Final Report

DFT T-TEAR National Transport Model Development

NTMv2R Demand Model Calibration and Validation

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Preface

This report describes the steps undertaken to recalibrate version two of the National Transport Model (NTMv2R) and reports the results of realism tests to validate the recalibrated model. The model uses the same structure as the original NTMv2 model but rebased to reflect travel patterns observed in 2015.

This report describes the procedure followed in recalibration, the goodness of fit to the National Travel Survey (NTS) data set, and the findings from realism tests in comparison to WebTAG recommendations.

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Abbreviations

λ_A	Destination choice parameter – lambda parameter for attraction zones
λ_D	Distance band choice parameter
λ_M	Main mode (walk, cycle, car, bus, rail) choice parameter
λ_m	Car sub-mode (car driver and passenger) choice parameter
DB	Distance band
DfT	Department for Transport
HB	Home-based (trip)
MSC	Mode-specific constant
NHB	Non-home-based (trip)
NTM	National Transport Model
NTS	National Travel Survey
OSQA	Output Specification and Quality Assurance
PSU	Primary sampling unit
PT	Public transport
VOC	Vehicle Operating Cost

1. Introduction

Output Stage 2 (OS2) of the National Travel Model (NTM) development project involved recalibration of the existing NTMv2 model to provide a spatially aggregate model available for policy assessment in the near term while the new detailed model, NTMv5, was being developed. The newly recalibrated model is named NTMv2R.

The NTMv2R tasks are summarised in Table 1.

Table 1 NTMv2R tasks

Task	Description
2.1	Output Specification and Quality Assurance plan (OSQA)
2.2	Receive existing NTMv2 model and traffic database
2.3	Update traffic database
2.4	Demand model – implementation
2.5	Impact of new data
2.6	Demand model – calibration and validation
2.7	Updated documentation
2.8	Output QA checks

This note is concerned with Task 2.6, the recalibration of NTMv2 so 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. The arguments for retaining the NTMv2 approach were set out in the proposal. In summary, this decision was made to reduce the delivery risk associated with developing a new model suitable for policy assessment over a short model development window.

Here we report the calibration approach and results, as well as the validation findings that show that the newly recalibrated model has met the acceptance criteria to match the observed data and realism tests requirements. We conclude that the model calibrates well when compared to travel patterns from the National Travel Survey (NTS) (2006–2014). The aggregate mode splits match well with the NTS patterns – in most cases within 1 per cent (refer to Section 4.3) – while all realism test requirements (fuel cost, public transport fare and journey time elasticity tests) are met[1] (refer to Section 4.4). However, we acknowledge that there are shortcomings in the calibration because of the decision to retain the existing model structure; specifically, there is a lack of geographical segmentation. The new NTMv5 will better address these shortcomings because the model will be based on statistically estimated parameters from observed travel patterns with more detailed geographical and demand segmentation.

The rest of this report is structured as follows: Section 2 defines the key parameters to be calibrated; Section 3 explains data assembly and the calibration method; Section 4 highlights the calibration outcome and findings from realism tests; and Section 5 provides a summary and quality assurance measures.

[1] The exception is the fare elasticity, where we see that a 10 per cent increase in public transport fare results in a bus fare elasticity of -0.98, slightly above the accepted range in WebTAG (-0.7 to -0.9). We agreed with DfT that in the light of all other acceptable results, this small discrepancy was acceptable. In particular, the NTS data includes some longer distance bus journeys whereas the WebTAG elasticity range is based on local models.

2. Parameters amenable to treatment within the calibration process

2.1. Introduction

This chapter summarises the choice model parameters that are adjusted in the calibration procedure. Detailed explanations of the NTMv2R demand model structure and travel characteristics are provided in the NTMv2R implementation report.[2]

The demand model is implemented using MEPLAN software. The two core programs, LUSA and TASA, use the terms 'factor' and 'flow' respectively to represent the different demand segments of trip purpose, traveller type and distance band (DB). The input trip ends by trip purpose and traveller type are one set of factors that are then allocated to DBs using a logit choice model to generate the more detailed set of factors. In the NTMv2R demand model, the traveller demand segmentation is consistent throughout the model and hence the flow definitions in TASA are identical to the most detailed set of factors defined in LUSA.

To assist modellers working with the NTMv2R, some references are provided to the MEPLAN software filenames and to specific groups of data within those files, e.g. UTF[7] refers to group 7 of the UTF file.

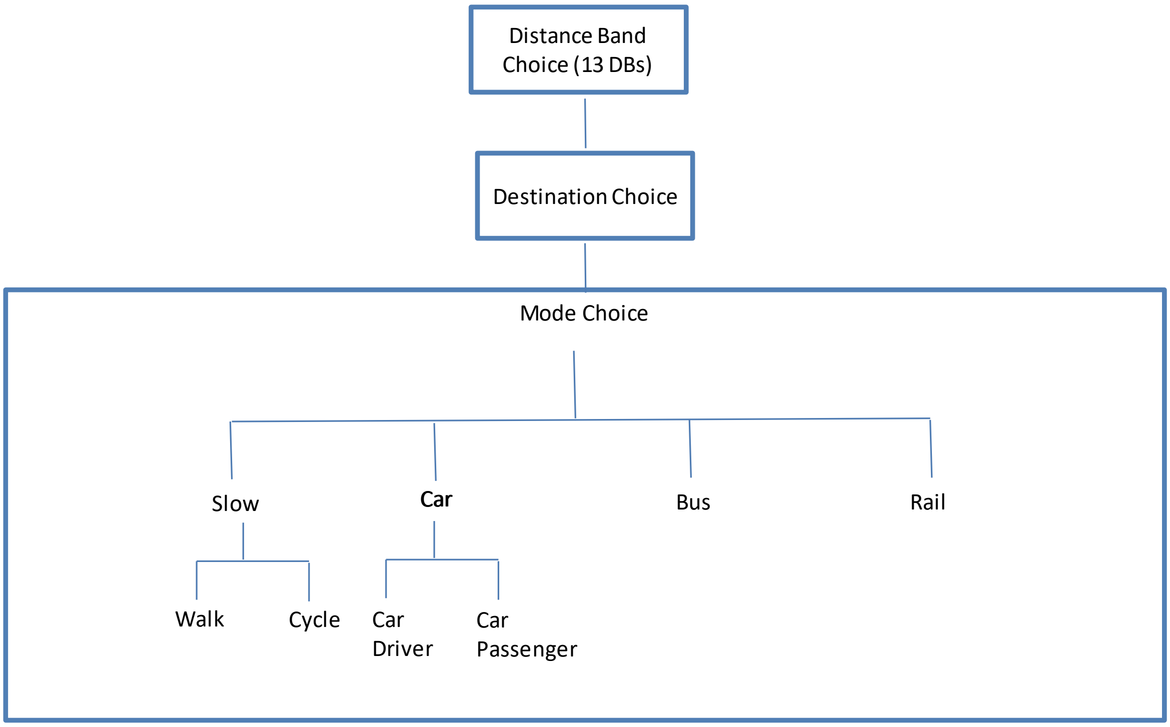
2.2. Choice parameters

The model choice hierarchy within NTMv2R is shown in Figure 1. It can be observed that three choice mechanisms operate within the demand model:

- Choice of distance band
- Choice of destination zone
- Choice of mode of travel (in two layers)
    - Choice of main mode (active, car, bus and rail)
    - Choice of sub-mode (walk and cycle under active; car driver and car passenger under car)

[2] NTM Future Model Development: NTMv2 recalibration-NTMv2R: Implementation Report

Figure 1 NTMv2R model choice hierarchy



The main choice parameters to be calibrated and their associated MEPLAN factors and files are listed below:

• λ_D	Distance band choice sensitivity	BdgtPar	ULP[3]
• λ_A	Destination (attraction) area type choice sensitivity	OLambda	ULP[1]
• λ_M	Main mode choice sensitivity (active {i.e. walk, cycle}, car, bus, rail)	LambdaM	UTF[10]
• λ_m	Sub-mode choice sensitivity (car driver/car passenger)	LambdaM	UTF[10]

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.

