Department for Transport

NATIONAL TRANSPORT MODEL VERSION 2R: OVERVIEW OF MODEL STRUCTURE AND UPDATE TO 2015

June 2020

Quality Control

Issue/revision	First issue	Revision 1	Revision 2	Revision 3
Remarks	Working document brought into WSP format	Update with DfT comments		
Date	23rd June 2020	29th June 2020		
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Project number	7006059	7006059		
Report number	1	2		
File reference	\\uk.wspgroup.com\central data\Projects\70006xxx\70006059 - T-TEAR NTM Futures\E Models and Drawings\05 Documentation			

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1. Preface

1.1 This document has been prepared to provide a description of the Department for Transport's (DfT) National Transport Model version 2 (NTMv2) which has been used over a long period to produce the DfT's National Road Traffic Forecasts. In parallel with a major development (Version 5) which is described elsewhere, the version 2 model has been recently updated.

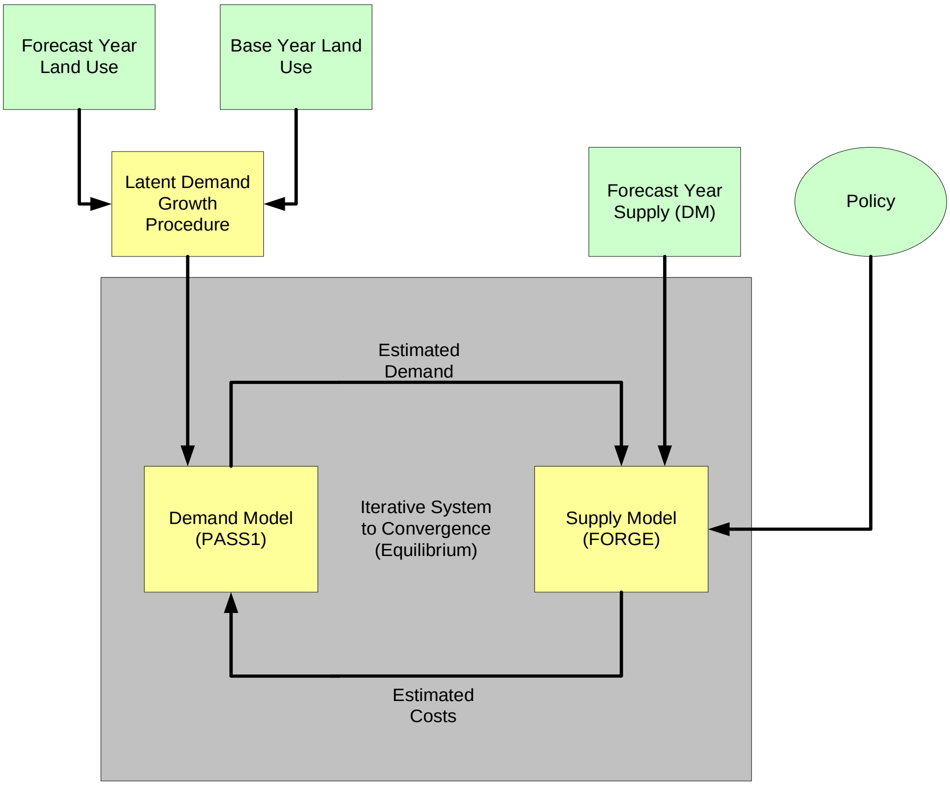
1.2 This document gives an overview to the NTMv2 model and then describes the update. It makes use of text from a number of existing documents, in particular the two Reports produced by the consultants involved in the update, which are available on the DfT Website:

- NTM Future Model Development: NTMv2 recalibration – NTMv2R: Demand Model Implementation, April 2018;
- NTMv2R Demand Model Calibration and Validation, Feb 2018

Background

1.3 Following extensive criticism of the 1989 National Road Traffic Forecasts (NRTF), DfT developed a supply-side module known as FORGE (Fitting on of Regional Growth and Elasticities) to take account of the interaction between demand and road capacity, and this was used in the 1997 NRTF. Subsequent work on the demand side, building on the National Trip End Model (NTEM) and linking this to a model (PASS1) which predicted changes in demand arising from cost changes, led to the first version of the National Transport Model (NTM) in 2000, with the basic structure as shown in Figure 1.

Figure 1: Outline Structure of V2 Model



1.4 The model was reviewed by Mott Macdonald/ITS Leeds in May 2001. A challenge at the time, given computing capacity, was to achieve an acceptable spatial representation for the whole of Great Britain. In transport modelling terms, the model was unconventional in avoiding the use of a) a network and b) an explicit spatial zoning system. Instead, the PASS1 model dealt with aggregate zones, and made use of detailed data from the National Travel Survey [NTS]. The Motts/ITS review gives a reasonable overview: “The PASS1 model is a distribution and mode choice component, which takes as input the trip ends at ward level from the trip generation stage. The ward level trip ends are aggregated to nongeographic area types. The whole Pass 1 model is essentially non-spatial with different zones representing different area types and distance bands, rather than geographical areas. 9 Area types and 12 distance bands are distinguished - the overall split across these is controlled to (observed) NTS proportions.” The 9 area types were subsequently increased to 15 (with some regional information) and the distance bands to 13 (for version 2.0, 2002). Note that the model refers to an average day (total for the week divided by 7).

1.5 Travel segmented by person type and production zone is segmented by a hierarchy of choice models relating to distance band, attraction zone type, and mode. Thus the choice of destination relates to **types** of zones (based on level of urbanisation), not to individual zones.

1.6 The process begins by aggregating the NTEM zonal trip ends to the area type definitions. This provides zone type Trip Ends for 8 purposes which represent a minor aggregation of the NTEM purposes.

1.7 The trip end output used in NTMv2 is at a considerable level of demand segmentation, based on:

- Person type [Child (0-15), Full time worker, Other 16-74, 75+ (Pensioner)[1]]
- SEG/Household income [Low, Medium, High] (based on social class variables from NTS)
- Household type [1 adult/0 car, 1 adult/1+ car, 2+ adult/0 car, 2+ adult/1 car, 2+ adult/ 2+ car]

1.8 In most cases, the level of detail is the same as in NTEM, or slightly more aggregate (the NTEM system uses a slightly more detailed person type specification (with a male/female distinction and a distinction between part time employment, students, and other). However, in the current NTEM, trip rates do not vary by income. Current proportions of trips split by purpose by employment status by household type (household income, composition and car ownership) are derived from NTS 2012-2014.

1.9 After inputting the modal costs, PASS1 then distributes the trip ends for each segment to combinations of zone type and distance, by mode. For each segment, the demand model then predicts the travel choice in terms of mode and destination. The origin and destination zone types within PASS1 are defined as combinations of 11‘Regions’ and 9 National Travel Survey (NTS) area types, and the distance[2] is represented by 13 bands.

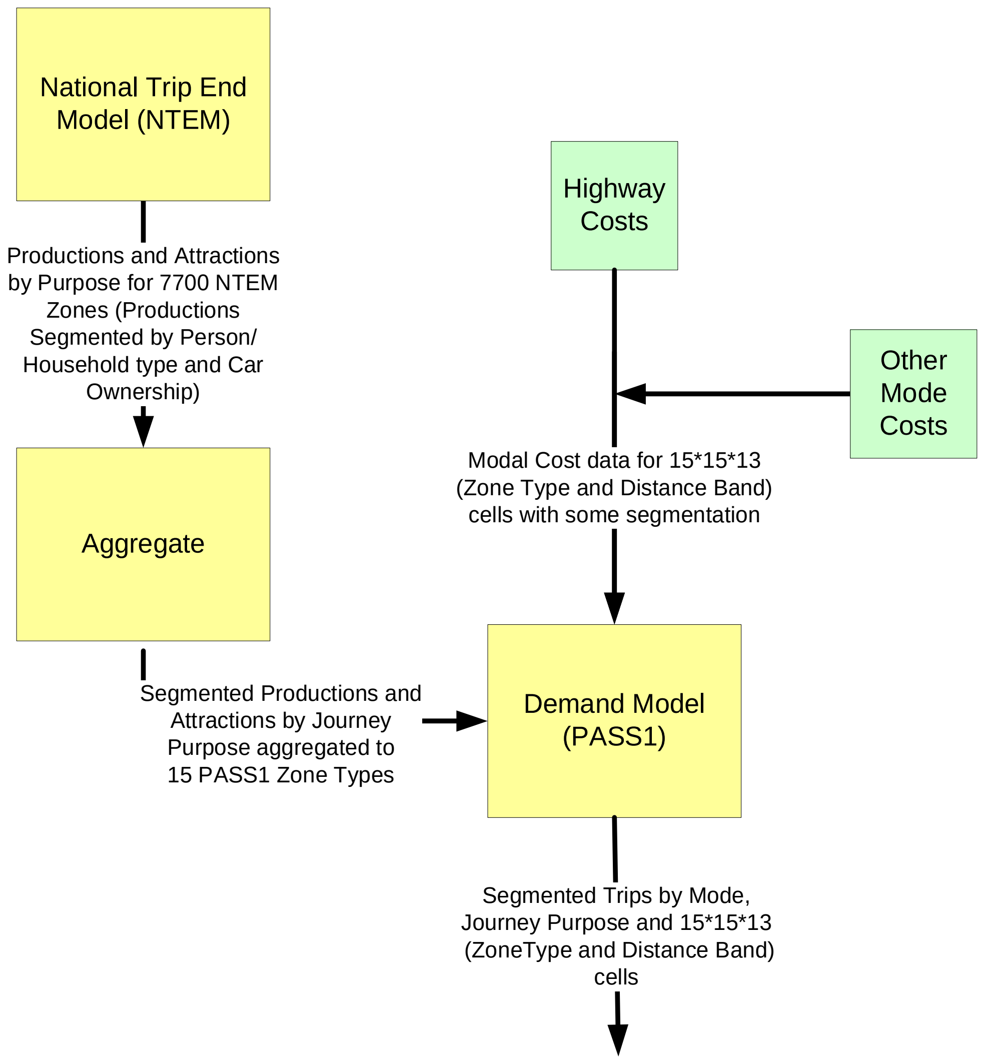
1.10 The PASS1 demand model is sensitive to changes in generalised cost, at the level of [mode * distance band * destination zone type]. The (nested logit) model was calibrated so that it closely reproduces the NTS data in the base year case. The calculation of generalised cost is generally in line with TAG conventions.

1.11 The cost data for highway is provided from a model which will be described below. For other modes, there is a set of base year costs, and some facilities for altering them within an overall Management Interface, which controls the operation of the entire model.

1.12 Thus we may describe the operation of the Demand model according to the following Figure 2:

[1] These are the V2R definitions: in V2 pensioners were defined as 65+ and “Other” was therefore 16-64
[2] Note that these distances are as reported in the National Travel Survey

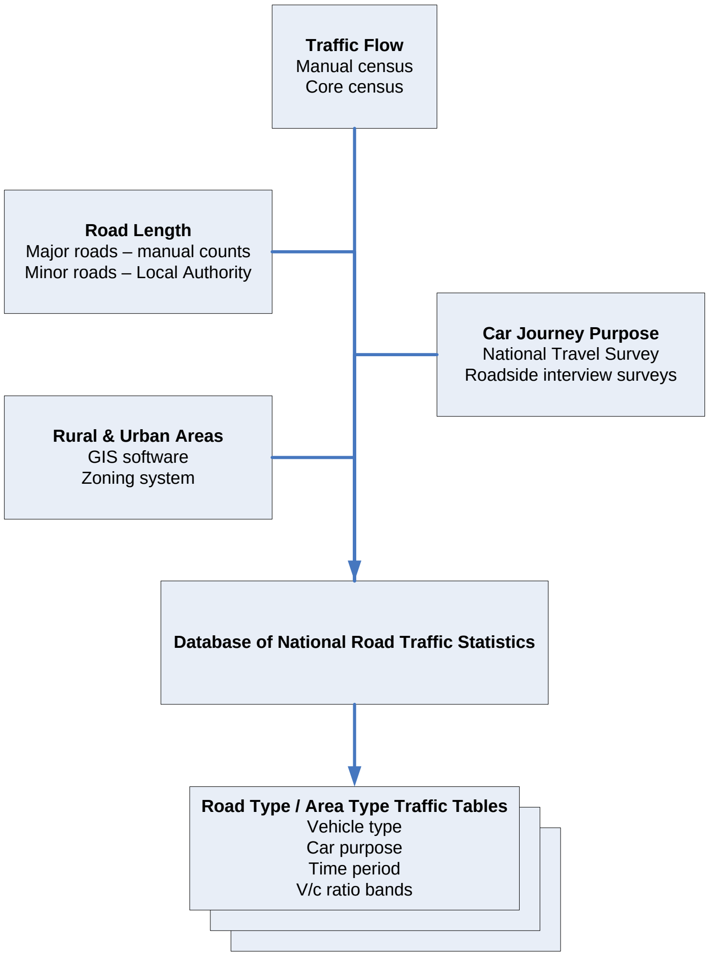
Figure 2: PASS1 Inputs and Outputs



1.13 Given the output demand for car travel, the model now needs to consider the supply implications for the highway mode (there are no supply effects modelled for other modes, though the input fares and level of service can be changed manually). As noted above, the highway supply model is provided by FORGE, which relies on a base set of traffic data derived from the Traffic Census. It holds data on the traffic on individual road links during nineteen time periods that span a week. However, it does not use a road network and has no trip matrix. Hence, when FORGE considers, for example, how congested traffic might change route, it has to use stylised rules rather than consider the practical alternative routes between given origins and destinations.

