making the response non-linear to actual cost change, while ensuring that increasing costs always result in decreasing demand and vice versa.

To achieve this, a factor is applied to both time and monetary components of cost change based on the base highway distance between the origin and destination, functions as follows:

$$\begin{aligned} \text{TimeFactor} &= \sqrt{20} * \left(\frac{1}{\max(D, 20)} \right)^{0.5} \\ \text{MonetaryFactor} &= \sqrt{20} D_0^{\eta_s} * \left(\frac{1}{\max(D, 20)} \right)^{0.5} * \left(\frac{1}{\max(D, D_c)} \right)^{\eta_s} \end{aligned}$$

Where D is distance in kilometres, and other parameters were initially derived from UK WebTAG advice. The cost damping parameters are presented in Table 2.8. As part of the model calibration process both the CDTIMEPOWER and CDTIMETHRESH were adjusted in order to achieve the expected demand response associated with the NTpM.

⁶ UK WebTAG Unit M2.1 Variable Demand Modelling

Table 2.8 Cost Damping Parameters

FromHomeFac	Commuting	Business	Other	HGV
CDTimePower	0.2	0.2	0.2	0.2
CDMoneyPower	0.421	0.00	0.315	0.00
CDTimeThresh	140.0	140.0	140.0	140.0
CDMoneyThresh	6.0	5.0	6.0	5.0
CDMoneyBase	13.9	14.8	13.0	22.9

2.6 Choice Model (Logit)

The Choice Model process is illustrated in Figure 2.2 and shows how each element of the model is ordered from least sensitive to most sensitive. The VDM process therefore follows this hierarchy in identifying the demand response.

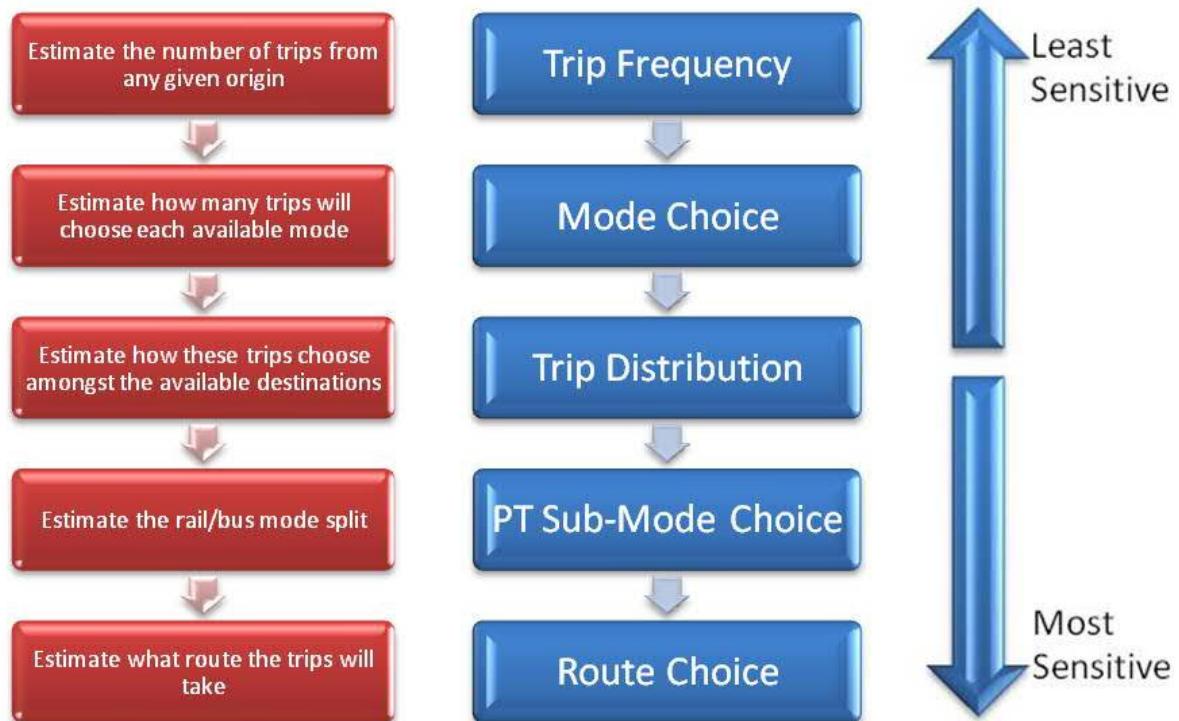


Figure 2.2: Choice Structure of VDM

2.6.1 Choice Model Formulae

The formulae used by the demand model are presented in Table 2.9 and Table 2.10. The following terminology is applied:

- i = Production zone
- j = Attraction zone
- m = Mode
- $*$ = Aggregation over an index
- D = Base Demand (persons)
- \hat{D} = Model Output Demand (persons)
- θ_m = Mode Choice sensitivity relative to distribution
- λ_d = Distribution sensitivity (inverse minutes)
- λ_s = Sub-mode choice sensitivity (inverse minutes)
- ΔC = Difference in generalised cost between base and test (minutes)

Table 2.9 Composite Cost Change Formula

Composite Cost	Formula
Over Mode Choice	$\Delta C_{*i*} = \frac{-1}{\theta_m} \log_e \left(\frac{\sum_{mj} D_{mij} e^{-\theta_m \Delta C_{mij*}}}{\sum_{mj} D_{mij}} \right)$
Over Attraction Zones	$\Delta C_{mi*} = \frac{-1}{\lambda_d} \log_e \left(\frac{\sum_j D_{mij} e^{-\lambda_d \Delta C_{mij}}}{\sum_j D_{mij}} \right)$
Over Public Transport	$\Delta C_{miRailBus*} = \frac{-1}{\lambda_s} \log_e \left(\frac{\sum_{rail,bus} D_{mij} e^{-\lambda_s \Delta C_{mij}}}{\sum_{rail,bus} D_{mij}} \right)$

Table 2.10 Hierarchy Logit Model Formula

Choice	Formula
Trip Frequency	$\widehat{D}_{*i*} = D_{*i*} e^{\theta_t \Delta C_{*i*}}$
Model Choice	$\widehat{D}_{mi*} = \widehat{D}_{*i*} \frac{\sum_j D_{mij} e^{\theta_m \Delta C_{mi*}}}{\sum_m D_{mij} e^{\theta_m \Delta C_{mi*}}}$
Distribution	$\widehat{D}_{mij*} = \widehat{D}_{mi*} \frac{D_{mij} e^{-\lambda_d \Delta C_{mij}}}{\sum_j D_{mij} e^{-\lambda_d \Delta C_{mij}}}$
PT Sub-Mode	$\widehat{D}_{mij} = \widehat{D}_{PTij} \frac{D_{mij} e^{-\lambda_s \Delta C_{mij}}}{\sum_j D_{mij} e^{-\lambda_s \Delta C_{mij}}}$

2.7 Demand Model Calibration

The model sensitivity and cost-dampening parameters have been calibrated starting at UK WebTAG guidance to give an acceptable level of model sensitivity.⁷ The model parameters employed in the VDM are set out in Table 2.11.

Table 2.11 Demand Model Parameters

Purpose	AlphaLog	H Lambda λ_d	PT Lambda λ_d	Mode Theta θ_m	PT Theta	SubMode Lambda λ_s
Commuting	0.33	-0.065	-0.033	0.68	0	-0.1
Business	0.33	-0.067	-0.036	0.45	0	-0.1
Other	0.33	-0.090	-0.036	0.53	0	-0.1
HGV	n/a	-0.030	n/a	n/a	0	n/a

⁷ TAG Unit M2 Variable Demand Modelling (March 2017), Department for Transport.

3 Reference Scenario

3.1 Overview

The model uses a 'Do-Minimum Pivoting' process, whereby the cost changes from the 'Do-Minimum', referred to as the 'Reference' Scenario, are compared with the costs from a 'Do-Something', referred to as the 'Test' Scenario, when performing the variable demand model calculations. This section of the report outlines the process for creating the Reference Scenario and calculating the Reference cost skims.

3.2 Reference Scenario Inputs

To generate the reference cost skims for use in the variable demand model, a set of 18 input demand matrices must be assigned to the reference network for the relevant year been assessed. Details of these 18 demand matrices are outlined in Table 3.1. The TII NTpM base (2016) or future year (2030, 2040, 2050) demand matrices can be used or alternatively demand matrices can be interpolated for alternative years between 2016 and 2050.