2.3. Mode-specific constants

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 (these are in MEPLAN UTF[8] file). This means there are over 1,500 MSCs to be adjusted.[3] For NTMv2 calibration, a FORTRAN macro was developed to automate the adjustments of the MSCs. However, because of changes in the MEPLAN input and output files in the version used for NTMv2R (5.2), the automated code was not helpful for our purpose. In addition, we aimed to have more control on MSCs to avoid large MSCs, which can have a substantial influence on model elasticities.

For this task, we therefore developed a spreadsheet-based semi-automatic tool for adjusting MSCs. This allowed more control in defining the MSCs.[4] Another difference with NTMv2 is that we also defined MSCs for the main car mode.[5] This has proved to be very helpful for adjusting overall mode shares between car passengers and drivers, while controlling for the scale of the choice.

2.4. Distance band constraints

Distance band (DB) constraints force the model to exactly replicate demand across a given DB profile by introducing extra implicit disutility terms[6] in the MEPLAN LAZ file of zonal and study-wide characteristics. In NTMv2 and NTMV2R, constraints have been imposed to match NTS profiles over all 13 DBs and for each of the 23 segments by purpose and household type distinguished in the aggregated NTS data set.

2.5. Size terms

Size terms are weights that reflect the number of opportunities available at a given distance by destination area type. They are introduced into the choice disutility for destination areas as logarithmic terms weighted by $-1/\lambda_A$, which can be found in the MEPLAN DRD file. The larger the size terms, the more attractive the destination area type. However, the size terms also influence the composite disutility of all area types used to determine the DB split for a flow at the top level of the choice hierarchy.

For NTMv2R, it is agreed with the Department for Transport (DfT) that the size terms would not be updated as the relative attraction of area types is unlikely to be significantly different from those in

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[3] It should be noted that the calibration in NTMv2 and NTMv2R was based on trial and error with the aim of achieving the best match to the observed NTS data. This is different to more typical model estimations where we seek 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. Estimation of disaggregate models, using maximum likelihood estimation methods, will be used for NTMv5.

[4] This approach is further explained in Section 3.

[5] NTMv2 incorporated separate MSCs for car drivers and car passengers; NTMv2R has additionally estimated an MSC for the main car mode. This gives more flexibility for calibration.

[6] These disutility terms act in a similar way to MSCs in utility functions for modes. However, unlike the MSCs, which are set by the user in MEPLAN, the distance disutility terms are automatically estimated so that the model exactly replicates the distance band profiles (in MEPLAN parlance these are called distance band constraints). In future year policy tests and forecasts, there are no constraints, but the distance disutility terms are retained (these are read from base year MEPLAN LAZ file and are used as constants).

NTMv2.[7] However, because of calibrating a different set of λ_A , it was necessary that the size terms be weighted by the ratio of the old and new λ_A values.

2.6. Passenger guilt factor

Consistent with the NTMv2 model, a mechanism exists within the model to implement additional disutilities for the passenger mode to reflect a percentage of the fuel costs perceived by the driver. The multiplier by which driver fuel costs are scaled is known as the 'guilt factor'.

The guilt factor in version NTMv2 of the model was 50 per cent. In NTMv2R, this is calibrated to 87 per cent. This is discussed further in Section 4.

2.7. Terminal disutilities

The UTT file contains a set of additional costs and times that can be added into the final disutility. These may be specified by flow,[8] mode and zone (i.e. area type and region).[9] Using the UTT file, it is possible to add in disutilities to influence mode share by origin or by destination. This approach is already used to reflect car parking costs using destination end terminal costs for car drivers and terminal disutilities for car passengers. In the recalibration, the UTT file has been updated (by adjusting rail disutilities) to ensure we get the right share of rail trips to London.

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[7] Refer to Section 2.4 of NTMv2R implementation report for a review of zone definitions and the changes in them.

[8] The 'flow' number subsumes such elements as distance band, purpose, household category and person type.

[9] UTT[1] contains information for origin zones. UTT[2] contains information for destination zones.

3. Model calibration method

3.1. Introduction

Task 2.6 can be broken down into two main stages:

1. Assembly of estimation choice data

   This involves manipulating NTS data provided by DfT and extracting the required information for model calibration.

2. Demand model calibration

   This involves adjusting the sensitivity parameters, setting model constraints and constants, and checking how these impact the predicted travel flows and realism test outputs.

These two stages are described further in Sections 3.2 and 3.3 below.

3.2. Assembly of data

RAND Europe signed a data use agreement for NTS data covering the 2002–2014 period. The DfT confirmed that the 2015 NTS data would not be available in time for the Task 2.6 recalibration work; therefore, all of the NTS data to be used for the recalibration has been collected prior to the 2015, i.e. only NTS data collected up to 2014 was used.

A key part of the data analysis was to explore the sample sizes of trips by journey purpose and year for the recent years of NTS data. The trade-off here was that 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. This is due to the recent changes in trip making behaviour (refer to Jahanshahi et al, 2015, which discusses changes in travel behaviour over time using NTS data).

As a result of this analysis, we concluded that for DB and destination choice for all purposes, we needed to combine at least three NTS years (2012–2014) to get sufficient sample sizes.[10] Even then, there are limits to the degree of classification which can be considered for calibration. These limits were discussed with the DfT and it was agreed that for recalibration of mode choice the aim was to get sample sizes of above 1,000 for each flow when all modes are aggregated. This led to using nine years of data from 2006

10 NTS advise not to use the sample size less than 300 while using those less than 1,000 with caution. Refer to the NTS report on notes and definitions (accessed online 25 April 2017): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/457688/nts2014-notes.pdf

to 2014. The decision was also made based on analysis of distance profiles for each mode, which suggested that variations over years are small.

The NTS data includes households from England, Scotland and Wales up to 2012, but England only from 2013 onwards. It has been assumed, in discussion with the client, that Scottish and Welsh households will have similar travel behaviour to English households, specifically after accounting for the variations by area types.[11] Therefore, we agreed to use English households only for all years of NTS data included in the calibration samples. The assumption when applying the model is that behavioural parameters that reflect the behaviour of English households can be transferred to predict the behaviour of Scottish and Welsh households.

The NTS data was received in SPSS format and in a nested structure with primary sampling unit (PSU), household, individual and trip tables. Later, we also received some additional variables including area types of trip origins and destinations.