1.14 The base traffic data, which applies to 5 vehicle types, has had the car data further disaggregated to 6 purposes, using NTS data. Thus for each identified site, we have the flows by vehicle type/purpose in both directions for the 19 periods. In addition, each site is classified by road type, sub-region, and (road) area type as illustrated in Figure 3. This is taken from *FORGE – The Road Capacity and Costs Model – Research Report*, DfT, April 2005: https://webarchive.nationalarchives.gov.uk/20110202223628/http://www.dft.gov.uk/pgr/economics/ntm

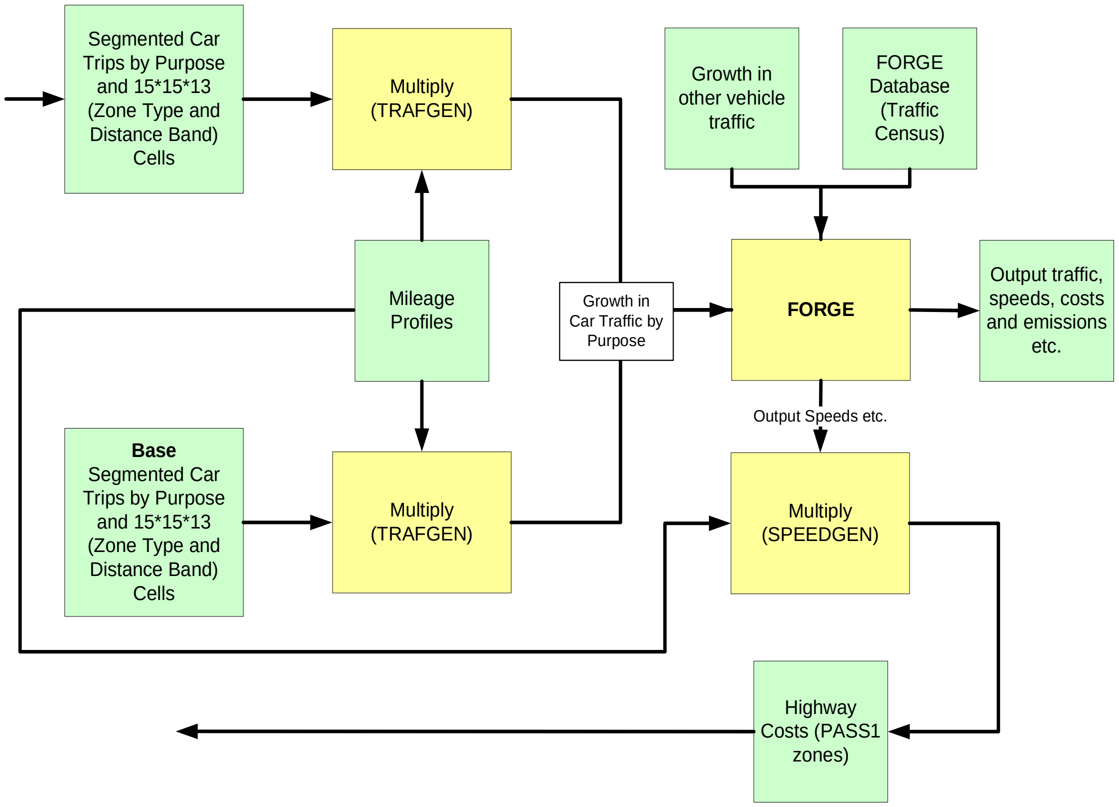
Figure 3: The National Road Traffic Database, Inputs and Outputs



1.15 In order to make use of FORGE, a "bridge" is required between the trips from PASS1 and the traffic passing the "sites" in the traffic database. This is provided by an earlier version of the NTM which constructed a zone-to-zone matrix and a network, and by assigning the matrix derived a set of "mileage profiles". Each element of the matrix can be associated with a particular PASS1 Zone Type and Distance band cell, and, via the assignment paths, each of the links traversed between each origin and destination can be classified according to the dimensions of FORGE (see below): road type, (road) area type and sub-region. A set of mileage profiles has been calculated for different user classes: these give the kilometres travelled by each combination of origin zone type, destination zone type and distance band on each combination of road type, area type and sub-region.

1.16 For forecasting purposes, it is necessary to calculate appropriate growth factors for the traffic at each site: these come from different sources according to vehicle type. The PASS1 output for car drivers (Segmented Trips by 15 * 15 * 13 (Zone Type and Distance band) cells) is multiplied within the TRAFGEN routine by the mileage profiles (which vary by income/Value of Time (VoT) user classes) to give an estimate of the car traffic for each combination of road type, sub-region, and (road) area type. It is then compared with the corresponding base estimate, in order to derive a growth factor. This factor is applied to the observed traffic in the FORGE data base, as illustrated in Figure 4.

Figure 4: FORGE Supply Procedure



1.17 In addition to the car traffic from PASS1, freight forecasts are currently provided from an external source (the Great Britain Freight Model - GBFM [2]) which provides forecasts of Heavy Goods Vehicle (HGV) movements only, and an additional “Light Goods Vehicle (LGV) traffic” module. These are input to a module TGROW in a way which is conformant with the FORGE database.

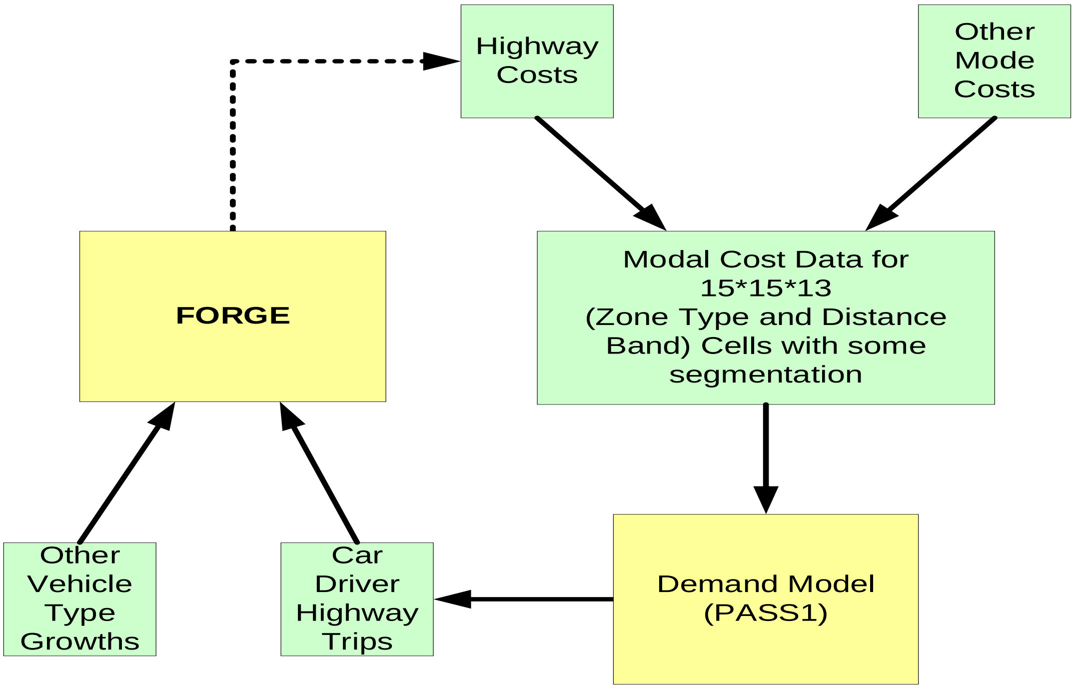
1.18 FORGE then takes the forecast Annual Average Daily link Flow (AADF) at each site and deduces the consequences for speeds by applying capacity and speed-flow relationships, generally compatible with the “COBA” in Appendix D of TAG Unit M3.1. Each site is first grouped by the standard FORGE “RAS” combinations [road type, (road) area type, and sub-region], and this determines the appropriate maximum hourly capacity of the link and speed flow relationship to use. The AADF for the site, multiplied by 7 to convert to a weekly basis, is distributed across each of the 19 FORGE time periods and taken together with the theoretical capacity this is used to calculate the volume to capacity (v/c) ratio of the link in each time period. Then the traffic on the link (flow in period * length) is grouped with other similarly classified links (i.e., the same RAS combination) into one of 26 v/c bands, which range from 0 to 1.3 (and above) and increase in steps of v/c 0.05. The total car traffic in each v/c band is further subdivided (by fixed proportions that vary by RAS and period) into 6 “purposes” which have varying income/VoT.

1.19 With the traffic aggregated by v/c band in this manner it is then possible to calculate a speed (based on v/c ratio) from the speed flow curve and thus the components of generalised cost (time, fuel cost, other operating cost, tolls) on a per Km basis, using more or less standard relationships (based on tag-unit-a1-3-(user-and-provider-impacts). As a result of these changes in generalised costs FORGE allows further changes to take place, with the aim of a) simulating routeing responses, and b) time of day shifting (from busy periods to less busy periods). These changes are modelled by means of elasticities at the level of the v/c band within each RAS combination: the elasticities vary by purpose and vehicle type. Allowance can also be made for changes to road capacity, which affects the distribution between v/c bands. More details are given in the FORGE reported cited above.

1.20 At the end of this process, involving some iteration, FORGE produces for each v/c band, separately by time period and income/VoT user class, the components of generalised cost (time, fuel cost, other operating cost, tolls) on a **per Km** basis, and these are averaged, traffic-weighted, across v/c bands to the standard FORGE RAS combinations. Then the mileage profiles are applied again within the SPEEDGEN routine, this time to provide the appropriate costs for the PASS1 Demand model. For each PASS1 "cell" (Origin zone type, Destination zone type, distance band), the mileage profiles give kilometres travelled on each combination of road type, area type and sub-region. Multiplying these by the FORGE estimates of generalised cost per Km, and summing over the FORGE combinations gives us the overall generalised cost for the cell.

1.21 The procedure iterates between PASS1 and FORGE until acceptable convergence is obtained. Thus the model can essentially be summarised in the following Figure 5.

Figure 5: V2 Equilibrium Process



1.22 On this basis, the main model outputs are:

- trips by Purpose and mode for each Origin zone type, Destination zone type, distance band cell from PASS1;
- traffic and speeds by vehicle type/journey purpose and time period for each road type, (road) area type, and sub-region (RAS) from FORGE.

1.23 The derived speeds are also used in the calculation of vehicle emissions and the marginal external costs (MECs) which are used in the appraisal of a range of transport policies.

2. The Update

Aims and Objectives

2.1 At the outset of the work to develop the new spatially detailed version of the NTM (v5), it was recognised that it was advisable as a short term exercise to have a parallel update of NTMv2, which might continue to be used due to its scale and speed of operation. NTMv2 had been in regular use by the DfT team to provide forecasts and scenario impacts for a variety of policy analyses, but it was based on old data inputs (mainly more than 10 years old) and hence updates were required.

2.2 For this reason the Demand Model from NTM version 2 has been updated to incorporate the latest available NTS data and represent a 2015 Base Year, without any changes to the model choice structure, software and basic implementation, which have been taken as defined by NTMv2. The updated model is known as NTMv2R.

2.3 As described in the previous Chapter, NTMv2 comprises three main components which are relevant to this update task:

1. A traffic database providing the Base year traffic conditions by road type, area type and sub region
2. A demand model for forecasting personal travel demand by purpose, mode and traveller type (PASS1)
3. A statistical traffic forecasting tool (FORGE) which allocates forecast growth in road vehicle travel to the available capacity

2.4 The traffic database was updated to include all 2015 hourly counts/ATC data & AADF's by Atkins and DfT. In addition, the associated FORGE tool has been updated by DfT, though the changes are minor and relate mainly to the fuel cost functions. This Report describes the work on the second component – PASS1. Although the work is relatively independent from the tasks to implement the new spatially detailed model (v5), the base year and some of the input data are common to both models.

2.5 The premise for the updating work of NTMv2 was to reduce risk and effort by retaining the model structure and implementation unchanged. NTMv2R therefore has exactly the same dimensions as the earlier model and continues to be implemented using the MEPLAN modelling software. There have however been a number of small enhancements incorporated while updating the data inputs as set out below.

2.6 The data inputs to the NTMv2R demand model which require updating include:

- Travel characteristics (i.e. generalised cost components) by mode (car, bus, rail, walk and cycle) for different combinations of purpose, trip length (distance band) and production / attraction zones (area types)
- All costs expressed in 2015 values and prices
- Travel demand inputs (trip ends) – trip productions and attractions by zone

2.7 The following enhancements have been applied to the demand model:

- Small geographic adjustments to the zone definitions to achieve better compatibility with NTEMv7 geography and areas available from the NTS;
- The demand model has been linked to NTEMv7 to provide updated trip ends;
- One small change in age group for consistency with the update to the NTEM dataset which provides the trip end inputs. The upper age band has been revised from those aged 65+ to those aged 75+.
- Functional form for forecasting vehicle operating costs has been revised in line with changes set out in the TAG databook.
- Upgraded to MEPLAN version 5.2 to utilise 64 bit version and streamline running process;

2.8 In addition to these modifications the main task has been updating the inputs to the model to incorporate values of time from the TAG databook and revise trip characteristics for all modes of travel based on the latest best available data sources, including NTS, Transport Statistics Great Britain, National Express ticket prices, Transport for London road user charge, and MOIRA rail model results.

2.9 Following these updates to the model, the choice parameters and constants were updated through a re-calibration exercise, to ensure that it best replicates travel behaviour in the 2015 base year given the constraints of retaining the NTMv2 approach. The recalibration process involves adjusting the model parameters without making any changes to the NTMv2 model structure.

PASS1 Model Structure

2.10 The demand model operates with production – attraction (P/A) trips (which are defined as: the from home legs of home based trips, and non-home based trips) for a single time period to reflect an average day (full week / 7). Volumes of trip productions by traveller type and trip attractions by trip purpose are taken directly from the DfT's NTEM dataset for the year of interest.

2.11 The demand model aims to carry out the distribution and modal split stages of a conventional four stage demand model. It incorporates a high degree of traveller segmentation to enable a range of policies to be tested. The model takes as input the total trip productions and attractions by purpose and traveller type (all modes combined) from NTEM: it should be noted that the modal split available in NTEM is not used.

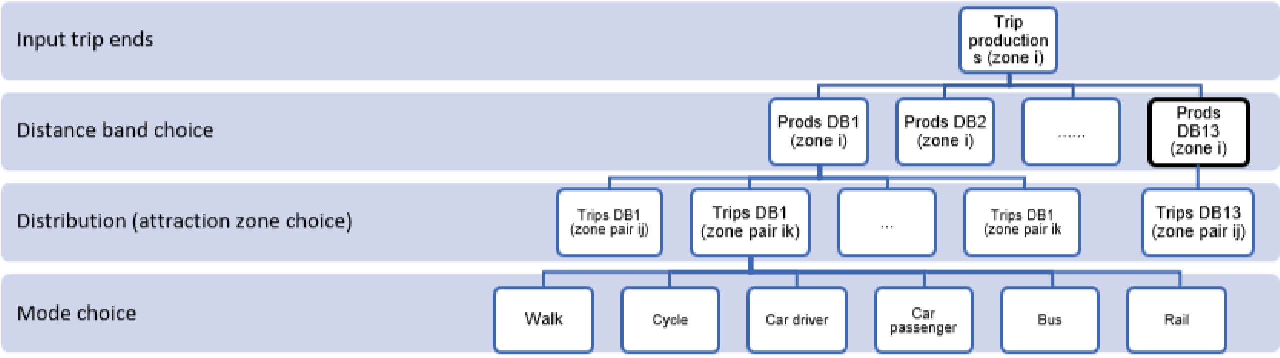
2.12 As noted, there are three choice mechanisms that operate within the demand model for each input trip production:

- Choice of distance band;

- Choice of attraction zone;
- Choice of mode of travel.