Table 3.1 Reference Scenario Demand (Trip) Matrices

Mode	Time Period	Matrix Name	Matrix No.	Trip Purpose
Highway	AM Peak	AMHKLV	1	Commuting
		AMEBLV	2	Employers Business
		AMNWLV	3	Other
	Inter Peak	AMHV	4	HGV
		IPHKLV	6	Commuting
		IPEBLV	7	Employers Business
		IPNWLV	8	Other
		IPHV	9	HGV
		CNWDHKRail	21	Commuting (Non-Car Available)
		CAWDHKRail	22	Commuting (Car Available)
Rail	15 hour (07:00 – 22:00)	CAWDEBRail	23	Business (Car Available)
		CNWDNWRail	24	Other (Non-Car Available)
		CAWDNWRail	25	Other (Car Available)
		CNWDHKBus	31	Commuting (Non-Car Available)
		CAWDHKBus	32	Commuting (Car Available)
Bus	15 hour (07:00 – 22:00)	CAWDEBBus	33	Business (Car Available)

Mode	Time Period	Matrix Name	Matrix No.	Trip Purpose
		CNWDNWBus	34	Other (Non-Car Available)
		CAWDNWBus	35	Other (Car Available)

3.3 Reference Network

To generate the costs skims, a reference scenario network needs to be developed for all modes; highway, bus and rail. This is generally the base year network plus any committed schemes, both in terms of infrastructure and service provision, which are thought to be in place by the given future year.

3.4 Running the Reference Scenario

The reference scenario highway and public transport cost skims are generated by assigning the reference demand on the reference network. Table 3.2 presents the model procedures which are carried out in the reference scenario VISUM model. The VDM User Manual contains more detailed information on the procedures presented below.

Table 3.2 Reference Scenario Model Procedures

Assignment Model	Outline Procedure
Import Demand Matrices	Imports the AM and Inter Peak highway reference scenario demand matrices (LV & HV) – Listed in Table 3.1
AM Peak Highway Assignment	Imports the 15hr public transport reference scenario demand matrices (Heavy Rail & Inter-Urban Bus) – Listed in Table 3.1
	Imports the AM Impedance Cost Parameters (Python Script)
	Initialises the AM Peak highway assignment
	Updates the Port Tunnel variable toll value for the AM Peak
	Sums the AM Peak light vehicle demand (by trip purpose) into the relevant highway assignment matrix
	Copies the AM Peak HGV demand into the relevant highway assignment matrix
	Assigns the highway demand and skims time, distance and tolls costs
	Calculates the AM Peak skim matrices (LV & HV)
	Saves the AM Peak skim matrices into the relevant matrix numbers for saving externally during procedures 79-109
	Stores the AM Peak link flows (Light and Heavies) as User Defined Attributes
Inter Peak Highway Assignment	Imports the Inter Peak impedance cost parameters (Python Script)
	Initialises the Inter Peak highway assignment
	Updates the Port Tunnel variable toll value for the Inter Peak
	Sums the Inter Peak light vehicle demand (by trip purpose) into the relevant highway assignment matrix

Assignment Model	Outline Procedure
	Copies the Inter Peak HGV demand into the relevant highway assignment matrix
	Assigns the highway demand and skims time, distance and tolls costs
	Calculates the Inter Peak skim matrices (LV & HV)
	Saves the Inter Peak skim matrices into the relevant matrix numbers for saving externally during procedures 79-109
	Stores the Inter Peak link flows (Light and Heavies) as user defined attributes
Calculate 15hr Highway Skims	The AM and Inter Peak cost skims are used to generate weighted 15hr time, distance and toll skims for light vehicles and HGVs.
	Initialises the heavy rail assignment
	Edits share of PuT trips in zones with multiple stops
Heavy Rail Assignment	Sums the purpose and car availability demand into the rail assignment matrix
	Assigns the rail demand and skims perceived journey time and in-vehicle distance cost
	Calculates a rail fare matrix based on fixed cost per kilometre of rail travel
	Initialises the inter-urban bus assignment
	Edits share of PuT trips in zones with multiple stops
Inter-Urban Bus Assignment	Sums the purpose and car availability demand into the bus assignment matrix
	Assigns the bus demand, and skims perceived time and in-vehicle distance
	Calculates a bus fare matrix based on a cost per kilometre
Out Demand & Cost Skim Matrices	Saves the demand and cost skim matrices for all modes to an external folder for use in the test scenario.
Save Model	Saves the 'reference scenario' version file