The following steps were used to assemble the NTS data. SPSS syntax code was developed to ensure consistency in assumptions between implementation (OS 2.4) and calibration (OS 2.6)

1. Household, individual and trip data was linked to produce one table of NTS data.
2. The NTS data was recoded into variables with required segmentations for the model calibration.[12] Table 2 provides the list of variables created, the underlying NTS variable/variables and the associated assumptions, if any.

Table 2 NTS variable definitions for the NTMv2R model recalibration

Variable description	Categories	Base NTS variable/s	Comments
Age Band	1 '0–15' 2 '16–74' 3 '75+'	Age	N/A
Number of Adults in Household	1 '1 adult' 2 '2+ adults'	HHoldNumAdults	N/A
Household Type	1 '1 adult, 0 cars' 2 '1 adult, 1+ cars' 3 '2+ adults, 0 cars' 4 '2+ adults, 1 car' 5 '2+ adults, 2+ cars'	HHoldNumAdults and NumCarVan_B02ID	N/A
Person Category	1 'Child 0–15' 2 'Full Time 16–74' 3 'Other 16–74' 4 'Pensioner 75+'.	Age and EcoStat_B01ID	N/A

[11] This issue was raised in the OSQA2 Queries Discussion Paper of 5 April 2016, and in the meeting on 11 April 2016 and concluded that this should not be a problem, assuming that for a given model segment Scottish and Welsh households behave like English households.

[12] Please refer to Section 2 of NTMv2R implementation report (Atkins, 2017) for more information on model structure and segmentation definitions.

Variable description	Categories	Base NTS variable/s	Comments
SEG_Income	1 'Professional and managerial – High Income' 2 'Skilled manual and non-manual – Medium Income' 3 'Semi-skilled manual and other manual – Low Income'	SC_B01ID	N/A
Trip Purposes	1 'HB Work' 2 'HB Employers Business' 3 'HB Education' 4 'HB Shopping/Personal Business' 5 'HB Recreation/Social/Visiting friends and relatives' 6 'HB Holiday/Day trip' 7 'NHB Employers Business' 8 'NHB Other'	TripPurpFrom_B01ID and TripPurpTo_B01ID	Trips from 'home' and 'escort from home' are considered home based (HB). The trips to 'home' or to 'escort home' are considered as returned and are excluded because the HB models are only estimated from outbound trips.[13] All other trips are considered non-home-based (NHB).
Travel Type	105 traveller types, 1–105	Built based on the combination of household type, person category, SEG_Income and purposes	N/A
Household Region	1 'N&E' 2 'SOUTH' 3 'WEST' 4 'LONDON'	HHoldGOR_B02ID	N/A
Mode of Travel	1 'Walk' 2 'Cycle' 3 'Car driver' 4 'Car passenger' 5 'Bus' 6 'Rail'	MainMode_B04ID	N/A
Distance Bands	1 '< 1 miles' 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'	TripDisIncSW	Unweighted distance for trip including short walk
Origin Region	1 'N&E' 2 'SOUTH'	TripOrigGOR_B02ID	Based on the variable received later from NTS team

[13] 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 LOS.

Variable description	Categories	Base NTS variable/s	Comments
	3 'WEST' 4 'LONDON'		
Destination Region	1 'N&E' 2 'SOUTH' 3 'WEST' 4 'LONDON'	TripDestGOR_B02ID	Based on the variable received later from NTS team
Origin Zone		TripOrigNTMZonTy_B01ID[14] and TripOrigGOR_B02ID and TripOrigUA1998_B01ID	15 Demand model zones are the combination of region and area types[15]
Destination Zone		TripDestNTMZonTy_B01ID and TripDestGOR_B02ID and TripDestUA1998_B01ID	15 Demand model zones are the combination of region and area types
Area Types	1 'Central London' 2 'Inner London' 3 'Outer London' 4 'Metropolitan' 5 'Outer Conurbation' 6 'Urban Big (pop. > 250k)' 7 'Urban Large (pop. > 100k)' 8 'Urban Medium (pop > 25k)' 9 'Rural'	NA (derived from zone)	

A comprehensive list of demand model definitions is provided in Appendix A.

3.3. Demand model calibration

The following stages were undertaken to recalibrate the NTMv2R demand model.

Stage 1 No constants run

First, we set up a 'no constants' run in which we used the sensitivity parameters from the previous version of NTMv2 but with the input files updated to the new 2015 base year. In addition:

1. DB constraints and MSCs were removed – including destination-specific constants that had been applied to match rail trips to London. In line with NTMv2, the model is doubly constrained for all purposes with both production and attraction trip ends coming from National Trip End Model (NTEM v7.0).

14 There are 728 records out of total of 403,193 NTS records from 2012 to 2014 where TripDestNTMZonTy_B01IDn or TripDestNTMZonTy_B01ID are coded as -8 (i.e. not given). The corresponding origin and destination zones to those are coded as -9 (i.e. not available) and excluded from analysis.

15 For more information on the demand model zoning system, refer to the implementation report (NTM Future Model Development: NTMv2 recalibration-NTMv2R: Implementation Report).

2. All soft policy adjustments (e.g. parking charges, fuel price tests, etc.)[16] and the rail adjustments (i.e. UTT disutilities added to adjust rail trips to London) were removed.
3. The DRD file, which has size term weights from the current version of NTMv2, was used (consistent with the existing sensitivity parameters also used).

Stage 2 Calibration of the trip length sensitivity parameters (λ_D and λ_A)

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. (This is to account for cost damping as trip lengths increase.)

Section 4.1 provides the comparison of the model results with NTS data for our best Stage 2 run and shows a reasonable match to the NTS data set even before adding the DB constraints.

Stage 3 Introducing DB constraints

At this stage, the DB constraints were introduced to ensure that the model matched the distance profiles observed in the NTS data. The DB constraints are set in MEPLAN ULC[1] file.[17] These constraints were derived from applying NTS profile on NTEM total trips by purpose and car availability (based on car ownership and household size).

After introducing the DB constraints, we expect the trips by DBs to match perfectly to the observed data.

Stage 4 Calibration of the mode choice parameters

This stage involves matching modal splits to those observed in the NTS data. The parameters that could be adjusted to improve the fit to the NTS data were:

1. λ_M. Main mode choice (active {i.e. walk, cycle}, car, bus, rail) sensitivity parameter. This influences the mode choice sensitivity: lower λ_M values correspond with lower sensitivity to costs. λ_M is set in the MEPLAN UTF[10] file.
2. MSCs. These constants affect mode splits over all zones by segment (i.e. purposes, car availability and DB). These were set to achieve a better match to the observed patterns, but it is noted that these changes also impact upon the model elasticities. As such, the calibration of the MSCs and λ_M parameters were made iteratively in order to achieve the best match to the observed data while meeting elasticity criteria. The MSCs are in the UTF[8] file.
3. Rail adjustments parameters. The disutility for rail can be modified by adding a constant by origin or destination zone. This had been used previously in NTMv2 to modify the disutility for rail trips to London (zones 1, 2, and 3) to increase the rail share to these zones. We also

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[16] Soft policy adjustments were made to the model by DfT for policy testing (e.g. for testing the impact of increases in parking prices); these were removed before starting the calibration.