2.13 The choices are all modelled using absolute logit choice models and implemented with an assumed structure (unchanged from NTMv2) as shown in Figure 6 below.

Figure 6: Demand model choice hierarchy



2.14 The distance band choice and distribution module of the demand model split the trip productions into distance bands and allocate them to attraction zones to match a set of specified trip attraction constraints. Travel characteristics used in the distribution model are taken from the linked modal split model.

2.15 The distance bands used within the demand model are shown in Table 2-1:. They are the standard 12 bands as used in presentation of data collected in the NTS plus a further distance band to improve the representation of the longest distance trips primarily for the purpose of identifying rail and air trips. Because the NTS collects information on travel distances in miles, the demand model has been implemented using a distance unit of miles.

Table 2-1: Distance band numbers and distance ranges

Distance band	Range (miles)
1	<1 mile
2	1-2 miles
3	2-3 miles
4	3-5 miles
5	5-10 miles
6	10-15 miles
7	15-25 miles
8	25-35 miles
9	35-50 miles
10	50-100 miles
11	100-200 miles
12	200-300 miles
13	> 300 miles

2.16 The zone types are consistent throughout each stage of the demand model and defined as shown in Table 2-2. NTMv2R zone types are designed to be as similar as possible to NTMv2 zone types, for consistency with other parts of the model, but aligning with NTEMv7 zone boundaries and using more up-to-date data on built-up areas.

Table 2-2: Zone type numbers and descriptions

Zone Number	Description
1	Central London
2	Inner London
3	Outer London
4	N & E Central Conurbation
5	West Central Conurbation
6	N & E Conurbation Surrounds
7	West Conurbation Surrounds
8	N & E Urban Big
9	West Urban Big
10	South Urban Big
11	Not defined
12	N & E Urban Large
13	West Urban Large

2.17 NTEMv7 zones in England and Wales are identical to Middle layer Super Output Areas (MSOA), which nest within Local Authority Districts (LAD) and Regions. NTEMv7 zones in Scotland are based upon groups of Data Zones, which nest within Council Areas (CA) and Regions. This provides a hierarchy of administrative boundaries that allows NTEMv7 zones to be mapped onto NTMv2R zone types.

2.18 The 15 NTMv2R zone types are defined by combinations of Regions and Area Types, as shown in Table 2-3: below. These definitions are identical to NTMv2 – although the exact combinations of NTEMv7 zones that make up each Area Type do not match the previous boundaries perfectly (since NTMv2 was not based on MSOAs). Some settlements will also have changed area type in the updated model for 2015 most likely due to increases in the population in the specific urban area (eg towns between 50,000 and 100,000 population). The area type definitions are taken from NTS according to size of urban area (based on population).

2.19 Not all the combinations of zone pairs and distance bands exist, for example it is not possible to travel from the Inner London area to a rural area within a distance band of under 1 mile.

Table 2-3: Definition of model zones by Region and Area type

Region	Area type 1: Central London	Area type 2: Inner London	Area type 3: Outer London	Area type 4: Metropolitan	Area type 5: Outer Conurbation	Area type 6: Urban Big (pop>250k)	Area type 7: Urban Large (pop>100k)	Area type 8: Urban medium (pop<25k)	Area type 9&10: Small Urban & Rural
London	1	2	3	-	-	-	-	-	-
South East	-	-	-	-	-	10	14	16	17
East of England	-	-	-	-	-	10	14	16	17
South West	-	-	-	-	-	10	14	16	17
Wales	-	-	-	-	-	10	14	16	17
West Midlands	-	-	-	5	7	9	13	16	17
North West	-	-	-	5	7	9	13	16	17
East Midlands	-	-	-	4	6	8	12	16	17
Yorkshire and the Humber	-	-	-	4	6	8	12	16	17
North East	-	-	-	4	6	8	12	16	17
Scotland	-	-	-	4	6	8	12	16	17

2.20 The modal split module splits the trips by traveller type, purpose and distance band into the different modes of travel. The same six modes are used in the demand model as in the NTEM model with the definition of the modes based on the NTS classification of modes as shown in Table 2-4. For some model inputs there is no distinction between the walk and cycle modes and these are sometimes referred to as active modes.

Table 2-4: Definition of demand model modes

Main mode	**NTS mode definitions**
1 Walk	Walk < 1 mile Walk 1+ miles
2 Cycle	Bicycle
3 Car driver	Private: car driver Motor cycle / scooter / moped: driver Van / lorry: driver Taxi Minicab
4 Car passenger	Private: car passenger Motorcycle / scooter / moped: passenger Van / lorry: passenger Other: private transport
5 Bus	Private (hire) bus London stage bus Other stage bus Express bus Excursion / tour bus
6 Rail	LT underground Surface rail Other public transport (includes Light Rail / metros etc) Domestic Air

2.21 The dimensions and units used by NTMv2R are shown in Table 2-5. Updates have been made to the prices to reflect the 2015 Base Year. As noted above the model is operating with P/A trips.

Table 2-5: Dimensions and units

Dimension	Units
Distance	Miles
Time	Minutes
Cost / Money	Pence in 2015 prices
Speed	Miles per hour
Disutility	Generalised Minutes
Trips	Average day, outward legs (from home) for HB; one way for NHB

2.22 Travel characteristics are input to NTMv2R for each of the six travel modes represented in the model and are generally:

- Travel time (minutes) - actual elapsed time incurred at each stage of trip (minutes) – not weighted in any way
- Monetary cost of travel (pence in 2015 prices)

2.23 Modes with multiple stages (e.g. walking, waiting and riding on public transport) require separate characteristics for each stage of travel.

2.24 The two components (money and time) are combined to create a generalised cost (or disutility) of travel. They are combined using a value of time (pence per minute) appropriate to the traveller type (person type and trip purpose).

- Disutility = generalised costs in minutes including weighted time components, money costs converted to time units using appropriate values of time, additional perceived generalised costs and alternative specific constants.

Detailed model description

Notation

2.25 The following notation for zones and distance bands is adopted (loosely) in the formulations below:

i origin zone

j destination zone

l distance band

$\alpha^m, \beta^m, \gamma^m$ Weights on time component by mode m (see Table 4 2 for values implemented)

ASCs, Alternative specific constants – mixture of global, origin and destination specific constants for each demand segment and mode. Values derived during model calibration.

A, B, C “Guilt factors” (see below) which determine the proportion of monetary costs associated with car travel and borne by the driver which are additionally perceived by the car passengers.

Generalised cost

2.26 The disutility / generalised cost of each mode is defined slightly differently based on relevant travel characteristics as set out below. The derivation of the cost components (vehicle operating costs etc) are provided in Chapter 4.

2.27 To ensure there is no double counting of money costs, they must either be shared between travellers (eg car drivers and passengers) or paid by one member of the group. The assumption here is that all costs are paid by the drivers with the passengers perceiving some costs in the form of additional disutility. The proportion of money costs perceived is determined by “guilt factors” (i.e. car passenger costs = guilt factor* car driver costs).

Walk and cycle:

$$Time\ Components = \alpha^m.traveltime_{ijl}$$
$$Cost = 0$$
$$Disutility\ =\ Time\ Components\ +\ ASCs$$

Car driver:

$$Time\ components = ridetime_{ijl} + \beta^m.parksearch_j$$
$$Cost = voc_{ijl} + park_j + RUC_j$$
$$Disutility\ =\ Time\ components\ +\ (Money\ costs)/vot\ +\ ASCs$$

Car passenger:

$$Time\ components = \gamma^m.ridetime_{ijl} + \beta^m.parksearch_j$$

Where: $\gamma^m \geq 1$ for car passenger (parameter being determined as part of calibration)

$Cost = 0$ (ie no money cost in pence)

$$Perceived\ Costs = A.\widetilde{voc}_l + B.park_j + C.RUC_j$$

Where:

$\widetilde{voc}_l$ is the approximate vehicle operating cost based on an average speed of travel as described later in Section 4.

A, *B* and *C* are guilt factors for each cost component

$$Disutility\ =\ Time\ components\ +\ Perceived\ costs/vot\ +\ ASCs$$

Bus:

$$Time\ Components = ridetime_{ijl} + \alpha^m(access_i + egress_j) + \beta^m.wait_{il}$$
$$Cost = fare_{ijl}$$
$$Disutility\ =\ Time\ components\ +\ (Money\ costs)/vot\ +\ ASCs$$

Rail:

$$TimeComponents = ridetime_{ijl} + \alpha^m(access_i + egress_j) + \beta^m.wait_{il} + interconnect_{ijl} + crowdtime_{ijl}$$

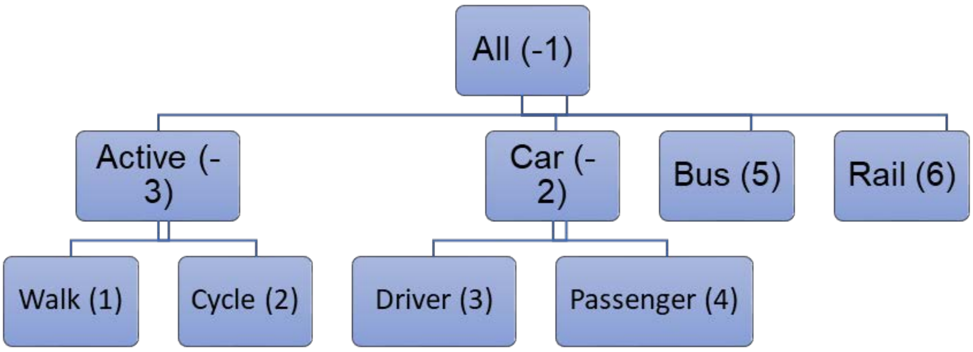
$$Cost = fare_{ijl}$$

$$Disutility = Time\ components + (Money\ costs)/vot + ASCs$$

Choice model specifications

2.28 The **mode choice** model is a hierarchical logit model as shown in Figure 7 below, for each of the trip purpose, traveller type and distance band combinations output from the distribution model. Walk and cycle are sub modes of the "active" or non-mechanised mode, while car trips are subsequently split between drivers and passengers.

Figure 7: Mode choice hierarchy



2.29 Note however that the sub-mode parameter λ_m only applies to the car sub-mode choice component (the sub-mode choice parameter for walk and cycle has been set as equal to λ_M). This is an assumption in-line with the original NTMv2 structure.

2.30 Thus the P/A modal trips, T^m_{ijl}, from zone *i* to zone *j* by distance band *l,* are calculated from the trip productions by distance band for the zone T_{ijl} as:

$$T^m_{ijl} = T_{ijl}\frac{exp(-\lambda^M u^m_{ijl})}{\sum_M exp(-\lambda^M u^M_{ijl})}$$

Where:

λ^M is the lambda (sensitivity) parameter for mode choice

M is the full set of modes (but combining car driver and passenger)

u^M_{ijl} the disutility of travel associated with each zone pair and distance band (ijl) is calculated from the input characteristics to the demand model for mode m., except in the case of car where it is obtained as a logsum as shown below.

2.31 For the combined car mode the demand is further split between driver and passenger using the function:

$$p^r_{ijl,m=car} = \frac{exp\left(-\lambda^m u^r_{ijl}\right)}{\sum_R exp\left(-\lambda^m u^R_{ijl}\right)}$$

Where:

λ^m, is the lambda (sensitivity) parameter for sub-mode choice

R, is the set of car driver and passenger sub-modes

u^r_{ijl}, the disutility of travel associated with each zone pair and distance band (*ijl*) is calculated from the input characteristics to the demand model for car sub-mode *r*.

2.32 This in turn provides the disutility for the combined car mode:

$$u^{m=car}_{ijl} = -\frac{1}{\lambda^m} ln \sum_R exp\left(-\lambda^m u^R_{ijl}\right)$$

2.33 The functional form of the **distribution model** (attraction zone choice) is a single level, multinomial logit model of discrete choice. The model takes the demand (trip productions) by purpose, traveller type and distance band and then distributes the trips amongst the attraction zones according to the level of disutility of locating in each zone. Zonal trip attractions by purpose from the trip end model are used as constraints to the distribution model.

2.34 Thus the P/A trips, T_{ijl}, from zone *i* to zone *j* by distance band *l,* are calculated from the trip productions by distance band for the zone $T_{i.l}$ as:

$$T_{ijl} = T_{i.l} \frac{exp\left(-\lambda^A\left(u_{ijl}+S_{ijl}\right)\right)}{\sum_J exp\left(-\lambda^A\left(u_{iJl}+S_{iJl}\right)\right)}$$

Where:

λ^A, is the lambda (sensitivity) parameter for distribution (attraction zone) choice

J, is the full set of destination zones

u_{ijl}, is the disutility of travel associated with each distance band (l) is calculated as the logsum of the modal disutilities for each zone pair and distance band (ijl) as follows:

$$u_{ijl} = -\frac{1}{\lambda^M} ln\left(\sum_M exp\left(-\lambda^M u^M_{ijl}\right)\right)$$

Where:

S_{ijl}, are the “size terms” that denote the importance for travel in the specific zone pair and distance band given the geography of the country and volume of attractions at the destination. Note that for technical reasons[3] the size terms have not been updated from NTMv2 – ie the geography of the country and associated opportunities are assumed not to have changed.

λ^M, is the lambda (sensitivity) parameter for mode choice

2.35 All trip purposes are doubly constrained to the NTEM v7 trip attraction totals in the base and forecast years. This results in iterative adjustments to the disutility of travel $u_{i,jl}$ for each attraction zone *j*.

[3] the size terms cannot easily be updated using the existing methodology

2.36 The **distance band choice** model is embedded within the trip distribution model. The trip productions by purpose and traveller type for each zone are inputs to the model. These trip ends are then split into the distance bands with the proportion being calculated using a logit segmentation function based on the relative disutilities of travel from each production zone for the different distance bands. The travel disutilities are calculated by the mode choice model and applied over all modes and attraction zones.