3.5 Public Transport Fares

Fares are not coded directly into the rail or bus network and therefore cannot be skimmed directly from the rail or bus assignment models. Instead fares are calculated using an average distance based fare in cents per km of travel for rail (12.3 cents) and bus (10.4 cents) and the in-vehicle distance skim for each mode. Details of the calculation of the rail and bus fares used in the NTpM are provided in NTpM Update – Model Development Report (2019)⁸.

⁸ <https://www.tii.ie/tii-library/strategic-planning/>

3.6 Reference Scenario Model Outputs

The reference scenario model produces twelve 15hr costs skim matrices which are saved for use in the test scenario model. These reference scenario cost skims are presented in Table 3.3.

Table 3.3 15hr Reference Cost Skims

Mode	VDM Matrix Name	VDM Matrix No.	Reference Cost
Highway	15TmLV_Ref	181	Time (Lights)
	15DsLV_Ref	182	Distance (Lights)
	15ChLV_Ref	183	Toll (Lights)
	15TmHV_Ref	184	Time (HGV)
	15DsHV_Ref	185	Distance (HGV)
	15ChHV_Ref	186	Toll (HGV)
Rail	PJT(Rail)_Ref	187	Perceived Journey Time
	IVD(Rail)_Ref	188	In-Vehicle Distance
	Fare(Rail)_Ref	189	Fare
Bus	PJT(Bus)_Ref	190	Perceived Journey Time
	IVD(Bus)_Ref	191	In-Vehicle Distance
	Fare(Bus)_Ref	192	Fare

3.7 Intra-Zonal Cost

Though the NTpM VDM is an incremental model and this issue is therefore less important than in an absolute model, it is important to ensure that the cost skims input to the demand model have a realistic representation of intra-zonal costs.

Assignment models do not output intra-zonal costs as intra-zonal demand is not assigned to the transport network. Therefore to provide an estimate of intra-zonal cost for use in an VDM the diagonal of the cost skims are set to 50% of the lowest inter-zonal value in the reference and test scenario assignment models. This should not be changed when using the NTpM VDM.

4 Test Scenario

4.1 Overview

The cost changes from the reference scenario are compared with the costs from the test scenario when performing the variable demand model calculations. The test scenario will involve an adjusted network to represent a proposed investment in transport infrastructure, e.g. a new road or public transport scheme and / or a policy based intervention such as fuel cost changes. The test scenario assignment model is also used as the interface with the VDM, and passes demand and travel cost skims between the VDM and assignment model.

4.2 Test Scenario Inputs

When running the test scenario there are a number of inputs required from the reference scenario as well as the presence of a series of files which are required for the variable demand model. These inputs are outlined in Table 4.1.

Table 4.1 Test Scenario Inputs

Inputs	Details
Demand Matrices	The 18 reference scenario demand matrices
Cost Skims	The 12 reference scenario cost skims
Networks	Highway and PT Test Scenario networks
	Demand Model Script (.py file)
Files for VDM	Trip Purpose Modelling Parameters (4 .txt files)
	Economic Parameters (.txt file)

4.3 Running the Test Scenario

The test scenario highway and public transport cost skims are initially generated by assigning the reference demand on the test network. The VDM then generates revised demand matrices for assignment on the test network and this loop repeats until the convergence criteria is met. The procedures carried out in the test scenario model run are listed in Table 4.2.