[17] The MEPLAN naming convention means that ULC[1] denotes the first section (group) of the text file ulc.dat.

checked the predicted rail trips to London for NTMv2R and modified rail adjustment parameters to get a better match to NTS and census data. These are incorporated in the UTT file.

As there are many MSCs that can vary by person types and modes, we developed a semi-automatic approach to ensure a good match at purpose, DB and household type levels. The following steps describe the semi-automatic procedure that was followed:

1. Total predicted trips by purpose, DBs, household types and user mode were extracted; we call this T_{Model}. The same information is extracted from NTS data, which forms our target trip volume and are called T_{NTS}.
2. We then estimated the main mode MSCs as $1/\lambda_M(\frac{T_{Model}}{T_{NTS}})$, where λ_M here is the main mode sensitivity parameter (i.e. the sensitivity parameters for cars, bus, rail and active modes).
3. We then ran the model by adding MSCs from step 2 as mode specific constants in the MEPLAN UTF file.
4. We repeated Stage 1 and 2 after getting the outcomes from the new run and added the calculated MSCs to the ones we got from step 3. However, this time, the constants are estimated for all sub-modes (i.e. car driver and passengers with their corresponding $\lambda_m$values as opposed to main car mode, λ_M). This helped in achieving a good general match in step 2 without the requirement for adding large MSCs for car drivers and passengers.
5. We repeated step 4 until an acceptable match to the NTS data was reached. Acceptable was defined as within 5 per cent for those segments in the NTS with a sample size of at least 1,000.

Section 4.2 compares the distance profile of NTS data with the final model after adding all constraints and constants (i.e. Run 62).[18]

Stage 5 Review and adjust choice parameters for realism tests

At this stage, we carried out three sets of realism tests as defined in WebTAG Unit M2 (DfT, 2014) and highlighted in Section 3.4.2. The results of the realism tests were reviewed and λ_M, λ_m and MSC were adjusted accordingly to ensure that the model responses were in line with recommended WebTAG values (refer to Section 3.4 for further discussions on acceptance criteria). The challenge was maintaining the good match to the NTS data while getting an acceptable elasticity response. This resulted in many test runs that involved changing the λ_M and λ_m parameters and rerunning the semi-automatic procedure described above. The results of the realism tests from the final Model (Run 62) are provided in Section 4.4.

[18] Run 62 is the best calibrated model. Its choice parameters are provided in Appendix B and the MSCs for that run are passed to the DfT in an Excel spreadsheet. More general information on the model parameters is provided in the NTMv2R implementation report.

3.4. Acceptance criteria

3.4.1. Goodness of fit measures

Because the NTMv2 model contains DB constraints, the model exactly replicates the distribution of trips by DB by purpose and household type.

In the NTMv2 (and NTMv2R) structure, mode choice is lower in the nesting structure – and therefore is more sensitive to generalised cost changes – than the DB and destination choices. In theory, mode choice parameters and MSCs could be estimated for each traveller type by DB and purpose. However, we did not have sufficient sample sizes in NTS data to allow for so many parameters. We are only able to compare the model predictions against the observed data at an aggregate level by DB and journey purpose. The acceptance criteria at DB level and at purpose level (by mode) were set as values to be ±5 per cent. These higher-level calibration acceptance criteria allowed more room to adjust parameters to ensure the correct elasticities and policy responses.

3.4.2. Realism tests

In line with WebTAG 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).

The resulting elasticities within acceptable range provided by WebTAG are summarised in Table 3 below.

Table 3 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 WebTAG Unit M2

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.

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.

3.5. Practical difficulties in calibration and realism tests

The following sections highlight the main techniques that have been used throughout the recalibration process. In practice, the biggest issue we faced was matching car driver and passenger splits to the observed data while maintaining reasonable responses to changes in fuel costs and journey times (i.e. in realism tests).

3.5.1. Cost damping

Cost damping reflects that the sensitivity of demand responses to changes in disutility reduces with increasing trip length. There is strong empirical evidence for cost damping (see Daly, 2010).[19] WebTAG Unit M2 (DfT, 2014) suggests some functional forms that allow reduction in cost sensitivity by distance. However, in the DB choice in NTMv2R the representation of distance is not continuous; therefore, we allowed for the main mode sensitivity parameters (i.e. λ_M) to vary by 13 DBs. Appendix B provides the model parameters for the final calibrated model (i.e. Run 62).

3.5.2. MSCs for car main modes as well as sub-modes

One of the differences between NTMv2R and NTMv2 is that in NTMv2R there are assigned MSCs for the main car mode. This assists considerably with improving the overall mode split.

In addition, adding MSCs for the car main mode reduces the need for MSCs for the car sub-modes (i.e. drivers and passengers) and gave more control to help meet demanding fuel cost realism test criteria.

3.5.3. Guilt factor and car driver fuel cost and journey time elasticity tests

In addition to the MSCs, another level for influencing car driver and passenger mode splits is the guilt factor: this assigns a proportion of the car journey cost to passengers (i.e. car passenger costs = guilt factor* car driver costs). A guilt factor value of 0.87 was found to give the best fuel cost responses, meaning that the passengers perceive 87 per cent of the cost assigned to drivers. This assumption was agreed with DfT

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[19] See Daly, A. (2010) Cost Damping in Travel Demand Models: Report of a study for the Department for transport, available at: http://www.rand.org/pubs/technical_reports/TR717.html

in order to obtain reasonable fuel price elasticities and keep the switching from drivers to passengers at a reasonable level.[20]

For the car journey time elasticities, WebTAG suggests an upper bound (not stronger than -2.0), but no lower bound is specified. Evidence on car journey time elasticities is provided in De Jong and Gunn (2001), although they provide little evidence on responses for car drivers and passengers separately.[21] The recalibrated model comfortably meets the WebTAG requirements.

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[20] Assuming a proportion of car driver costs for passenger modes helps to obtain reasonable mode split and fuel price elasticities and to keep switching from drivers to passengers at a reasonable level. The passenger costs are incorporated in the utility only for car passenger choice (i.e. the car passenger cost for evaluation purposes is considered to be zero). This approach was agreed with DfT on the basis that car passengers in NTMv2R are not explicitly considered in appraisals.

[21] The DfT kindly pointed us to De Jong and Gunn (2001). This paper provides elasticities (derived from transport models) on car driver and passenger responses to cost and time changes. There is limited information on car passenger responses, with only the Netherlands model providing fuel cost and car journey time car passenger responses that are not reported specifically; although they note that fuel cost increases lead to an increase in occupancy (more passengers) while journey time increases lead to reductions in the numbers of car passengers.

4. Calibration results

4.1. Stages 1 and 2 No constants run, calibrating DBs and destination choice parameters

As discussed in Chapter 3, Stage 1 involves setting up the no constants run and Stage 2 concerns calibrating DB and destination choice sensitivity parameters (i.e. λ_D and λ_A) before adding the DB constraints. This is to ensure we get the best behavioural model before adding the constraints, which ensure that the trip patterns match exactly for the base year.