2.37 Thus the trip productions, $T_{i,l}$, in zone *i*, by distance band *l*, are calculated from the total trip productions for the zone T_i as:

$$T_{i.l} = T_i \frac{exp\left(-\lambda^D u_{i.l}\right)}{\sum_L exp\left(-\lambda^D u_{i.L}\right)}$$

Where:

λ^D, is the lambda (sensitivity) parameter for distance band choice

L, is the full set of distance bands

$u_{i,j}$, is the disutility of travel associated with each distance band (*l*) is calculated as the logsum of the disutilities for each zone pair and distance band (*ijl*) from that production zone (*i*) as follows:

$$u_{i.l} = -\frac{1}{\lambda^A} ln\left(\sum_J exp\left(-\lambda^A\left(u_{iJl} + S_{iJl}\right)\right)\right)$$

Where:

λ^A, is the lambda (sensitivity) parameter for attraction zone choice

S_{ijl}, are the size terms as defined below.

2.38 All trip purposes are constrained in the base year to match distance band profiles derived from National Travel Survey (NTS) data. This results in iterative adjustments to the disutility of travel $\boldsymbol{u_{i.l}}$ for each distance band. These distance band specific constants are added to the disutility in all forecast / scenario runs, where distance band constraints are not applied.

Segmentations of travel and person type

2.39 The demand model is highly segmented, with a total 105 different categories of trips. These segments are made up of permutations of person type, household car availability, income group and trip purposes as set out below. Not all dimensions are included (or appropriate) for every trip purpose. The combinations included in the demand model are also summarised later in Table 2-10:10.

2.40 Within the demand model, eight different trip purposes are defined, including six home-based trip purposes and two non-home based trip purposes. They are listed in Table 2-6. The purposes are defined from the NTS variables "trip purpose from" and "trip purpose to". Escort purposes are treated in the same way as the main purpose (ie escort education is combined with education) since they are attracted to the same locations. If the "trip purpose to" is not home, this defines the purpose of the trip, otherwise the "purpose from" defines the purpose of the trip.

Table 2-6: Trip purpose[4]

Trip purpose	Home based on Non home-based	Description	NTS purpose definitions included
1	Home-based	Work (i.e. commuting)	Work, Escort work
2	Home-based	Employer's business	In the course of work, Escort in the course of work
3	Home-based	Education	Education, Escort education
4	Home-based	Personal business and shopping	Food shopping, Non food shopping, Personal business medical, Personal business eat / drink, Personal business other, Escort shopping / personal business
5	Home-based	Recreation, social and visiting friends/relatives	Eat / drink with friends, Visit friends, Other social, Entertain / public activity, Sport: participate, Other escort
6	Home-based	Holidays and day trips	Holiday: base, Day trip / just walk
7	Non Home-based	Employer's business	In the course of work, Escort in the course of work
8	Non Home-based	Other	All other combinations (except home to home excluded – negligible)

2.41 There are four person types, which are formed by combining age with employment status as shown in Table 2-7. The age bands have been revised as part of the update for consistency with NTEM.

Table 2-7: Person types

Person Type	Status	Age
1	Children	0-15
2	Full-time employed	16-74
3	Other (part time employed, students and non employed)	16-74
4	Pensioner	75 and over

2.42 For the trip purposes work and employer's business, the person types 1, 3 and 4 have been grouped together.

2.43 There are five household type groups, which are formed by combining the number of adults and cars within a household as shown in the following Table 2-8:8: These five categories are used for all home-based trip purposes with the exception of HB holiday and day trips which are not segmented by household type.

Table 2-8: Household type

Household Type	Number of adults	Number of cars
1	1 adult	0 car
2	1 adult	1+ cars
3	2 or more adults	0 car
4	2 or more adults	1 car
5	2 or more adults	2+ cars

[4] Note that within FORGE, purposes 3 and 4 are aggregated (Home Based Essential Other – HBEO) as are purposes 5 and 6 (Home Based Discretionary Other – HBDO)

2.44 A segmentation of the population into three socio-economic group (SEG) / income groups is used for the work and employer's business trips. The three groups were originally defined from the SEG of the individuals since this data was available from the Census of Population, the Family Expenditure Survey (FES) and the NTS which were all used in the development of the original model. The aggregation of the SEGs into the three income groups has been retained unchanged as shown in Table 2-9:9.

Table 2-9: SEG / income groups defined

Social class (NTS variable SC_B01ID)	**NTMv2R income band**
Professional occupations	High
Managerial and technical occupations	High
Skilled occupations – non-manual	Medium
Skilled occupations – manual	Medium
Partly skilled occupations	Low
Unskilled occupations	Low

2.45 The 105 combinations of the trip purposes, person types, household types and income / SEG groups modelled are shown in Table 2-10:10 below.

Table 2-10: Trip demand segments represented in Demand model

Purpose	**Person type**	**SEG / Income**	**1 adult / 0 car**	**1 adult /1+ car**	**2+ ad / 0 car**	**2+ ad / 1 car**	**2+ ad / 2+ car**	**All**
HB Work	Full time emp	High	1	2	3	4	5	
		Medium	6	7	8	9	10	
		Low	11	12	13	14	15	
	Rest of pop'n	All	16	17	18	19	20	
HB EB	Full time emp	High	21	22	23	24	25	
		Medium	26	27	28	29	30	
		Low	31	32	33	34	35	
	Rest of pop'n	All	36	37	38	39	40	
HB Educ	Child (0-15)		41	42	43	44	45	
	Full time emp		46	47	48	49	50	
	Other 16-74		51	52	53	54	55	
	75+		56	57	58	59	60	
HB PB / Shopping	Child (0-15)		61	62	63	64	65	
	Full time emp		66	67	68	69	60	
	Other 16-74		71	72	73	74	75	
	75+		76	77	78	79	80	
HB Rec / Visiting friends	Child (0-15)		81	82	83	84	85	
	Full time emp		86	87	88	89	90	
	Other 16-74		91	92	93	94	95	
	75+		96	97	98	99	100	
HB Hols / Day trips	All persons							101
NHB EB	All persons	High						102
		Medium						103
		Low						104
NHBO	All persons							105

2.46 Since the distribution model estimates the split of the trips by purpose and traveller type into the 13 distance bands, the 105 factors shown in Table 2-10 are thus expanded into 1365 factors that are then allocated amongst the different model attraction zones.

2.47 Time of day is not explicitly represented in the demand model, which represents travel for an average day (total for the week divided by seven). However, due to the large variation in rail travel characteristics between peak and off-peak travel these two time periods were incorporated for rail travel only in NTMv2 and have been retained for the input of updated characteristics in NTMv2R. In order not to introduce additional complexity associated with time of day choice the different trip purposes have been allocated to the time period in which they predominantly occur and hence adopt the most appropriate travel characteristics.

2.48 The correspondence between the rail time period characteristics used and the trip purposes within the demand model is shown in Table 2-111.

Table 2-11: Relationship between demand model purposes and rail time periods

Trip purpose	Time period – rail characteristics
Home-based work (HBW)	Peak
Home-based employer's business (HBEB)	Peak
Home-based education (HBEd)	Peak
Home-based personal business / shopping (HBPB/shop)	Inter-peak
Home-based recreation / visit friends (HBRec/VF)	Inter-peak
Home-based holidays / day trips (HBHols)	Inter-peak
Non home-based employer's business (NHBEB)	Peak
Non home-based other (NHBO)	Inter-peak

3. Demand Data

3.1 A data use agreement was signed for NTS data covering the 2002–2014 period (the 2015 NTS data was not available in time to be included). A key requirement was to explore the sample sizes of trips by journey purpose and year for the recent years of NTS data. While using more years of NTS data gives larger sample sizes for model calibration, it might make the sample less representative of 2015 travel conditions, in the light of recent changes in trip making behaviour (refer to Jahanshahi et al, 2015, which discusses changes in travel behaviour over time using NTS data).

3.2 The conclusion was that for distance band [DB] and destination choice for all purposes, it would be necessary to combine at least three NTS years (2012–2014) to get sufficient sample sizes. For the recalibration of mode choice, however, the aim was to get sample sizes of above 1,000 within each combination of purpose, household structure and distance band when all modes are aggregated, and this led to using nine years of data from 2006 to 2014. An analysis of distance profiles for each mode suggested that variations over years are small.

3.3 Up to 2012 NTS includes households from England, Scotland and Wales, but from 2013 onwards for England only. On the assumption that, after accounting for variations by area types, Scottish and Welsh households will have similar travel behaviour to English households, it was decided to use English households only for all years of NTS data included in the calibration samples.

3.4 Household, individual and trip data was linked to produce one table of NTS data, and the data was recoded into variables with the required segmentations for the model calibration. As in NTMv2, it is assumed that the return trips for the simple tours are in essence the same as outbound trips (and have the same distance profile). It is also assumed that they have the same level of service [LOS].

4. Cost Data

4.1 For HB trips only the characteristics for the outward leg are coded, as was done for NTMv2.

4.2 Where possible the same data providers have been used to provide the input data to the model as NTMv2. Where assumptions had been made for the previous NTMv2 calibration in 2003, without any source data, these assumptions have been retained – unless new data sources have emerged in the intervening period which enable improved assumptions to be made.

4.3 In NTS distances are coded for the entire journey by the main mode. There is no information on the distances associated with the access and egress stages of public transport trips or the parking stage of car trips relative to the main ride stage of the journey.

4.4 Values of time (vot) by traveller type are derived from DfT's TAG Databook. The TAG Databook July 2017 (v1.8.2) was downloaded and used to source the NTMv2R inputs. In NTMv2, two core values of time were taken from the databook for business and other travel. A profile was then applied to these to give a traveller type specific value of time by household type and person type based on the pattern of household disposable incomes. For NTMv2R three basic values of time were taken from the TAG Databook v1.8.2 for a 2015 value (base) year in 2015 prices as follows:

Table 4-1: Core values of time (2015 values in 2015 prices)

Purpose	VOT (£ per hour)	Source –TAG Databook Sheet A1.3.1
Commuting	11.43	Cell E45 – Perceived Cost Commuting
Business	18.59	Cell E40 – Perceived Cost Working Time – average of all working persons (not mode specific)
Other	5.22	Cell E46 – Perceived Cost Other

Source: TAG Databook v1.8.2

4.5 Further differentiation in values of time was also applied for the different traveller types within the model. For NTMv2 the pattern of variation in weekly disposable income was used to generate value of time profiles. They were originally derived using published data from the Family Expenditure Survey (now the Living Costs and Food Survey). The incomes were not readily available for the NTMv2 segmentation so a Furnessing process was adopted using number of households by the dimensions for which incomes were available to estimate the incomes for all household type combinations required (by size / car availability and income / socio economic group).

4.6 These value of time profiles have not been updated and are applied to the three core values of time to provide variations in values of time for the 105 segments.

4.7 Following traditional practice, the values of access / egress walking time and waiting times have been weighted in the calculation of the generalised cost or disutility of travel. The weights applied were taken from NTMv2 with some limited updates. The main cycle trips also have a weight to increase the time component of the generalised cost. Walk trips previously included a weight, though this has now been set to 1 (this improved the mode split of the model during calibration) as shown in Table 4-2. The rail access and egress weight was reduced to bring it within the range of typical values set out in TAG guidance (previously sourced from the National Rail Passenger Model).

Table 4-2: Time weighting by trip stage used in demand model

Trip stage	Weight	Change notes
Bus access & egress	2.0	No change
Bus wait	2.0	No change
Rail access & egress	2.0	Reduced from 2.81
Rail wait	2.0	Reduced from 2.22
Walk trips	1.0	Reduced from 2.0
Cycle trips	2.0	No change
Car (driver and passenger) parking search time	2.0	No change
Car (driver and passenger) ride time	1.0	No change
Bus ride time	1.0	No change
Rail ride time	1.0	No change

4.8 The monetary costs of travelling by car are not paid by both the drivers and passengers. If the full costs are incurred by the driver and influence their travel behaviour then there are no remaining monetary costs for the passengers to incur. While passengers rarely pay the actual car costs (money), their behaviour is closely linked to the behaviour of the drivers. To improve the responsiveness of car passengers in the demand model, their generalised cost of travel (disutility) includes a “perceived” monetary cost of travel (using “guilt factors”) coded in generalised minutes. This implementation has not been updated from NTMv2, though some adjustments have been made to the guilt factors applied during the model calibration stage to improve the behaviour of passengers without introducing large alternative specific constants.

4.9 The proportions of monetary costs perceived by the car passengers as a generalised cost (disutility) following the NTMv2R calibration are shown in as follows:

Table 4-3: Proportion of monetary cost perceived by Car Passenger

Cost item	Proportion	Notes
Fuel costs	87%	Previously 50%
Parking charges	100%	No change
Congestion charge	100%	No change
Any additional tolls coded on links	50%	None coded in base year

4.10 No changes from NTMv2 have been made to the characteristics of walking or cycling for NTMv2R. These modes have no monetary cost, only an assumed speed and hence travel time. The assumed walking speeds in the model are:

- 2.8 miles per hour for trips to / from zones 1 to 11 (larger urban areas)
- 3.5 miles per hour for trips to / from zones 12 to 17 (smaller urban and rural areas)

4.11 The assumed cycling speeds in the model are:

- 8 miles per hour for trips to / from zones 1 to 11 (larger urban areas)
- 9 miles per hour for trips to / from zones 12 to 17 (smaller urban and rural areas)

4.12 Trips between zones with different assumed speeds use an average of the two times (i.e. an average of the inverse speed) (3.11 mph for walking and 8.47 mph for cycling). Walking is only defined as a permitted mode of travel in distance bands 1 to 6, i.e. for trips up to 15 miles in length, while for cycling it is distance bands 1 to 7, i.e. for trips up to 25 miles in length.

4.13 The vehicle operating costs for car drivers are derived directly from the TAG databook (version 1.8.2, July 2017). All costs are calculated in 2015 prices. Perceived costs are used for both the fuel and non-fuel elements of operating costs. As shown in Equation 4.1, the functional form of fuel consumption estimation has been updated.

$$Fuel\ Consumption\ (litres\ per\ km) = \frac{a}{V} + b + cV + dV^2$$

Where:
V is the speed of travel in kilometres per hour; and
a, b, c and d are parameters to the consumption function as shown in Table 4-4.

4.14 The cost of fuel (pence per litre) is then applied to the fuel consumption (litres per km), to give a cost in pence per km. This includes the recent up-lift in the curves to capture the impacts of ‘real world emissions’ testing.

4.15 The non-fuel costs are estimated via Equation 4.2 as following:

$$Non\ fuel\ costs\ (pence\ per\ km) = a^1 + \frac{b^1}{V}$$

Where:
V is the speed of travel in kilometres per hour; and
a^1, b^1 are referenced from TAG databook as shown in Table 4-4.