Table 4.2 Test Scenario VISUM Procedures List

Procedure	Description
Run Script	Runs Python script to reset the demand iteration number to 0
Import Data	Imports the reference demand and travel cost skims
Initial Task	Copies the reference demand to the current iteration matrices for assignment in the test scenario
	Sets the 'blank' matrix to zero. It is important that all cells in this matrix are zero, so this is reset at the beginning of the model
Rail Assignment	Initialises the heavy rail assignment
	Edits share of PuT trips in zones with multiple stops

Procedure	Description
Bus Assignment	Sums the trip purpose and car availability demand matrices into the rail assignment matrix
	Assigns the rail demand, and skims the perceived journey time and in-vehicle distance matrices
	Calculates a rail fare matrix based on a cost per kilometre
	Stores the Rail Demand (pre VDM) as a user defined attribute for each link and zone
	Initialises the inter-urban bus assignment
	Edits share of PuT trips in zones with multiple stops
	Sums the trip purpose and car availability demand matrices into the bus assignment matrix
	Assigns the bus demand, and skims perceived journey time and in-vehicle distance
	Calculates a bus fare matrix based on a cost per kilometre
	Stores the Bus Demand (pre VDM) as a user defined attribute for each link and zone
AM Peak Highway Assignment	Imports the AM Peak impedance cost assignment parameters (Python Script)
	Initialises the AM Peak highway assignment
	Updates the Port Tunnel variable toll value for the AM Peak
	Sums the AM Peak light vehicle demand into the relevant highway assignment matrix
	Copies the AM Peak HGV demand into the relevant highway assignment matrix
	Assigns the AM highway demand, and skims time, distance and tolls costs
	Calculates the AM Peak skim matrices (LV & HV)
	Saves the AM Peak skim matrices into the relevant matrices
	Stores the AM Peak link flows and zone demand pre VDM (LV and HV) as user defined attributes
	Imports the Inter Peak impedance cost highway parameters (Python Script)
Inter Peak Highway Assignment	Initialises the Inter Peak highway assignment
	Updates the Port Tunnel variable toll value for the Inter Peak
	Sums the Inter Peak light vehicle demand into the relevant highway assignment matrix
	Copies the Inter Peak HGV demand into the relevant highway assignment matrix
	Assigns the Inter Peak highway demand, and skims time, distance and tolls costs
	Calculates the Inter Peak skim matrices (LV & HV)
	Saves the Inter Peak skim matrices into the relevant matrices
	Stores the Inter Peak link flows and zone demand pre VDM (LV and HV) as user defined attributes
	The AM and Inter Peak highway cost skims are used to generate weighted 15hr time, distance and toll skims for light vehicles and HGVs.
	<i>[Note that this process contains the AM & Inter Peak to 15hr highway demand conversion factors]</i>
Calculate 15hr Highway Skims	

Procedure	Description
	This runs the VDM Python script file
Run VDM Process	This takes the demand and costs from the assignments, compares the change in costs between the 'current' and 'previous' iteration ('previous' is reference scenario costs in the first iteration), and then calculates revised demand and convergence statistics.
	The %Gap network parameter is used as a convergence target for the VDM process
Check Convergence	If this %Gap is more than 0.1, and the number of iterations is less than the maximum of 30, then the procedures goes back to the 'AM Peak highway assignment' step
	We do not need to re-assign the PT demand as there is no congestion feedback in the PT assignments, i.e. whatever demand we assign we would get the same skinned matrices.
	Initialises the heavy rail assignment
	Edits share of PuT trips in zones with multiple stops
Final Rail Assignment	Sums the purpose and car availability demand into the rail assignment matrix
	Assigns the rail demand, and skims perceived time and in-vehicle distance
	Calculates a rail fare matrix based on a cost per kilometre
	Stores the Rail Demand (post VDM) as a user defined attribute for each link and zone
	Initialises the inter-urban bus assignment
	Edits share of PuT trips in zones with multiple stops
Final Bus Assignment	Sums the purpose and car availability demand into the bus assignment matrix
	Assigns the bus demand, and skims perceived time and in-vehicle distance
	Calculates a bus fare matrix based on a cost per kilometre
	Stores the Bus Demand (post VDM) as a user defined attribute for each link and zone
	Imports the AM Peak impedance cost highway parameters (Python Script)
	Initialises the AM Peak highway assignment
	Updates the Port Tunnel variable toll value for the AM Peak
Final AM Peak Highway Assignment	Sums the AM Peak light vehicle demand into the relevant highway assignment matrix
	Copies the AM Peak HGV demand into the relevant highway assignment matrix
	Assigns the AM highway demand, and skims time, distance and tolls costs
	Calculates the AM Peak skim matrices (LV & HV)
	Saves the AM Peak skim matrices into the relevant matrices
	Stores the AM Peak link flows and zone demand post VDM (LV and HV) as user defined attributes
Final Inter Peak	Imports the Inter Peak impedance cost highway parameters (Python Script)
	Initialises the Inter Peak highway assignment