Table 4 compares the absolute difference in trips for different DBs between the model and the NTS data for the end of Stage 2 run. Traffic is trips multiplied by distance and the DBs are defined in miles (as in the NTS). Table 5 shows the percentage differences. A graphical comparison of the distribution of trips for the end of Stage 2 model and NTS data is also shown in Figure 2.

Table 4 Absolute difference in trips (end of Stage 2 Run versus NTS)

	<1	1-2	2-3	3-5	5-10	10-15	15-25	25-35	35-50	50-100	100-200	>200	TOTAL	TRAFFIC	Mean trip length
HBW	-11174	-27109	-16218	-3558	48012	22122	-1178	-986	2365	-7947	-3358	-976	-5	-760672	-0.1
HBEB	-3051	-3936	-2479	-1117	6762	4560	4112	2513	1509	-2570	-4745	-1555	3	-981895	-0.6
HBEd	-19623	-31558	-14210	6627	44699	11561	2336	2233	1505	-1170	-2226	-170	2	126959	0
HBPB	-35818	-50501	-18481	10586	72728	25542	7417	1995	-813	-6447	-4635	-1578	-5	-632497	0.0
HBRec/VF	-15823	-17054	-8498	2642	37340	14657	7481	3189	538	-7370	-10547	-6562	-6	-3087989	-0.2
HBhol	-768	-2239	-1492	-40	3772	2602	4018	1555	502	-1474	-3132	-3303	0	-1204671	-0.4
NHBEB	-10851	4986	-6202	-5142	8610	5266	4847	2379	1728	-1875	-3246	-503	-4	-415162	-0.2
NHBO	-19447	-13888	-8234	335	34419	13788	7096	2658	155	-6278	-7801	-2860	-57	-1747138	-0.1
TOTAL	**-116554**	**-141298**	**-75814**	**10333**	**256342**	**100098**	**36129**	**15535**	**7489**	**-35131**	**-39689**	**-17508**	**-71**	**-8703064**	**-0.1**

Table 5 Percentage difference in trips (end of Stage 2 Run versus NTS)

	<1	1-2	2-3	3-5	5-10	10-15	15-25	25-35	35-50	50-100	100-200	>200	TOTAL	TRAFFIC	Mean trip length
HBW	-1.1%	-1.5%	-1.1%	-0.2%	1.5%	1.4%	-0.1%	-0.2%	0.9%	-5.2%	-20.9%	-32.3%	0.0%	-0.6%	-0.6%
HBEB	-3.2%	-2.7%	-2.0%	-0.5%	2.0%	2.6%	2.0%	2.7%	1.7%	-2.0%	-7.2%	-7.0%	0.0%	-2.3%	-2.3%
HBEd	-0.6%	-1.4%	-1.3%	0.6%	5.4%	4.8%	1.8%	5.9%	7.0%	-9.3%	-37.6%	-54.2%	0.0%	0.5%	0.5%
HBPB	-0.8%	-1.1%	-0.6%	0.3%	2.1%	2.3%	1.0%	1.0%	-0.8%	-7.8%	-22.5%	-34.0%	0.0%	-0.6%	-0.6%
HBRec/VF	-0.7%	-0.6%	-0.4%	0.1%	1.4%	1.4%	1.0%	1.0%	0.3%	-2.8%	-8.1%	-17.0%	0.0%	-2.3%	-2.3%
HBhol	-0.7%	-0.7%	-0.5%	0.0%	0.8%	1.1%	1.5%	1.2%	0.4%	-0.7%	-2.3%	-5.4%	0.0%	-1.6%	-1.6%
NHBEB	-4.0%	2.4%	-2.9%	-1.4%	2.0%	2.6%	2.5%	3.3%	2.4%	-2.4%	-9.9%	-7.1%	0.0%	-1.4%	-1.4%
NHBO	-0.7%	-0.6%	-0.5%	0.0%	1.4%	1.3%	0.9%	1.0%	0.1%	-3.4%	-9.7%	-16.9%	0.0%	-1.5%	-1.5%
TOTAL	**-0.8%**	**-1.0%**	**-0.8%**	**0.1%**	**1.9%**	**1.7%**	**0.9%**	**1.0%**	**0.7%**	**-3.1%**	**-8.1%**	**-11.3%**	**0.0%**	**-1.3%**	**-1.3%**

Figure 2 Comparing distance profile by purposes (end of Stage 2 Run versus NTS)

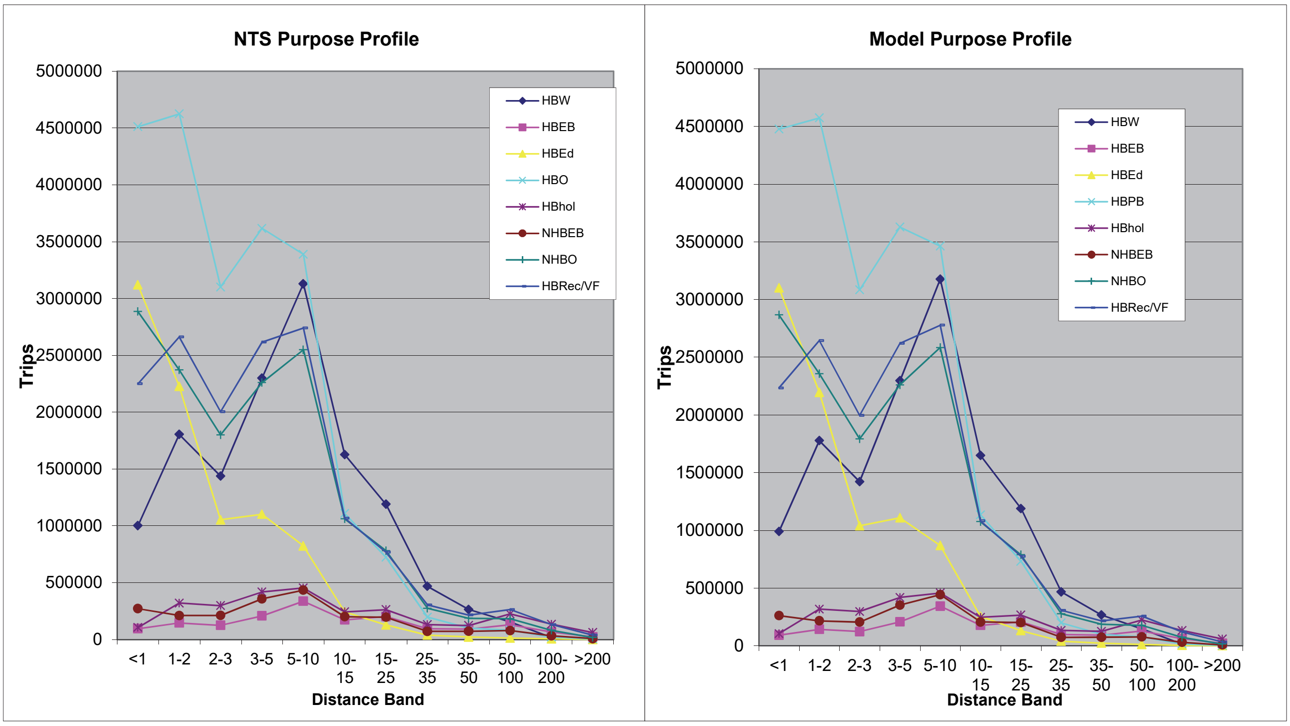

Table 5 demonstrates that in percentage terms there is a good match between predicted trips and the observed data for short DBs, which Figure 2 demonstrates constitutes the majority of the data. However, for all purposes there is a tendency to over-predict medium distance trips and under-predict short- and long-distance trips.