4.16 The parameters were set directly in the TAG databook to provide the parameters to the above functions in 2015 values and 2015 prices.

Table 4-4: TAG Parameter Values for Vehicle Operating Cost (average car)

Fuel cost pence / km	**Source table**	**a**	**b**	**c**	**d**
Non-working time	A1.3.13	90.2973	6.0010	-0.0383	0.000402
Working time	A1.3.12	75.2477	5.0012	-0.0319	0.000335
Non fuel (perceived)	**Source table**	**a[1]**	**b[1]**		
Non-working time	A1.3.9 and A1.3.14	Not perceived			
Working time	A1.3.9 and A1.3.14	5.3515	146.6614		

4.17 These parameters are used within the model to calculate the car vehicle operating costs based on the speed of travel input from FORGE for each combination of origin, destination and distance band. Because the car passengers are not paying the vehicle operating costs directly, the monetary costs are defined as zero and instead the values must be translated into a generalised cost (disutility) via the “guilt factors”.

4.18 Due to the functionality available in the software, this translation requires a simplification of the derivation of the vehicle operating costs in order to implement the perceived costs using a rule which automatically updates the values when forecasting. The simplification adopted when the demand model was originally implemented was to estimate an average perceived vehicle operating cost (including fuel and non-fuel costs as applicable) per mile from the average speeds of travel being used. This has been retained. The simplification will match well when the speeds are between 47 and 62 mph for working time trips and for speeds between 35 and 55 mph for non-working time trips. For the zone pair and distance band combinations where speeds are higher or lower the simplification underestimates the vehicle operating costs, particularly for short trips to / from the most urban areas.

4.19 Parking cost information is derived in the same way as implemented for NTMv2. Both average parking charges (by mode and trip attraction area type) and the proportion of trips paying for parking are derived from the 2012-2014 NTS. The combination of the two sets of information is applied to calculate the average parking charge for each car journey. However, NTS does not allow parking cost information for Central London to be distinguished from Inner London. Since Central London has individual patterns of parking supply with significantly higher parking costs for commuters, more realistic values have been assumed for Central London commuters.

4.20 In practice a small fraction of car journeys pay for parking, so the outcome average charges are low in all areas as shown in Table 4-4, and will not have much impact on the base year predictions. Incorporating the charges and proportions paying does however provide functionality for scenario testing focused on parking or demand management in urban areas.

Table 4-5: Average parking costs paid (2015 pence)

Area Type	Trip purpose							
	HBW	**HBEB**	**HBEdu**	**HBPB**	**HBRec**	**HBHol**	**NHBEB**	**NHBOth**
1 Central London	500	82.7	2	31.1	24.4	55.8	83.7	28
2 Inner London	22.6	82.7	2	31.1	24.4	55.8	83.7	28
3 Outer London	10.1	81.5	2.8	16.6	18.3	113.8	29.1	12.6
4 N&E Central Conurban	19.3	86	5	25.6	15.5	187.6	39.5	15.6
5 West Central Conurban	19.3	86	5	25.6	15.5	187.6	39.5	15.6
6 N&E Conurban surround	8	31.2	2	9.8	4.3	85.4	11.6	7.9
7 West Conurban surround	8	31.2	2	9.8	4.3	85.4	11.6	7.9
8 South Urban Big	7	27.2	5.7	22.1	8.9	31.9	12.4	10.7
9 N&E Urban Big	7	27.2	5.7	22.1	8.9	31.9	12.4	10.7
10 West Urban Big	5.4	20.8	2.8	20.9	10.5	36.1	17.2	15.1
12 South Urban Large	5.4	17.5	2.5	22.3	9.3	24.5	7.5	14.4
13 N&E Urban Large	6	7.6	2	14.9	3.4	15	10	9.4
14 West Urban Large	13	36.2	2.4	25.8	10.2	22.4	26.5	12.8
16 Urban Medium	4.9	8.7	2.1	15.5	4.9	20.5	8.7	8.7
17 Urban Small & Rural	2.1	4.2	0.4	5.2	3.5	30.9	4.2	6.4

4.21 The London congestion charge is coded by trip purpose and destination zone based on an assumed (derived) proportion of the trips ending in each model zone that will have passed through the charged area during the charged time periods. The approach is virtually unchanged from that previously implemented by the DfT’s NTM team for forecasting using NTMv2 (there was no congestion charge in the original NTMv2 1998 base year model).

4.22 The basic congestion charge was sourced from Transport for London’s website (https://tfl.gov.uk/modes/driving/congestion-charge). The implementation assumes most users will make use of the “auto pay” option giving a basic charge of £10.50 per day in 2015 during the charging period (0700--1800 hours). This is the charge assumed for the peak and interpeak periods with a zero charge assumed for the off-peak and weekend time periods.

4.23 The percentage of car trips for each purpose which occur in the four time periods were taken from the NTS data for 2012 to 2014 with the resulting profiles shown in Table 4-6. This is used to calculate the time period weighted charge for each trip purpose.

Table 4-6: Time period profiles by purpose for car (NTS 2012-2014)

Purpose	Peak (charged)	Inter Peak (charged)	Off Peak (free)	Weekend (free)
HBW	62.5%	10.9%	15.2%	11.4%
HBEB	55.1%	25.4%	7.1%	12.4%
HBEd	77.9%	20.6%	0.4%	1.1%
HBPB	23.9%	39.3%	3.8%	33.1%
HBRec	25.8%	21.7%	13.8%	38.6%
HBHol	18.7%	31.8%	5.8%	43.7%
NHBEB	31.3%	57.7%	4.7%	6.3%
NHBO	30.0%	37.7%	5.7%	26.7%

4.24 In NTMv2, the average car occupancy was applied to convert the charge per vehicle to the charge per car user. However, since within the demand model the car driver is assumed to incur the full (coded) road user charge, with passengers perceiving a proportion of the cost (via the guilt factor), the charge per vehicle is coded directly as the charge in the model files.

4.25 The charge per trip is then calculated by halving the congestion charge for the home based trips. The resulting charges (outward only for HB trips) for those who pay are as shown in Table 4-7.

Table 4-7: London Congestion charge by purpose for those paying

	HBW	HBEB	HBEd	HBPB	HBRec	HBHol	NHBEB	NHBO
Congestion charge	£3.86	£4.23	£5.17	£3.32	£2.50	£2.65	£9.35	£7.10

4.26 The final set of input information is the proportion of trips ending in each NTMv2R zone which are assumed to pay the London Congestion Charge. The derivation of these proportions has not been revised and the proportions have been taken directly from NTMv2. The assumed percentage of travellers to each destination paying the charge is shown in Table 4-8.

Table 4-8: Proportion of trips crossing cordon / paying London charge (as in NTMv2)

Destination zone in London:	Central	Inner	Outer	Rest
Proportion of PEAK trips paying cordon charge	75%	8%	2.5%	0%
Proportion of INTER PEAK trips paying cordon charge	75%	8%	2.5%	0%
Proportion of off peak and weekend trips paying cordon charge	0%	0%	0%	0%

Car journey speeds by distance band and home area type are derived using the Traffic database linked to the demand model in the Base Year. By assuming the same speeds also applied for the attraction zones, an average car speed for each production zone, attraction zone and distance band is then derived. The assumed car speeds range from 15 mph for the shortest journeys in London to 54 mph for longer journeys in other parts of the country as shown in Table 4-9:8.

Table 4-9: Car speeds (miles per hour) by distance band by origin area

	Origin Zone														
Dist Band	1	2	3	4	5	6	7	8	9	10	12	13	14	16	17
1	15.3	14.9	19.0	18.7	17.6	25.0	24.5	26.6	26.1	28.7	28.6	27.1	30.8	26.5	32.2
2	15.4	15.1	19.1	23.1	18.7	24.6	25.3	26.6	28.2	28.0	28.6	29.8	29.4	26.6	31.0
3	15.4	15.3	20.5	22.8	21.0	25.9	25.4	29.3	30.2	28.0	28.4	28.7	29.6	27.3	30.3
4	15.4	16.4	20.5	22.1	22.5	25.8	25.9	28.6	30.2	28.8	31.4	28.3	27.7	27.1	30.1
5	16.6	18.3	21.9	25.3	26.5	29.3	30.4	32.8	33.8	33.9	34.0	33.7	33.2	29.9	33.3
6	17.4	18.3	21.7	26.2	26.8	28.9	30.6	33.1	34.5	33.9	35.5	34.4	32.2	30.8	33.1
7	19.7	19.1	21.9	26.8	28.9	30.8	32.7	36.1	35.6	36.9	37.3	35.1	32.3	31.9	34.1
8	24.8	23.6	26.3	36.6	39.1	37.5	41.4	43.4	44.3	45.5	44.4	44.9	39.1	39.4	41.2
9	27.8	29.0	32.6	37.3	40.5	38.3	42.1	43.5	44.1	42.9	43.2	42.8	41.5	40.4	42.3
10	35.2	35.2	38.7	40.8	42.8	40.7	43.1	43.1	43.1	43.2	41.9	44.5	43.7	42.3	43.4
11	45.5	45.0	48.3	49.7	49.8	49.4	50.3	49.9	51.6	51.2	50.4	51.4	51.2	50.5	51.2
12	47.8	47.4	49.5	50.9	51.0	50.7	51.4	52.0	52.4	52.1	53.1	51.9	51.8	51.2	52.0
13	50.8	50.5	51.7	52.1	53.0	52.1	53.4	53.1	53.6	53.3	53.0	53.8	53.4	52.4	53.0

4.27 Parking search times vary by destination zone to reflect the assumed ease of locating a parking space in the zone. For NTMv2 these were based on professional judgement, but on reviewing them prior to commencing model calibration, it was found that car generalised costs for short distances were significantly lower (better) than for other modes. To more accurately reflect the time accessing / egressing car including time taken to park, the parking search times were increased by two minutes in all areas. The resulting parking search times assumed are listed in Table 4-9.

Table 4-10: Assumed parking search times by destination zone type

Destination Area	Search time (minutes)
Zone 1 - Central London	15
Zone 2 - Inner London	5
Zone 3 - Outer London	4
Zone 4 & 5 - Inner Conurbations	6
Zone 6 to 17 - All other area types	4

4.28 For bus trips, local bus fares are adopted for trips within London, Metropolitan areas or less than 25 miles, while coach prices are applied for longer journeys (greater than 25 miles) outside London and conurbations. In each case, a cost function containing a minimum fixed cost and a cost per mile is applied to determine the modelled cost for travellers.

4.29 The per-mile costs of local bus services are derived from the Transport Statistics Great Britain 2014-2015 for London, Metropolitan Areas and Other Areas respectively. The allocation of appropriate fare is determined by the "dominant" trip end area type – which is generally the trip destination or attraction zone. The costs per mile of coaches are estimated from a range of National Express full adult ticket prices linking to a sample of 20 locations spread across the country. Fixed minimum costs (50p for local buses, and 500p for coaches) are applied by assumption. The tariffs are as shown in Table 4-11.

Table 4-11: Bus and coach fares in 2015 base year

'Dominant' Area Type / Distance Band			**Cost function parameters**	
Area	Distance	Type	Fixed cost	Cost per mile
London (Zones 1 to 3)	Under 25 miles (Band 1 to 7)	Local bus	50p	30.83p
Metropolitan area (Zones 4 and 5)			50p	34.92p
Other area types (Zones 6 to 17)			50p	31.74p
All area types	Above 25 miles (band 8 to 13)	Coach	500p	14.18p

4.30 The fares concessions implemented within the demand model were reviewed. The assumptions had been modified for scenario testing in 2010 by the Department, and these have not been revised for NTMv2R.

4.31 For bus travel concessions are available for children and pensioners. In the model, these concessions are applied to the HB Education and HB personal business / shopping and social trip purposes for the children and 75+ age group which are explicitly identified. For other trip purposes (commuting, business, holidays and non home-based trips) children and pensioners are not explicitly identified and no concession is applied. Because of the change in age bands in the person type definition the concessions available for pensioners are now only applied to the age 75+ group of the population rather than 65+ as in the old model. Thus the impact of concessions will be under estimated by the model, and the impact of fares changes will affect a higher proportion of trips in the model than in reality.

4.32 Separate concessions are specified for trips wholly within London (to reflect concessions offered by TfL via the Oyster card) and other trips. The bus fare concessions applied in the NTMv2R demand model are listed in Table 4-12.

Table 4-12: Bus fares concessions

Traveller type	**Location of trip**	**Trip Purpose**	**Distance bands**	**Concession**
Children	Within London	HBEd, HBPB/Shop & HBRec/VF	1 to 7 (bus)	Free
Children	Outside London	HBEd, HBPB/Shop & HBRec/VF	1 to 7 (bus)	50% fare
Children	Everywhere	HBEd, HBPB/Shop & HBRec/VF	8+ (coach)	50% fare
Pensioner (age 75+)	Everywhere	HBEd, HBPB/Shop & HBRec/VF	1 to 7 (bus)	Free
Pensioner (age 75+)	Everywhere	HBEd, HBPB/Shop & HBRec/VF	8+ (coach)	82% fare

4.33 The assumed access and egress times between the origin / destination zone and the bus services in NTMv2R have not been updated, and are shown in Table 4-13.

Table 4-13: Assumed bus access and egress times

Zones	Access Time	Egress Time
1 to 16 – Urban areas	4 minutes	4 minutes
17 - Rural areas	6 minutes	6 minutes

4.34 Bus wait times are implemented for combinations of trip production zone and trip length within urban areas. The assumed wait times for the NTMv2 model have been retained unaltered for NTMv2R, and are summarised in Table 4-14.

Table 4-14: Assumed bus wait times

Zones	Up to 15 miles (Bands 1 to 6)	15 to 100 miles (Bands 7 to 10)	100+ miles (Bands 11 to 13)
1 to 5 (London and Conurbations)	6 minutes	10 minutes	15 minutes
6 to 17 (Urban and rural areas)	7 minutes	10 minutes	15 minutes

4.35 Average bus speeds by production zone (origin) by distance band are derived using the travel time and distance variables from NTS data for 2012-14, as shown in Table 4-15. Travel time is used in preference to total time since this relates more closely to the time spent moving on a bus rather than waiting time. To avoid issues with sample sizes, zones with similar patterns and the longer distance bands are aggregated into groups in the calculation.