Procedure	Description
Highway Assignment	Updates the Port Tunnel variable toll value for the Inter Peak Sums the Inter Peak light vehicle demand into the relevant highway assignment matrix
	Copies the Inter Peak HGV demand into the relevant highway assignment matrix
	Assigns the Inter Peak highway demand, and skims time, distance and tolls costs
	Calculates the Inter Peak skim matrices (LV & HV)
	Saves the Inter Peak skim matrices into the relevant matrices
	Stores the Inter Peak link flows and zone demand post VDM (LV and HV) as user defined attributes
Calculate 15hr Highway Skims	The AM and Inter Peak cost skims are used to generate weighted 15hr time, distance and toll skims for light vehicles and HGVs. <i>[Note that this process contains the AM & Inter Peak to 15hr highway demand conversion factors]</i>
Run Script	Runs a Python script to calculate the reference and test scenario total network demand and vehicle/passenger kilometres for each trip purpose
Save Model	Saves the test scenario version file

4.4 VDM Convergence

The VDM process uses the %GAP (network parameter) as a target for convergence. The % GAP is the percentage difference between the current generalised cost and the previous generalised cost divided by the previous generalised cost.

The convergence criterion for the demand model is:

- %GAP <0.1; or
- If more than 30 iterations are required then the model stops and convergence should be reviewed.

The %GAP network parameter is required to be less than 0.1 for convergence. If the %GAP is greater than 0.1 (and the model has not completed 30 iterations), then highways costs are calculated and fed back into the demand loop once again until the convergence criteria is satisfied.

The public transport demand is only assigned after the final iteration to report flows as there is no capacity constraint built into the public transport assignments (i.e. no matter what demand is assigned the same skims costs are produced).

4.5 VDM Output Data

The output data generated following the convergence of the VDM and assignment of the final highway and public transport models is as follows:

- 15hr highway demand and total vehicle km by trip purpose (reference & test scenario);
- 15hr public transport demand and total passenger km by trip purpose (reference & test scenario);
- AM & Inter Peak OD vehicle demand matrices (highway);
- 15hr OD passenger demand matrices (rail); and

- 15hr OD passenger demand matrices (bus).

5 VDM Validation

5.1 Introduction

The UK Department of Transport WebTAG guidance provides details on the validation of variable demand models (TAG Unit M2– Variable Demand Modelling). The guidance states that:

"Once the model has been scoped and developed, it is important to ensure that the model converges, is realistic and that sufficient sensitivity tests have been undertaken in order to further validate its fitness for purpose and to understand the operation of the model before applying it directly to scheme appraisal or testing strategies".

The WebTAG guidance makes reference to the calculation of elasticities of demand, and how these can be used in the validation process. The guidance states that:

"The acceptability of the model's responses is determined by its demand elasticities. These demand elasticities are calculated by changing a cost or time component by a small global proportionate amount and calculating the proportionate change in travel made"

5.2 Realism Testing

WebTAG recommends that the following 'realism tests' are undertaken using the base year model to understand the nature and scale of responses to a series of interventions, and that the results should lie within specified bands:

- Car Fuel Cost Elasticity;
- Car Journey Time Elasticity; and
- Public Transport Fare Elasticity

5.2.1 Car Fuel Elasticity

The UK Department for Transport guidance on Variable Demand Modelling (TAG Unit M2) suggests that the elasticity of car use with respect to fuel cost should lie within the range -0.25 to -0.35 (overall, across all trip purposes). Evidence on fuel price elasticity⁹ in Ireland suggests that in testing for the impact of petrol prices on car demand in the context of the National Transport Model, that values of -0.2 (low), -0.3 (medium) and -0.4 (high) should be used. The report indicates that the medium value of -0.3 accords well with international experience and is therefore used in this realism test.