Overall, these results suggest that even before adding the DB constraints, the DB and destination choice parameters are well adjusted showing a good initial match to the NTS data. Adding the DB constraints in Stage 3 will further improve the match, particularly for longer DBs.

4.2. Stage 3 Adding the distance constraints

After application of the distance constraints, we expect the number of trips by DB to almost exactly match the NTS data, which is what we observe in Table 6 below. In percentage terms, the difference between predicted and NTS trips is 0.0 per cent for all combinations of purpose and DB.

Table 6 Absolute difference in number of trips by purposes and distance bands (Run62 versus NTS)

	<1	1-2	2-3	3-5	5-10	10-15	15-25	25-35	35-50	50-100	100-200	>200
HBW	2	4	2	23	-47	5	5	1	0	1	1	0
HBEB	2	1	0	0	1	0	0	0	-1	0	0	0
HBEd	-11	8	4	4	3	0	0	0	-1	0	-1	0
HBPB	33	11	-34	-4	-12	1	2	0	-1	1	0	0
HBRec/VF	-14	-9	-9	11	29	-5	-3	-2	-1	-1	-1	-1
HBhol	-5	0	1	1	1	0	1	1	0	1	0	-1
NHBEB	-1	0	0	0	-1	-1	0	0	-1	-1	0	1
NHBO	-5	13	-54	-57	-43	30	-6	-2	-2	-2	-1	0
Total	**0**	**28**	**-89**	**-23**	**-68**	**31**	**-3**	**-3**	**-5**	**-2**	**-2**	**-2**

Table 7 Absolute difference in trips by household type and distance bands (Run62 versus NTS)

	<1	1-2	2-3	3-5	5-10	10-15	15-25	25-35	35-50	50-100	100-200	>200
1 Ad/0 car	-2	-3	-1	-2	-1	0	-1	1	0	1	1	0
1 Ad/1 car	3	1	1	1	2	-1	1	-1	-1	0	0	-1
2 Ad/0 car	2	2	0	1	0	-1	1	1	0	0	0	0
2 Ad/1 car	-7	-17	-30	19	28	3	2	-1	-1	0	0	-1
2 Ad/2+car	16	32	-8	15	-55	-1	0	-1	-1	-1	-1	0
Car n/a	-11	12	-52	-57	-43	30	-5	-2	-2	-2	-1	0
Total	**0**	**27**	**-90**	**-23**	**-69**	**31**	**-3**	**-3**	**-5**	**-2**	**-2**	**-2**

This comparison demonstrates that the model predictions by household type and distance band closely match the NTS data as expected. In percentage terms, the difference between predicted and NTS trips is 0.0 per cent for all combinations of household type and distance band.

4.3. Stage 4 Mode choice calibration

This stage compares the modal split from the calibrated model with that from NTS data. As agreed with the DfT, the acceptance criteria for the segments with the number of records of above 1,000 is 5 per cent. We only consider segments with 1,000 observations or more in line with NTS recommendations, which are not to rely on the NTS data where the sample size is less than 1,000 to ensure that comparisons are statistically robust.

Table 8 shows the absolute difference in predictions by (high-level) mode, between the model projections and NTS, overall and by distance band. The percentage differences are shown in Table 9. The NTMv2R model assumes walk trips occur within the first six distance bands and cycle trips within the first seven distance bands. We have greyed out the distance bands which are not modelled in Table 8 and Table 9. It can be observed that all percentage differences, except for rail trips over 200 miles, are well below 5 per cent (in most cases below 1 per cent). Table 10 and Table 11 show the values for the detailed modes (car driver and passenger, bicycle and walking).

Table 8 Main mode split by distance band – absolute difference between the model projections and 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	21,319	5,916	1,122	-349	389	205	555						**22,828**
Car	-21,356	-4,098	-231	7,178	6,826	-6,797	5,335	7,160	3,359	1,459	3,066	3,152	**5,053**
Bus	26	-1,806	-341	846	2,902	1,466	760	251	366	552	-175	240	**5,085**
Rail	9	16	-637	-7,697	-10,185	5,157	-6,652	-3,413	-2,342	-1,214	-2,752	-3,395	**-33,105**
Total	**-2**	**28**	**-87**	**-22**	**-68**	**31**	**-3**	**-3**	**-5**	**-2**	**-2**	**-2**	**-139**

Table 9 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 10 Sub-mode split by distance band – absolute difference between the model projections and 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	20,897	5,668	1,047	226	53	2							**27,723**
Cycle	422	248	76	-574	337	203	640						**-4,895**
Driver	-15,426	-8,979	-9,208	-3,262	9,942	-839	8,598	6,480	4,305	4,752	3,879	2,119	**2,361**
Passenger	-5,930	4,881	8,976	10,440	-3,116	-5,958	-3,263	680	-946	-3,293	-813	1,034	**2,692**
Bus	26	-1,806	-341	846	2,902	1,466	760	251	366	552	-175	240	**5,085**
Rail	9	16	-637	-7,697	-10,185	5,157	-6,652	-3,413	-2,342	-1,214	-2,752	-3,395	**-33,105**
Total	**-2**	**28**	**-87**	**-22**	**-68**	**31**	**-3**	**-3**	**-5**	**-2**	**-2**	**-2**	**-139**

Table 11 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%**

We also see a good match by household type and purpose, as shown in Table 12 to Table 15.

Table 12 Sub-mode split by household types – absolute difference between the model projections and 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	-5,281	7,461	-4,875	7,910	19,470	30,41	**27,725**
Cycle	-372	267	-659	-1,274	381	-3,238	**-4,895**
Driver	1,427	-9,504	1,774	15,273	-1,076	-5,536	**2358**
Passenger	-811	2,298	-3,898	2,360	1,556	1,187	**2692**
Bus	-1,860	3,938	-3,404	-2,226	6,977	1,659	**5084**
Rail	6,889	-4,455	11,067	-22,048	-27,313	2,754	**-33106**
Total	**-8**	**5**	**6**	**-5**	**-5**	**-134**	**-141**

Table 13 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 14 Sub-mode split by purposes- – absolute difference with NTS (2006–2014)

	HB WORK	HB EDUC	HB EB	HB PB	HB Rec/VF	HB HOL	NHB EB	NHB OTHER	Total
Walk	825	19,973	305	2,926	655	-1	1,380	1,662	**27,724**
Cycle	-3,358	1,745	83	-292	166	-1,929	72	-1,381	**-4,895**
Driver	51,390	-39,342	-2,159	-622	-1372	418	-3,206	-2,749	**2,360**
Passenger	10,434	3,810	-1,419	7,989	-19,309	2,053	-295	-570	**2,693**
Bus	-6,472	12,292	222	-10,247	7,630	543	229	887	**5,084**
Rail	-52,824	1,527	2,971	244	12,223	-1,084	1,817	2,021	**-33,106**
Total	**-4**	**5**	**3**	**-2**	**-7**	**-1**	**-4**	**-129**	**-139**

Table 15 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%**

Finally, Table 16 compares the total rail trips to London for commuting. The comparison is made against NTS data and 2011 Census Journey to Work (JTW) data. It can be observed that our results match closer to Census JTW, which is considered a more trustworthy source as the sample size in NTS for rail travel is small.