Table 4-15: Estimated average bus speed (miles per hour)

		Origin Area (zone groups and zones)														
No.	**Band (miles)**	**A**		**B**	**C**				**D**			**E**			**F**	**G**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**14**	**16**	**17**
1	<1	2.4	2.4	2.6	2.3	2.3	2.3	2.3	3.2	3.2	3.2	2.2	2.2	2.2	2.9	2.9
2	1-2	4.1	4.1	4.6	5.0	5.0	5.0	5.0	4.7	4.7	4.7	4.7	4.7	4.7	5.0	5.3
3	2-3	5.2	5.2	5.8	6.4	6.4	6.4	6.4	6.1	6.1	6.1	6.3	6.3	6.3	7.2	7.8
4	3-5	6.3	6.3	6.8	7.9	7.9	7.9	7.9	7.2	7.2	7.2	7.6	7.6	7.6	8.7	9.5
5	5-10	7.7	7.7	8.5	9.7	9.7	9.7	9.7	9.2	9.2	9.2	10.0	10.0	10.0	11.4	13.1
6	10-15	9.9	9.9	10.2	11.4	11.4	11.4	11.4	12.8	12.8	12.8	14.8	14.8	14.8	12.9	15.4
7	15-25	14.8	14.8	12.8	15.3	15.3	15.3	15.3	15.6	15.6	15.6	16.1	16.1	16.1	16.5	18.7
8	25-35	28.7	28.7	28.7	20.2	20.2	20.2	20.2	19.1	19.1	19.1	23.2	23.2	23.2	22.2	21.2
9	35-50	31.8	31.8	31.8	26.8	26.8	26.8	26.8	26.1	26.1	26.1	20.7	20.7	20.7	20.7	23.8
10	50-100	27.8	27.8	29.8	27.0	27.0	27.0	27.0	25.2	25.2	25.2	25.7	25.7	25.7	25.3	28.0
11	100-200	32.8	32.8	36.5	34.7	34.7	34.7	34.7	34.8	34.8	34.8	30.3	30.3	30.3	31.5	34.5
12	200-300	32.8	32.8	36.5	34.7	34.7	34.7	34.7	34.8	34.8	34.8	30.3	30.3	30.3	31.5	34.5
13	>300	32.8	32.8	36.5	34.7	34.7	34.7	34.7	34.8	34.8	34.8	30.3	30.3	30.3	31.5	34.5

4.36 Rail fares have been derived from MOIRA revenues based on ticket sales (including season tickets) for station pair combinations for full, reduced and season tickets. This has been aggregated to the NTMv2R zone pair and distance band (ODL) combinations to give average revenue per trip for the combinations where data is available, and this is used as fare paid per trip. For ODL combinations where no information can be extracted from MOIRA, the revenues have been estimated from more aggregate MOIRA information by origin or destination and distance band or failing that purely by distance band.

4.37 The relationship between the rail ticket types and the fares assumed by trip purpose within the demand model are unchanged from NTMv2, and are shown in Table 4-16.

Table 4-16: Relationship between rail ticket types and fares by trip purpose

Trip purpose	Ticket type
HB Work	Season tickets
HB Employer's business	Full tickets
HB Education	Season tickets
HB Personal business / shopping	Reduced tickets (saver fares)
HB Recreation / visiting friend	Reduced tickets (saver fares)
HB Holidays & day trips	Reduced tickets (saver fares)
NHB Employers' business	Full tickets
NHB Other	Reduced tickets (saver fares)

4.38 Rail fare concessions are coded in the model for Children and Pensioners (now defined as adults aged 75+). In NTMv2R the concessions for London residents are obtained from Transport for London's website, and for rail travel elsewhere in the country based on the National Rail website. The assumptions implemented for the 2015 base year are shown in Table 4-17.

4.39 The differences implemented in the peak and inter peak fares take into account the discounts available to everyone for off peak travel and include a mix of fares based on the use of advanced purchase tickets.

Table 4-17: Rail fare concessions

Traveller type	Location	Rail provider discount	Model assumption
Children	Within London	< 11s travel free (TfL) 11-16 typically pay 50% (with Zip Oyster)	Pay 40% (to take account of some children being free)
	Elsewhere	5 to 15 – 50% discount <5s free (with an adult)	Pay 50%
75+	Within London	60+ Oyster / Freedom card – free travel for residents	Free (pay 0%)
	Elsewhere	Senior rail card – third off	Pay 67% of fare

4.40 As well as revenue, the MOIRA dataset also provides the average travel time between each station pair. As with revenue, this has been aggregated to the NTMv2R zone pair and distance band (ODL) combinations. These average journey times include time taken for making any transfers between trains/stations in the course of the trip but exclude the wait and access/egress times at the start/end of the journey. These access and wait times are added as separate model inputs as set out below. Again as with revenue, where no information can be extracted from

MOIRA, the times have been estimated from more aggregate MOIRA information. The same average journey time is input for both the peak and inter-peak rail characteristics.

4.41 Rail wait times are dependent on the frequencies of the rail services available. MOIRA represents such frequencies as service intervals with associated frequency penalties. The frequency penalties are used to derive the rail wait times for NTMv2R. Differences in frequency penalty between full-price and reduced journeys which correspond to the varying service intervals are used to estimate that part of the MOIRA generalised journey time which is due to the frequency penalty. The results for the set of station pairs were summarised into the NTMv2R zone pair and distance band combinations to give the average frequency penalty (not weighted, simple average based on services available) for full and reduced ticket types.

4.42 Wait times are typically assumed to be half the frequency (service interval) for frequent services, with a maximum wait time for less frequent services where passengers schedule their arrival times. The MOIRA frequency penalties effectively include a weight on the wait time to give the generalised journey times. This weight is applied explicitly in the NTMv2R (value of 2 as shown in Table 4-2:2). The wait times for input to NTM are therefore taken as half of the average frequency penalty up to a maximum wait time of 30 minutes.

4.43 NTMv2R requires rail wait information to be coded for peak and inter-peak travel. The full price tickets were assumed to provide information relevant to “peak” travel, while the characteristics associated with reduced ticket types were assumed to relate to “inter-peak” travel. Where no information could be obtained from the MOIRA processing, wait times were infilled using information from the previous. The entire set of rail wait times used in the model is as shown in Table 4-18 for peak travel and Table 4-19 for inter-peak travel with infilled values from NTMv2 shown in red text.

Table 4-18: NTMv2R peak rail wait times by origin area by distance band (minutes)

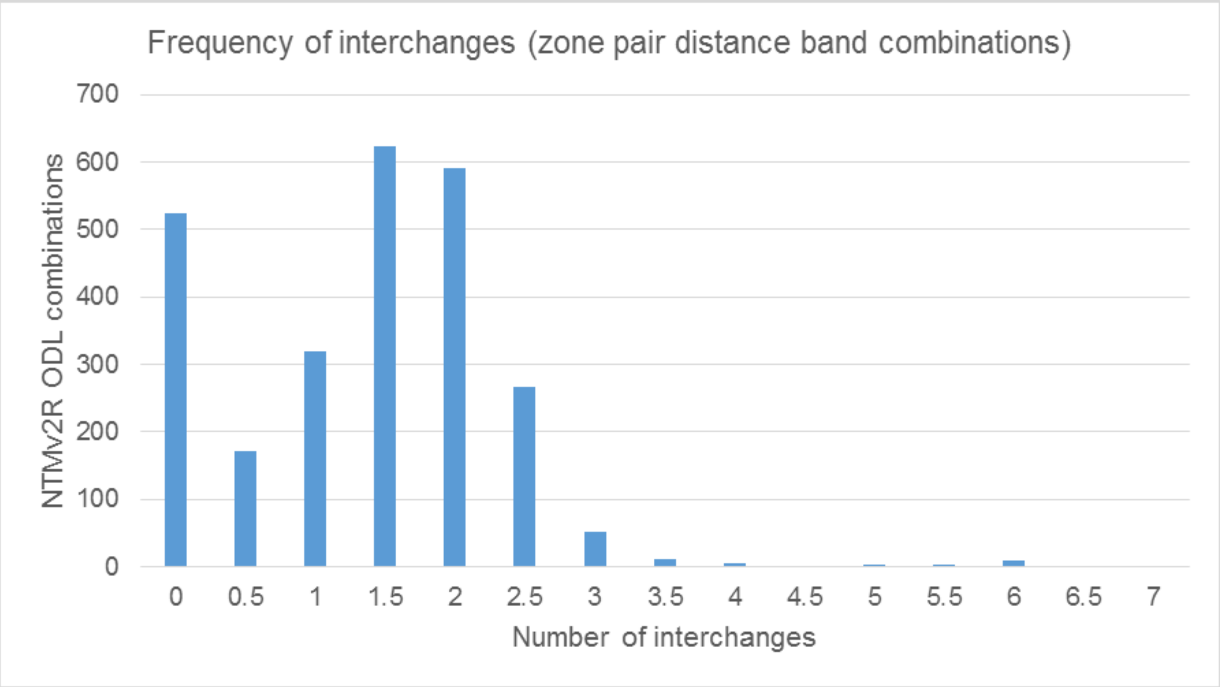
	Distance Band												
Origin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	**1.99**	**0.97**	3.33	3.75	4.12	5.85	6.16	6.95	9.07	13.86	15.94	23.62	27.03
2	5.24	4.70	5.30	4.61	5.93	7.78	8.30	10.15	9.99	13.14	15.92	20.25	26.44
3	6.48	7.01	7.01	8.06	7.48	7.72	9.10	9.85	10.26	12.65	15.88	20.24	25.05
4	**2.00**	9.50	9.50	10.17	15.56	12.23	16.76	13.93	16.53	17.60	18.16	18.52	23.67
5	9.19	8.84	8.70	9.85	11.19	11.25	12.38	13.99	14.72	15.90	15.39	20.97	29.70
6	**12.91**	19.50	9.00	13.00	13.05	13.55	14.52	15.11	16.29	17.74	17.96	19.91	26.27
7	7.67	10.33	11.63	10.88	10.86	12.24	13.26	14.79	15.67	16.93	17.07	19.53	30.00
8	**15.38**	29.50	15.50	15.17	20.26	15.57	18.03	18.55	16.90	17.30	18.21	23.62	22.73
9	**4.38**	**4.38**	17.50	19.50	17.33	19.50	15.07	15.42	16.87	18.22	19.35	19.25	28.07
10	5.00	7.67	**10.32**	7.50	7.93	9.20	12.83	12.92	12.04	14.14	16.81	20.17	26.56
12	**21.08**	13.00	16.00	16.60	16.27	21.59	19.69	18.17	16.57	17.08	19.25	22.97	30.00
13	**15.00**	15.50	**15.00**	13.30	15.17	17.56	14.34	16.47	17.43	18.75	19.37	20.42	29.10
14	14.50	13.80	13.80	15.32	15.04	13.34	11.00	10.58	12.57	13.64	17.77	20.79	26.86
16	11.50	12.23	11.28	14.35	12.55	12.13	11.58	12.38	13.72	15.34	18.39	21.10	27.45
17	19.50	18.57	17.90	16.43	15.61	15.25	15.48	14.67	15.59	17.64	20.61	24.59	28.35

Table 4-19: NTMv2R inter-peak rail wait times by origin area by distance band (minutes)

	Distance Band												
Origin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	**1.12**	**1.62**	3.33	3.75	4.06	5.53	5.68	6.35	7.93	10.63	11.76	15.57	17.27
2	5.19	4.56	5.14	4.48	5.61	7.14	7.49	8.70	8.63	10.39	11.77	13.89	16.97
3	6.18	6.33	6.48	7.36	6.78	6.98	8.03	8.51	8.83	10.16	11.76	13.89	16.28
4	**2.00**	8.50	8.50	8.50	11.22	9.54	12.18	10.76	12.03	12.61	12.88	13.07	15.60
5	7.88	7.60	7.48	8.35	9.27	9.32	9.96	10.85	11.21	11.79	11.48	14.24	18.60
6	**13.01**	13.50	7.75	10.50	10.00	10.50	11.03	11.36	11.97	12.66	12.77	13.75	16.88
7	6.83	8.78	9.46	8.99	9.01	9.89	10.40	11.21	11.64	12.27	12.32	13.53	19.92
8	**14.57**	18.50	11.50	11.33	13.91	11.59	12.81	13.05	12.28	12.43	12.89	15.56	15.11
9	**4.77**	**4.77**	12.50	13.50	12.50	13.50	11.32	11.52	12.24	12.88	13.45	13.37	17.79
10	5.00	6.83	**7.45**	7.00	7.17	7.70	10.26	10.32	9.65	10.90	12.24	13.86	17.03
12	**21.08**	10.50	11.83	12.10	11.88	14.56	13.59	12.87	12.08	12.32	13.41	15.23	20.39
13	**15.00**	11.50	**15.00**	10.50	11.50	12.56	11.03	12.07	12.48	13.14	13.44	13.96	18.30
14	11.00	10.40	10.40	11.41	11.21	10.28	8.99	8.81	10.05	10.63	12.68	14.16	17.18
16	9.25	9.82	9.36	10.88	9.91	9.72	9.35	9.79	10.63	11.48	12.99	14.32	17.48
17	13.50	13.00	12.65	11.92	11.38	11.31	11.49	11.02	11.56	12.63	14.08	16.05	17.93

4.44 The number of interchanges was estimated from the differences in the MOIRA generalised journey times between Full-price and Season tickets (since PDFH makes different assumptions for how the interchange penalty varies with distance), and then summarised to give the average number of interchanges for the demand model zone pair and distance band combinations. On average there are 1.16 interchanges per modelled combination. A significant number (over 500) have no interchanges, while just over 600 have between 1 and 1.5 interchanges. The highest number of interchanges is 6.16. As with fare and time, where no information can be extracted from MOIRA, the number of interchanges was estimated from more aggregate average numbers.

Figure 8: Profile of number of interchanges assumed



4.45 TAG unit M3-2, public transport assignment modelling, suggests an interchange penalty of 5 to 10 minutes of in-vehicle time per interchange should be included. A 5 minute interchange penalty has been applied to the average number of interchanges for each zone pair and distance band combination.

4.46 In NTMv2 rail access and egress times were obtained from the earlier National Rail Passenger model operated by the Department: separate access times are coded for each origin zone and time period (peak/interpeak) and separate egress times for each destination zone and time period. Although other sources are available, on review these appeared reasonably intuitive in the way they varied by zone, and have therefore been retained – but rounded to a whole number of minutes, as shown in Table 4-20.