Within the NTpM, a test was executed which involved increasing car fuel cost by 10%. The resulting elasticity of traffic (vehicle kms) to car fuel price is shown in Table 5.1 for each trip purpose. The overall result of -0.241 is consistent with expectations as set out above. The relatively low sensitivity of employer's business trips and higher sensitivity of Car Other trips are plausible and reflect the differential in values of time that are applied.

⁹ *The Impact of Fuel Prices on Fuel Consumption and Traffic in Ireland, NRA Transport and Research Note, November 2013*

Table 5.1 Fuel Price Elasticity (10% increase in fuel costs)

Purpose	Car km to Car Fuel
Commuting	-0.174
Business	-0.194
Other	-0.335
All Car	-0.241

While the results of the test are on the lower side of the expected range, this reflects the nature of the NTpM and in particular the lack of competitive alternative public transport options for inter-urban travel along many corridors. In general, drivers have poor alternatives to using their car and are not as responsive to increases in fuel cost relative to other jurisdictions upon which the expected range was developed.

WebTAG specifies that analysts should not use models for scheme appraisal which have elasticities outside this range (-0.25 to -0.35) without providing a reasoned case for doing so. As outlined at the outset of this report, the NTpM and the VDM module should not be used for scheme appraisal under any circumstance.

5.2.2 Car Journey Time Elasticity

Table 5.2 sets out the base year direct elasticities of the model to changes in car travel cost and time. The fuel related test involved a 10% increase in fuel cost, and the model was then run to convergence to reflect changes in congestion. The time related test was undertaken by reducing travel times by 10% and applying the demand model (a single iteration).

This reflects the 'doubly constrained' operation of the model – that land use – including employment – is not assumed to change as a function of travel costs but may indicate a lack of sensitivity for this segment. However given the limited data available for calibration we have not sought to refine the model parameters in this respect.

The sensitivity of the model to car time reflects both the sensitivity to cost and the value of time and is best therefore considered as a verification of the model response rather than a target sensitivity to calibrate the model against. Car trips represent 93% of trips in the model and this is reflected in the low trip elasticity.

The sensitivity of traffic (vehicle demand to time) is plausible given the nature of the NTpM - general research in the UK would indicate a range of up to -2.0 for this elasticity for example.

Table 5.2 Highway Elasticities

Purpose	Car km to Car Fuel	Car Trips to Car Time
Commuting	-0.174	-0.006
Business	-0.194	-0.002
Other	-0.335	-0.007
All Car	-0.241	-0.006

5.2.3 Public Transport Fare Elasticity

The base year elasticities of demand to public transport fares (10% increase in fares) are illustrated in Table 5.3. The model was run to convergence to reflect road congestion effects. Research into fare elasticities shows a range broadly between -0.2 and -0.9 (in the longer term) with lower values in context with lower fares or for longer trips. The elasticity of -0.066 for all Public Transport trips is outside of the expected WebTAG range but reflect the longer nature of the inter-urban public transport trips in the NTpM.

Table 5.3 Public Transport Elasticities

Purpose	PT Trips to PT Fare
Commuting	-0.058
Business	-0.100
Other	-0.068
All PT	-0.066

6 Conclusions

The VDM module of the NTpM was developed by TII to help inform, at a strategic level, the potential multi-modal demand responses arising from proposed changes to the National Road Network (NRN) or policy changes at a national level. The NTpM by its very nature is a high level strategic transport modelling tool and is appropriate for assessing impacts on strategic inter-urban demand only (road, heavy rail and inter-urban-bus), particularly along national road corridors. As such, the VDM module should also only be used to inform the high level assessment of potential demand response and should not be used for scheme appraisal/design.

Outside of the urban areas in Ireland there is, in general, limited opportunities for travel by public transport and people simply do not have a feasible alternative to private car for the majority of trips they need to makeFigure 1.3. As such, the demand responses generated by the VDM module as highlighted by the 'Realism Test' are in general outside of the expected range set out in WebTAG, however it should be noted that the expected ranges set out in WebTAG are based on studies which are influenced by more urban/regional studies in the UK and Europe and in general do not reflect the specific strategic nature of the NTpM.