Table 16 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%

4.4. Stage 5 Realism tests

WebTAG acceptance criteria for realism tests are discussed in Section 3.4. Here, we report the results for fuel price, public transport fare and journey time realism tests.

4.4.1. Fuel price elasticity tests

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. The kilometrage elasticity is calculated as log (changes in vehicle distance)/ log (1.1). [22]

WebTAG recommends an overall elasticity of -0.3 for car vehicle kilometres with the range of -0.25 to -0.35 set as acceptable. Our results, shown in Table 17, give an elasticity of -0.32 for car driver kilometres (i.e. traffic km). This fits with WebTAG guidance. 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.

[22] 1.1 accounts for 10 per cent increase in fuel costs.

Table 17 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%**	

In general, the percentage differences across purposes (refer to Table 18) are also in line with what we expect, with holiday trips being the most elastic and employed business the least elastic purposes to increases in fuel costs. However, the commute car kilometrage elasticity is lower than expected.

Table 18 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**

4.4.2. Public transport fares elasticity test

Table 19 shows the responses for 10 per cent increase in (both) bus and rail fares. WebTAG requires trip elasticity between -0.2 and -0.9 for all public transport modes and suggests between -0.7 and -0.9 for bus fares. As shown in Table 19, elasticity for buses with respect to 10 per cent increase in fare is -0.98, while that for combined public transport modes is -0.85; the latter is within the WebTAG guidance range and the former is slightly higher than the maximum value. The bus fare elasticity is higher than the WebTAG guidance values because it includes long-distance bus trips, which form only a small fraction of bus demand in the local models WebTAG is typically used for. Table 19 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.

Table 19 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**

The percentage difference by purposes as a result of 10 per cent increase in public transport fare is shown in Table 20. 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 20 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**

4.4.3. Car journey time elasticity tests

Finally, the car journey time elasticity is shown in Table 21. The WebTAG recommendation is that the car journey time elasticity should not be stronger than -2.0. This criteria is met in the recalibrated model. While the presented elasticities for this test are all for trips, due to increasing trip length the traffic elasticity (0.44) is more than double the figure for trips end exceeds the fuel price elasticity.

Table 21 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 22 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 22 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%**

5. Summary

This report has demonstrated that we have achieved a high-standard calibrated model following procedures detailed in the OSQA. We have calibrated the NTMv2 model and achieved the agreed match to the NTS data and met WebTAG realism test requirements, except for the bus fare elasticity test, which is slightly above the maximum limit recommended in WebTAG as a result of differences in the proportions of long-distance bus trips between the model and the WebTAG evidence. Given the limitations of retaining the existing model structure, we believe that the calibrated model is fit for the purpose of modelling strategic policies on the roads network.

Appendix C provides a brief explanation of the quality assurance procedures adopted for this work.

References

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Appendix A Demand model definitions

Dimensions and units

The dimensions and units used by NTMv2R are shown in Table 23.

Table 23 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

Zones

The combinations of area type and region that make up the NTMv2R zones are shown in Table 24. Note that zone numbers 11 and 15 are not used.

Table 24 NTMv2R zone definitions

	Area type								
	1	2	3	4	5	6	7	8	9 & 10
Region	Central London	Inner London	Outer London	Metropolitan	Outer Conurbation	Urban Big (pop > 250k)	Urban Large (pop > 100k)	Urban Medium (pop >25k)	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
York. & Humber				4	6	8	12	16	17
North East				4	6	8	12	16	17
Scotland				4	6	8	12	16	17

Trip purposes

Eight trip purposes are defined in the NTMv2R demand model: six home-based purposes and two non-home-based purposes. The definitions of the trip purposes are assumed to be entirely consistent with the purpose definitions in the National Trip End Model (NTEM v7.0) from which the trip ends are obtained. The purposes and their relationship with NTEM are shown in Table 25.

Table 25 NTMv2R trip purposes

NTEM v7.0 Trip Purpose		NTMv2R Trip Purpose	
1	HB Work	1	HB Work
2	HB Employers Business (EB)	2	HB EB
3	HB Education	3	HB Educ
4	HB Shopping	4	HB PB/Shop
5	HB Personal Business (PB)	4	HB PB/Shop
6	HB Recreation/Social	5	HB Rec/VF
7	HB Visiting friends and relatives	5	HB Rec/VF

NTEM v7.0 Trip Purpose		NTMv2R Trip Purpose	
8	HB Holiday/Day trip	6	HB Hols
11	NHB Work	8	NHB Other
12	NHB Employers Business	7	NHB EB
13	NHB Education	8	NHB Other
14	NHB Shopping	8	NHB Other
15	NHB Personal Business	8	NHB Other
16	NHB Recreation/Social	8	NHB Other
18	NHB Holiday/Day trip	8	NHB Other

Traveller types

The demand segmentation in NTMv2R is derived primarily from the NTEM v7.0 data set. The segmentation adopted varies by trip purpose to retain/introduce additional segmentation related to employment for commuting and business trips.

The 88 traveller types in NTEM v7.0 are made up of a combination of 8 household types and 11 person types. These map onto 5 household types and 4 person types in NTMv2R. For convenience, household types and person types are shown separately in the tables below, rather than listing out the 88 traveller types in full.

The correspondence between NTEM v7.0 household types and NTMv2R household types is shown in Table 26.

Table 26 Household type correspondence

NTEM v7.0 Household Type		NTMv2R Household Type	
1	1 adult household with no car	1	1-Ad/0-Car
2	1 adult household with one or more cars	2	1-Ad/1+Car
3	2 adult household with no car	3	2+Ad/0-Car
4	2 adult household with two or more cars	4	2+Ad/1-Car
5	2 adult household with two or more cars	5	2+Ad/2+Car
6	3+ adult household with no car	3	2+Ad/0-Car
7	3+ adult household with one car	4	2+Ad/1-Car
8	3+ adult household with two or more cars	5	2+Ad/2+Car

The correspondence between NTEM v7.0 person types and NTMv2R person types is shown in Table 27.

Table 27 Person type correspondence

NTEM v7.0 Person Type		NTMv2R Person Type	
1	Children (0–15)	1	Child (0–15)
2	Males in full time employment (16–74)	2	Full-time emp

NTEM v7.0 Person Type		NTMv2R Person Type	
3	Males in part time employment (16–74)	3	Other 16–74[23]
4	Male students (16–74)	3	Other 16–74
5	Male not employed/students (16–74)	3	Other 16–74
6	Male 75+	4	Pensioner
7	Females in full time employment (16–74)	2	Full time emp
8	Females in part time employment (16–74)	3	Other 16–74
9	Female students (16–74)	3	Other 16–74
10	Female not employed/students (16–74)	3	Other 16–74
11	Female 75+	4	Pensioner

NTMv2R does not include every combination of trip purpose, household type and person type (160 possible combinations). However, it does include some income segmentation for HB work (full-time employed persons), HB employer's business (full-time employed persons) and NHB employer's business (all persons), which is applied to the output NTEM v7.0 data as a separate process (since income information is not available in the NTEM v7.0 data set). The resulting 105 modelled combinations in NTMv2R are set out in Table 28.