Table 4-20: Rail access and egress times by zone

Zone	Access by Origin zone		Egress by Destination zone	
	Peak	Interpeak	Peak	Interpeak
1	6	6	6	6
2	9	8	8	8
3	11	11	11	11
4	11	11	11	11
5	12	12	13	13
6	21	21	21	21
7	16	16	15	15
8	23	22	22	22
9	21	20	20	20
10	14	14	14	14
12	25	23	23	23
13	24	25	25	25
14	18	19	20	20
16	18	18	18	18
17	31	32	32	32

4.47 In NTMv2 rail crowding was included as additional perceived time for each zone pair and distance band combination for the peak and inter peak models, using information from the national rail passenger model which is no longer available. On review, these were not considered adequate for NTMv2R and, given the aggregate nature of the demand model both spatially and by time period, it was decided not to implement crowding in the updated 2015 base year model. The overcrowding functionality has however been retained so that alterative forecasts can be implemented to test assumed levels of overcrowding.

5. Model Calibration

5.1 We begin by summarising the choice model parameters that are adjusted in the calibration procedure. In both NTMv2 and NTMv2R the calibration was based on trial and error with the aim of achieving the best match to the observed NTS data, in contrast to more typical model estimations using simultaneous estimation of sensitivity parameters and alternative specific constants by maximising the likelihood of replicating the observed choices in the model (mainly at disaggregate levels). NTMv2R aims to match the data at the aggregate level tabulated by specified segmentations.

5.2 The main structural parameters to be calibrated are listed below:

- λ_D Distance band choice sensitivity
- λ_A Destination (attraction) area type choice sensitivity
- λ_M Main mode choice sensitivity (active {i.e. walk, cycle}, car, bus, rail)
- λ_m Sub-mode choice sensitivity (car driver/car passenger)

5.3 λ_m only applies to the car sub-mode choice component (in line with the original NTMv2 structure the sub-mode choice parameter for walk and cycle has been set to λ_M).

5.4 In line with the NTMv2 structure, mode-specific constants (MSCs) can be adjusted for each mode within each DB and by purpose and household structure: this means there are over 1,500 MSCs to be adjusted. Although a FORTRAN macro had been developed to automate the adjustments of the MSCs for the originalNTMv2 calibration, this was not found to be helpful, and a spreadsheet-based semi-automatic tool was therefore developed to adjust MSCs. In addition, MSCs were defined for the main car mode, in addition to the separate MSCs for car drivers and car passengers used in NTMv2. This was very helpful for adjusting overall mode shares between car passengers and drivers, while controlling for the scale of the choice.

5.5 Distance band (DB) constraints force the model to exactly replicate demand across a given DB profile by introducing extra implicit disutility terms. As in NTMv2, constraints have been imposed to match NTS profiles over all 13 DBs and for each of the 20 segments by purpose and household type (6 HB purposes *3 HH Types + 2 NHB Purposes) distinguished in the aggregated NTS data set. These distance disutility terms are retained in future year policy tests and forecasts, but no further constraints are imposed.

5.6 It was agreed with DfT that the size terms, which are weights that reflect the number of opportunities available at a given distance by destination area type, would not be updated (as it was felt that the relative attraction of area types was unlikely to be significantly different from those in NTMv2). However, since they are introduced into the choice disutility for destination areas as logarithmic terms weighted by $-1/\lambda_A$, which would be re-calibrated, it was necessary that the original size terms be weighted by the ratio of the old and new λ_A values.

5.7 As noted earlier, the NTMv2 model uses additional disutilities ('guilt factor') for the passenger mode to reflect a percentage of the fuel costs perceived by the driver. While in NTMv2 this was 50 per cent of the fuel cost, it has been calibrated to 87 per cent for NTMv2R, as is further discussed below.

5.8 Finally, additional costs and times can be added into the final disutility to influence mode share by origin or by destination. This was used in NTMv2 to reflect car parking costs using destination end terminal costs for car drivers and terminal disutilities for car passengers. In the recalibration, the rail disutilities have also been adjusted to ensure the correct share of rail trips to London.

5.9 As noted, the calibration process was done by an iterative trial and error, with the general aims of achieving a good fit to the base NTS data as well as an acceptable elasticity response in line with recommended TAG realism tests. Note that the NTS sample is different between the mode choice model and the distance/attraction zone choice model.

5.10 The parameters that could be adjusted to obtain an acceptable match (defined as within 5 per cent for those segments in the NTS with a sample size of at least 1,000) to those modal splits observed in the NTS data were:

1. λ_M Main mode choice (active {i.e. walk, cycle}, car, bus, rail) sensitivity parameter, which influences the mode choice sensitivity:
2. MSCs. These constants affect mode splits over all zones by segment (i.e. purposes, car availability and DB).

5.11 As noted earlier, the NTMv2R model assumes walk trips occur within the first six distance bands and cycle trips within the first seven distance bands.

5.12 In addition, as noted above, terminal disutilities for rail were used to modify the disutility for rail trips to London (are type zones 1, 2, and 3) to increase the rail share to these zones. The sub-mode split sensitivity parameters λ_m were also calibrated.

5.13 The next step was to calibrate the trip length sensitivity parameters by adjusting λ_D and λ_A to get the closest possible match to the NTS DB patterns using a trial and error approach before adding DB constraints. The initial destination choice values had been set to two times the DB sensitivity parameter (λ_D), as per the approach followed in the original NTMv2 development work, but later these were allowed to vary across DBs to get lower values (i.e. lower sensitivity) for higher trip lengths, thus accounting for cost damping. The DB constraints were introduced to ensure that the model matched the distance profiles observed in the NTS data.

5.14 A number of practical difficulties were encountered in the calibration process. The biggest issue was matching car driver and passenger splits to the observed data while maintaining reasonable realism tests responses to changes in fuel costs and journey times.

5.15 TAG Unit M2 (DfT, 2014) suggests some functional forms for cost damping that allow reduction in cost sensitivity by distance. However, in the DB choice in NTMv2R the representation of distance is not continuous; to deal with this, the main mode sensitivity parameters (λ_M) were allowed to vary by 13 DBs.

5.16 As noted, the guilt factor value of 0.5 was changed to 0.87, by agreement with DfT, since this was found to give the best fuel cost responses and to keep the switching from drivers to passengers at a reasonable level. Note that the passenger costs are incorporated in the utility only for car passenger choice (for appraisal purposes the car passenger cost is considered to be zero). This approach was agreed on the basis that car passengers in NTMv2R are not explicitly considered in appraisals.

5.17 Table 5-1 and Table 5-2 report the calibrated model parameters for NTMv2R as delivered to DfT – these relate to the best fitting run of the model achieved during calibration

Table 5-1: λ_D and λ_A varying by distance bands and purposes[5]

	λ_D	λ_A (destination choice parameters)												
		DB1	DB2	DB3	DB4	DB5	DB6	DB7	DB8	DB9	DB10	DB11	DB12	DB13
HBW	0.0012	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.011	0.010	0.015	0.008	0.008
HBEB	0.00045	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.003	0.003
HBEd	0.0021	0.015	0.015	0.013	0.013	0.013	0.013	0.013	0.011	0.009	0.009	0.009	0.009	0.009
HBPB	0.00087	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.008	0.008
HBRec	0.00028	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.012	0.012
HBHol	0.00012	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
NHBEB	0.0007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.003	0.003
NHBO	0.00037	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.006	0.006

Table 5-2: λ_M varying by distance bands and purposes[6]

	DB1	**DB2**	**DB3**	**DB4**	**DB5**	**DB6**	**DB7**	**DB8**	**DB9**	**DB10**	**DB11**	**DB12**	**DB13**
HBW	0.11	0.108	0.105	0.1	0.098	0.093	0.09	0.087	0.08	0.075	0.074	0.073	0.073
HBEB	0.07	0.07	0.067	0.065	0.06	0.057	0.055	0.045	0.043	0.04	0.037	0.03	0.03
HBEd	0.12	0.085	0.07	0.05	0.032	0.028	0.019	0.015	0.015	0.012	0.01	0.009	0.009
HBPB	0.12	0.11	0.1	0.095	0.093	0.09	0.087	0.085	0.083	0.08	0.077	0.07	0.07
HBRec	0.1	0.09	0.085	0.083	0.08	0.078	0.073	0.07	0.068	0.063	0.06	0.055	0.055
HBHol	0.07	0.068	0.065	0.06	0.058	0.053	0.05	0.046	0.042	0.04	0.035	0.03	0.03
NHBEB	0.105	0.105	0.101	0.095	0.093	0.09	0.085	0.08	0.077	0.075	0.07	0.065	0.065
NHBO	0.09	0.085	0.083	0.08	0.077	0.073	0.07	0.067	0.063	0.06	0.055	0.05	0.05

[5] λ_D is distance band choice parameter and varies by purposes while λ_A does vary by distance bands.
[6] Similar to NTMv2, λ_m for car drivers and passengers are a multiplier of λ_M (i.e. main mode sensitivity parameter). This multiplier is derived to be 4.44 (based on calibration). In line with what is assumed for NTMv2, λ_m for walk and cycle are set to be equal to λ_M. This means walk and cycle are modelled in the same hierarchy as the rest of main modes (i.e. main car mode, bus and rail) in the choice tree.

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5.18 Table 5-3 to Table 5-7 compare the modal split from the calibrated model with that from NTS data. As noted, according to the acceptance criteria estimates should be within 5 per cent for those segments with more than 1,000 records. Those distance bands which are not modelled for walk and cycle are greyed out. A positive value indicates that the model predicts more trips than are observed.

5.19 Table 5-3 shows the percentage difference in predictions by (high-level) mode, between the model projections and NTS, overall and by distance band. All percentage differences, except for rail trips over 200 miles, are well below 5 per cent (in most cases below 1 per cent). Table 5-4 shows the values for the detailed modes (car driver and passenger, bicycle and walking).

5.20 We also see a good match by household type and purpose, as shown in Table 5-5 and Table 5-6.

5.21 Finally, Table 5-7 compares the total rail trips to London for commuting. The comparison is made against NTS data and 2011 Census Journey to Work (JTW) data. The model results are closer to Census JTW, which is considered a more trustworthy source as the sample size in NTS for rail travel is small.

Table 5-3: Main mode split by distance band – percentage difference with NTS (2006–2014)

	<1	1-2	2-3	3-5	5-10	10-15	15-25	25-35	35-50	50-100	100-200	>200	Total
Active	0.2%	0.1%	0.1%	-0.1%	0.2%	0.6%	2.8%						**0.1%**
Car	-0.7%	0.0%	0.0%	0.1%	0.1%	-0.1%	0.1%	0.5%	0.4%	0.2%	0.8%	3.0%	**0.0%**
Bus	0.0%	-0.2%	0.0%	0.1%	0.2%	0.4%	0.5%	0.6%	1.9%	2.5%	-1.1%	3.5%	**0.1%**
Rail	0.1%	0.0%	-0.6%	-2.5%	-1.4%	1.0%	-1.7%	-2.0%	-1.5%	-0.8%	-3.6%	-7.9%	**-1.2%**
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Table 5-4: Sub-mode split by distance band – percentage difference with NTS (2006–2014)

	<1	1-2	2-3	3-5	5-10	10-15	15-25	25-35	35-50	50-100	100-200	>200	Total
Walk	0.2%	0.1%	0.2%	0.1%	0.2%	0.2%							**0.2%**
Cycle	0.2%	0.1%	0.0%	-0.2%	0.2%	0.6%	3.2%						**-0.4%**
Driver	-0.8%	-0.2%	-0.2%	0.0%	0.1%	0.0%	0.3%	0.7%	0.7%	0.8%	1.8%	4.3%	**0.0%**
Passenger	-0.5%	0.1%	0.3%	0.3%	-0.1%	-0.4%	-0.3%	0.2%	-0.3%	-0.8%	-0.4%	1.9%	**0.0%**
Bus	0.0%	-0.2%	0.0%	0.1%	0.2%	0.4%	0.5%	0.6%	1.9%	2.5%	-1.1%	3.5%	**0.1%**
Rail	0.1%	0.0%	-0.6%	-2.5%	-1.4%	1.0%	-1.7%	-2.0%	-1.5%	-0.8%	-3.6%	-7.9%	**-1.2%**
Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**

Table 5-5: Sub-mode split by household types – percentage difference with NTS (2006–2014)

	1 adult/0 car	**1 adult/1+ car**	**2+ adults/0 car**	**2+ adults/ 1 car**	**2+ adults/2+ cars**	**Car not applicable**	**TOTAL**
Walk	-0.3%	1.0%	-0.2%	0.2%	0.6%	0.1%	**0.2%**
Cycle	-0.4%	0.5%	-0.3%	-0.3%	0.2%	-0.9%	**-0.4%**
Driver	0.8%	-0.3%	0.5%	0.2%	0.0%	-0.1%	**0.0%**
Passenger	-0.1%	0.3%	-0.5%	0.0%	0.0%	0.0%	**0.0%**
Bus	-0.2%	2.5%	-0.2%	-0.2%	1.1%	0.2%	**0.1%**
Rail	3.4%	-4.6%	1.8%	-3.1%	-5.5%	0.5%	**-1.2%**
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Table 5-6: Sub-mode split by purposes – percentage difference with NTS (2006–2014)

	HB WORK	**HB EDUC**	**HB EB**	**HB PB**	**HB Rec/VF**	**HB HOL**	**NHB EB**	**NHB OTHER**	**Total**
Walk	0.1%	0.6%	0.3%	0.1%	0.0%	0.0%	0.5%	0.1%	**0.2%**
Cycle	-0.7%	1.4%	0.3%	-0.1%	0.1%	-0.9%	0.4%	-1.2%	**-0.4%**
Driver	0.6%	-2.1%	-0.2%	0.0%	0.0%	0.0%	-0.2%	0.0%	**0.0%**
Passenger	0.7%	0.2%	-1.0%	0.1%	-0.4%	0.2%	-0.2%	0.0%	**0.0%**
Bus	-0.6%	1.3%	0.3%	-0.5%	0.8%	0.5%	0.4%	0.1%	**0.1%**
Rail	-4.6%	0.9%	1.9%	0.1%	3.2%	-0.9%	1.8%	0.6%	**-1.2%**
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Table 5-7: National percentage of commuting trips (from all areas) to London –area types that go by rail

	Model	**NTS 2012-2014**	**Census JTW_values (2011)**
Central London	72%	50%	72%
Inner London	38%	24%	50%
Outer London	15%	13%	14%

6. Assessment

6.1 In line with TAG Unit M2 (DfT, 2014) recommendations, three sets of realism tests are performed to quantify:

1. The car driver (i.e. traffic km) response (in vehicle kms) to a 10 per cent increase in fuel costs.
2. The combined public transport (i.e. rail and bus) response (in number of trips) to a 10 per cent increase in rail and bus fares.
3. The car driver (i.e. car trips) response to 10 per cent increase in car journey time (i.e. reduction in speed).