Table 28 NTMv2R demand model segments

			Household Type					
Purpose	Person Type	SEG / Income	1 adult / 0 car (1)	1 adult / 1+ car (2)	2+ adult / 0 car (3)	2+ adult / 1 car (4)	2+ adult / 2+ car (5)	All
HB Work (1)	Full-time employed (2)	High	1	2	3	4	5	
		Medium	6	7	8	9	10	
		Low	11	12	13	14	15	
	Rest of population	All	16	17	18	19	20	
HB EB (2)	Full-time employed (2)	High	21	22	23	24	25	
		Medium	26	27	28	29	30	
		Low	31	32	33	34	35	
	Rest of population	All	36	37	38	39	40	
HB Education (3)	Child (0–15) (1)	All	41	42	43	44	45	
	Full-time employed (2)	All	46	47	48	49	50	
	Other 16–74 (3)	All	51	52	53	54	55	
	Pensioner (4)	All	56	57	58	59	60	
HB PB/ Shopping (4)	Child (0–15) (1)	All	61	62	63	64	65	
	Full-time employed (2)	All	66	67	68	69	70	

[23] In NTMv2 this age range was 16–64 but in NTMv2R it has been updated to 16–74 in line with the 2011 census and derived data.

			Household Type					
Purpose	Person Type	SEG / Income	1 adult / 0 car (1)	1 adult / 1+ car (2)	2+ adult / 0 car (3)	2+ adult / 1 car (4)	2+ adult / 2+ car (5)	All
	Other 16–74 (3)	All	71	72	73	74	75	
	Pensioner (4)	All	76	77	78	79	80	
HB Rec/ Visiting friends (5)	Child (0–15) (1)	All	81	82	83	84	85	
	Full-time employed (2)	All	86	87	88	89	90	
	Other 16–74 (3)	All	91	92	93	94	95	
	Pensioner (4)	All	96	97	98	99	100	
HB Hols/Day trips (6)	All persons	All						101
NHB EB (7)	All persons	High						102
		Medium						103
		Low						104
NHBO (8)	All persons	All						105

Distance bands

There are 13 DBs defined in NTMv2R (unchanged). A fixed travel distance is assumed for each distance band modelled – note these distances are in miles consistent with NTS. These are an input assumption to the model and have not been changed between NTMv2 and NTMv2R. The assumed distances of travel are shown in Table 29.

Table 29 Assumed distances by distance band

Distband	Distance	Average Length (miles)
1	< 1 mile	0.5
2	1–2 miles	1.5
3	2–3 miles	2.5
4	3–5 miles	4
5	5–10 miles	7.5
6	10–15 miles	12.5
7	15–25 miles	20
8	25–35 miles	30
9	35–50 miles	42.5
10	50–100 miles	75
11	100–200 miles	150
12	200–300 miles	250
13	300 miles and above	350

Modes

There are six modes of travel defined in the NTMv2R demand model. The definitions of these modes are identical to the modes defined in NTEM v7.0. The relationship to the NTS mode definitions is shown in Table 30.

Table 30 NTMv2R (and NTEM) modes and source definitions

NTMv2R and NTEM v7.0 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 Motor cycle/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, metro, etc.) Domestic air

Time period

A single time period is used throughout the demand model. The time period covered is an average day. The total weekly trip end demand is taken from NTEM v7.0 and divided by 7 to give the demand for an average day.

Appendix B Model parameters

Table 31 and Table 32 report the calibrated model parameters for NTMv2R – for our best mode Run62.

Table 31 λ_D and λ_A varying by distance bands and purposes[24]

	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

[24] λ_D is distance band choice parameter and varies by purposes while λ_A does vary by distance bands.

Table 32 λ_M varying by distance bands and purposes[25]

	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

[25] 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.

Appendix C Quality assurance checks

In addition to the standard RAND Europe peer review procedure of a full review of the report by an expert who has not been involved in the project (Charlene Rohr for this report), we have followed the quality assurance checks highlighted in the OSQA of OS2.6. Table 33 below provides a summary of what has been done by way of quality assurance for the model recalibration task. The first two columns contain explanations of the potential risks, as taken from the OSQA, and the third column provides a brief explanation of what is done to mitigate or avoid these.

Table 33 Quality assurance checks

Risks	Task description	Description of what is done
Appropriate use of data	Evidence of review of sample sizes and treatment of small samples	NTS sample sizes were comprehensively reviewed and suggestions provided to deal with small sample sizes. The acceptance criteria highlighted in Section 3.4 are the result of the sample size review.
Inappropriate generalised costs input to calibration process	Sense checks to be applied to generalised costs and findings reported, e.g. through comparisons of modelled generalised costs with targets based on midpoint distances of distance bands (set standards)	An automated procedure was developed to generate the necessary inputs for the model calibration process to minimise errors. The calibration process involves amendments to certain parameters (e.g. lambda sensitivity values, guilt factor, etc.) in the following files only (UTT, UTF, ULP and DRD). No changes have been made to other input parameters, e.g. Values of Time, Vehicle Operation Costs, etc. These have been implemented and reviewed by other agencies.
Significant changes to choice parameters from existing model	Updated parameters expected to lie within ranges provided in WebTAG and support implemented model structure Realism test results, overall and by trip purpose, to meet agreed criteria based on WebTAG guidance and more recent evidence	The current calibrated models exceed the specified targets for matching to NTS data and meet all WebTAG requirements for realism tests, specifically: • The fuel price elasticity is -0.32, within the WebTAG range. • The car time elasticity is less than -2 (the value is low, but this is impacted by the car passenger constraint, which has been given priority in the

		calibration, as directed by DfT). • The public transport fare elasticity is within the bounds of WebTAG guidance; the bus elasticity is somewhat higher, but within the level of acceptability given acceptance of previous results by DfT. The output spreadsheets and elasticity tests have been checked by Charlene Rohr and James Fox at RAND Europe.
Consistency of input data for calibration – NTS England for 2013 onwards	Utilise data for England Review impact on results Scotland and Wales not currently separate zones so not possible to review results specific to these areas	Only the NTS data (2006–2014) for England was used, as agreed with DfT.
Large constants required to match observed mode shares by distance band	Scale of modal constants to be monitored (set min and max) to avoid no response for some model segments Quality of results to be measured against targets based on NTS. Two sets of targets will be set: Demand model results within X per cent for matching demand profiles. Alternative specific constants, which account for no more than Y per cent or Y minutes of the generalised cost. X will be derived from the ranges (confidence intervals) associated with the various demand segments in the NTS data. Y will be set based on a review of the range of variation in generalised time components in NTS (e.g. bus constants not more than 30 minutes of IVT).	The model calibrates well against the data before adding the constraints. Also, we avoid large constraints by adding MSCs on both main mode and sub-modes. The suitability of constraints is demonstrated in this model by both the good match to the NTS data and appropriate responses against realism tests.