6.2 The resulting elasticities within acceptable range provided by TAG are summarised in Table 6-1:6-1 below.

Table 6-1: Summary of recommended elasticity range

	High	**Low**
Average fuel cost (km)	-0.35	-0.25
PT main mode fare (trips)	-0.9	-0.2
Bus fare (trips)	-0.9	-0.7
Car journey time (trips)	No stronger than -2.0	

Source: Table 6.2 TAG Unit M2

6.3 The elasticities were calculated as log(change in demand)/log(change in cost). For the fuel cost elasticity test, fuel cost is increased by 10 per cent while all other parameters are kept the same as the base run. For public transport main mode and bus fare tests, both rail and bus fares are increased by 10 per cent. Finally, for the car journey time test, the car journey time is increased by 10 per cent. The change in demand that was then calculated for each test was an average over all traveller types.

6.4 Note that these are “first round” tests – they do not include possible supply effects via FORGE. The TAG Guidance states that “The elasticities should be calculated from a converged run of the demand/supply loop”.

6.5 We expected certain levels of variation in elasticity response by purposes and person types:

1. Fuel cost elasticities would be expected to be weaker than -0.3 (i.e. closer to zero) for HBEd, which are shorter (and therefore have a lower cost), and stronger than -0.3 for HBHol where the trip length is longer than average. Also, we expect the elasticity to be weaker for business trips, because of lower cost sensitivity for business travellers and stronger for recreation ones.
2. Shorter trips (those in lower DBs) are expected to be less sensitive to cost changes.

Fuel price elasticity tests

6.6 Fuel price realism tests involve measuring the changes in car driver (i.e. vehicles) trips and kilometres as a result of a 10 per cent increase in fuel costs. Our results, shown in Table 6-2, give an elasticity of -0.32 for car driver kilometres (i.e. traffic km). In line with our expectations, the increase in fuel prices leads to a reduction in average travel distance for drivers and passengers, while for other modes it has increased.

6.7 In general, the percentage differences across purposes shown in Table 6-3 are also in line with what we expect, with holiday trips being the most elastic and employers' business the least elastic purposes to increases in fuel costs. However, the Home-based work car kilometrage elasticity is lower than expected.

Table 6-2: Direct elasticity and cross elasticity for 10 per cent increase in fuel cost

	<1	**1-2**	**2-3**	**3-5**	**5-10**	**10-15**	**15-25**	**25-35**	**35-50**	**50-100**	**100-200**	**>200**	**Total trips**	**Traffic (kms)**	**Mean trip length**	**KM Elasticity**
Walk	0.2%	0.9%	1.7%	3.0%	6.2%	9.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.5%**	**0.9%**	**0.4%**	***0.09***
Cycle	0.2%	0.9%	1.4%	2.1%	3.7%	6.3%	9.7%	0.0%	0.0%	0.0%	0.0%	0.0%	**1.7%**	**3.3%**	**1.6%**	***0.35***
Driver	-0.5%	-0.5%	-0.4%	-0.5%	-0.7%	-1.1%	-1.5%	-1.8%	-2.6%	-4.5%	-9.2%	-17.1%	**-0.9%**	**-3.0%**	**-2.1%**	***-0.32***
Passenger	-0.4%	-0.4%	-0.2%	-0.2%	-0.3%	-0.2%	-0.2%	-0.7%	-0.9%	-2.3%	-4.0%	-9.3%	**-0.4%**	**-1.8%**	**-1.4%**	***-0.19***
Bus	0.1%	0.7%	1.4%	2.0%	3.4%	5.5%	8.3%	9.9%	16.4%	29.9%	59.2%	66.5%	**2.8%**	**12.0%**	**8.9%**	***1.19***
Rail	0.1%	0.4%	0.8%	1.0%	1.9%	2.9%	5.4%	8.2%	8.9%	16.4%	22.8%	22.0%	**4.9%**	**12.7%**	**7.5%**	***1.26***
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.2%**	**-0.4%**	**-0.4%**	**0.0%**	**-0.1%**	**-0.1%**	

Table 6-3: Percentage difference in the number of trips as a result of 10 per cent increase in fuel costs and total car kilometrage elasticities by purposes

	HB WORK	**HBEB**	**HB EDU**	**HB PB**	**HB RVF**	**HBHOLS**	**NHB EB**	**NHB OTHER**	**Total**
Walk	0.3%	0.1%	0.3%	0.6%	0.6%	0.8%	0.1%	0.5%	0.5%
Cycle	1.2%	0.4%	0.8%	1.8%	2.3%	2.7%	0.6%	2.6%	1.7%
Driver	-0.6%	-0.3%	-0.5%	-0.9%	-1.0%	-2.3%	-0.2%	-1.2%	-0.9%
Passenger	-0.5%	-0.2%	-0.7%	-0.5%	-0.4%	-1.2%	0.3%	0.1%	-0.4%
Bus	1.7%	0.5%	1.1%	3.0%	3.1%	13.1%	0.9%	4.8%	2.8%
Rail	2.2%	2.0%	1.5%	7.5%	8.2%	16.8%	1.8%	7.3%	4.9%
Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Car KM elasticity	**-0.14**	**-0.12**	**-0.11**	**-0.23**	**-0.38**	**-1.08**	**-0.09**	**-0.48**	**-0.32**

Public transport fares elasticity test

6.8 Table 6-4:6-4 shows the responses for 10 per cent increase in (both) bus and rail fares. Elasticity for buses is -0.98, while that for combined public transport modes is -0.85; the latter is within the TAG guidance range and the former is slightly higher than the maximum value. The bus fare elasticity is higher than the TAG guidance values because it includes long-distance bus trips, which form only a small fraction of bus demand in the local models TAG is typically used for. Table 6-4:6-4 also shows that the drop in trips is increasing by distance band, which is intuitively correct. This is because the longer distance trips have higher costs. The model responses demonstrate that even after factoring in the effect of cost damping travellers are modelled as being more sensitive to changes in cost when they travel further. However, some of the longest distance bands might seem to be extreme. That is partly due to the NTMv2 model structure, which does not allow the implementation of a continuous cost damping approach.

6.9 The percentage difference by purposes as a result of 10 per cent increase in public transport fare is shown in Table 6-5:6-5. Again, it can be observed that holiday trips have the most and the business trips have the least level of response to change in fares. The holiday trip responses are on the higher end but that is due to the fact that the model is more sensitive in the longer distances where these trips dominate.

Table 6-4: Direct elasticity and cross elasticity for 10 per cent increase in all public transport fares

	<1	1-2	2-3	3-5	5-10	10-15	15-25	25-35	35-50	50-100	100-200	>200	Total trips	Elasticity
Walk	0.1%	1.1%	3.3%	4.7%	5.5%	2.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.5%**	**0.06**
Cycle	0.1%	0.8%	2.5%	3.8%	5.0%	4.0%	6.5%	0.0%	0.0%	0.0%	0.0%	0.0%	**2.3%**	**0.24**
Driver	0.0%	0.3%	0.5%	0.7%	0.8%	0.8%	0.8%	1.1%	1.6%	2.4%	4.7%	8.7%	**0.7%**	**0.07**
Passenger	0.1%	0.4%	1.1%	1.7%	2.0%	2.0%	1.9%	2.7%	2.8%	4.9%	8.1%	13.6%	**1.6%**	**0.17**
Bus	-6.3%	-7.2%	-6.8%	-7.5%	-10.0%	-13.2%	-15.5%	-25.3%	-32.1%	-41.7%	-52.4%	-52.2%	**-8.9%**	**-0.98**
Rail	-7.9%	-7.6%	-6.0%	-2.1%	-2.4%	-2.9%	-5.0%	-7.6%	-8.3%	-15.3%	-23.7%	-22.1%	**-5.4%**	**-0.58**
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**-0.1%**	**-0.1%**	**-0.2%**	**0.0%**	
All PT modes	-6.4%	-7.2%	-6.7%	-6.7%	-7.3%	-7.1%	-8.0%	-10.9%	-11.0%	-18.7%	-28.7%	-26.7%	**-7.8%**	**-0.85**

Table 6-5: Percentage difference in the number of trips as a result of 10 per cent increase in public transport fare

	HB WORK	HBEB	HB EDU	HB PB	HB RVF	HBHOLS	NHB EB	NHB OTHER	Total trips
Walk	0.6%	0.3%	0.4%	0.8%	0.6%	0.3%	0.1%	0.3%	0.5%
Cycle	2.8%	1.2%	1.5%	2.9%	2.4%	1.5%	0.4%	2.2%	2.3%
Driver	0.8%	0.6%	0.6%	0.6%	0.4%	1.6%	0.3%	1.0%	0.7%
Passenger	2.1%	1.4%	1.0%	2.0%	1.5%	2.5%	0.4%	1.2%	1.6%
Bus	-8.0%	-2.8%	-4.5%	-9.3%	-8.8%	-23.2%	-3.7%	-15.0%	-8.9%
Rail	-2.3%	-4.7%	-1.5%	-7.2%	-8.2%	-19.3%	-3.9%	-8.2%	-5.4%
Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bus+Rail	-5.1%	-4.1%	-4.1%	-9.1%	-8.6%	-21.2%	-3.9%	-12.5%	-7.8%
PT trip elasticity	**-0.55**	**-0.44**	**-0.43**	**-1.00**	**-0.95**	**-2.50**	**-0.41**	**-1.41**	**-0.85**

Car journey time elasticity tests

6.10 Finally, the car journey time elasticity is shown in Table 6-6:6-6. While the presented elasticities for this test are all for trips, due to an increased response with trip length the traffic elasticity (0.44) is more than double the figure for trips and exceeds the fuel price elasticity.

6.11 Table 6-7 shows the percentage difference in number of trips by purposes. Again, this is in line with our expectation, with holiday trips being the most sensitive journey purpose.

Table 6-6: Direct elasticity and cross elasticity for 10 per cent increase in car journey time

	<1	**1-2**	**2-3**	**3-5**	**5-10**	**10-15**	**15-25**	**25-35**	**35-50**	**50-100**	**100-200**	**>200**	**Total trips**	**Traffic (km)**	**Mean trip length**	**Elasticity**
Walk	0.4%	2.1%	3.8%	6.6%	11.8%	22.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**1.0%**	**1.9%**	**0.9%**	**0.11**
Cycle	0.5%	2.3%	4.0%	6.2%	10.3%	17.2%	23.8%	0.0%	0.0%	0.0%	0.0%	0.0%	**4.8%**	**9.1%**	**4.1%**	**0.49**
Driver	-1.0%	-1.1%	-0.9%	-1.3%	-1.8%	-2.7%	-3.8%	-3.9%	-5.7%	-8.1%	-6.1%	-9.6%	**-1.9%**	**-4.1%**	**-2.2%**	**-0.20**
Passenger	-0.9%	-1.0%	-0.6%	-0.7%	-0.7%	-0.8%	-1.0%	-2.1%	-3.0%	-6.2%	-15.7%	-25.2%	**-1.2%**	**-5.6%**	**-4.5%**	**-0.12**
Bus	0.2%	1.6%	3.0%	4.7%	7.7%	12.5%	17.8%	18.3%	31.9%	49.9%	71.5%	77.7%	**5.9%**	**18.4%**	**11.8%**	**0.60**
Rail	0.3%	1.3%	2.4%	3.1%	5.7%	9.0%	16.8%	20.2%	22.8%	35.2%	39.2%	32.4%	**12.3%**	**25.0%**	**11.4%**	**1.21**
Total	**0.1%**	**0.1%**	**0.0%**	**0.0%**	**0.0%**	**-0.1%**	**-0.2%**	**-0.2%**	**-0.2%**	**-0.4%**	**-0.5%**	**-0.5%**	**0.0%**	**-0.2%**	**-0.2%**	

Table 6-7: Percentage difference in trips by purposes for 10 per cent increase in car journey time

	HB WORK	**HBEB**	**HB EDU**	**HB PB**	**HB RVF**	**HB HOLS**	**NHB EB**	**NHB OTHER**	**Total**
Walk	1.4%	0.9%	0.7%	1.1%	1.1%	1.9%	1.2%	1.0%	**1.0%**
Cycle	5.8%	3.8%	1.7%	3.4%	4.2%	5.9%	7.2%	5.6%	**4.8%**
Driver	-2.5%	-2.5%	-1.0%	-1.6%	-1.4%	-2.8%	-1.8%	-2.1%	**-1.9%**
Passenger	-2.9%	-3.0%	-1.5%	-0.9%	-1.1%	-2.8%	-1.0%	-0.3%	**-1.2%**
Bus	7.8%	4.7%	2.3%	4.7%	5.5%	19.3%	10.5%	9.7%	**5.9%**
Rail	10.0%	17.2%	2.9%	13.3%	13.0%	24.4%	18.7%	14.0%	**12.3%**
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

7. Summary and Conclusions

7.1 The transport demand model PASS1, a core component of the national modelling framework used by the Department to test the impacts of a wide range of scenarios and to produce the road traffic forecasts, has been updated and recalibrated, and the updated model is known as NTMv2R. The updating of the demand model has been carried out assuming no changes in the model design and structure. Updates in guidance, in line with evidence from research, mean that commuting trips now have a higher value of time than in the old NTMv2 model which may affect their responsiveness to changes in travel conditions.

7.2 The most significant revision to the demand model inputs was the change in travel demand for 2015 taken from NTEMv7. There is a reduction of -23% in the total number of personal trips being made for all purposes and summed over all modes. Although the underlying mid year population assumptions will have changed little, there have been some significant changes in NTEMv7 to the trip rates based on evidence from detailed analysis of time trends from the NTS data. This has resulted in fewer trips being forecast per person in 2015 in NTEMv7 than in the earlier NTEM datasets.

7.3 The results presented here demonstrate that the updated NTMv2R model produces trip length and mode choice profiles which match well with observed data; and that the elasticities of response to changes in cost and time are in line with the evidence provided in TAG guidance except for the bus fare elasticity test, which is slightly above the maximum limit recommended in TAG as a result of differences in the proportions of long-distance bus trips between the model and the TAG evidence. Given the limitations of retaining the existing model structure, it is believed that the calibrated model is fit for the purpose of modelling strategic policies on the roads network.

7.4 In addition to the demand model re-calibration and the changes in cost, the Traffic Database which feeds into FORGE has been updated to 2015, and minor changes have been made to FORGE itself. The model has also been made consistent with NTEM 7.2.

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