

AtkinsRéalis



BSTM2 Variable Demand Model (VDM) Development and Validation Report

Buckinghamshire Council

12 June 2026

BUCKINGHAMSHIRE STRATEGIC TRANSPORT MODEL 2

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Abbreviations

ABD	AddressBase Data
AMAI	Absolute Model Applied Incrementally
AMR	Annual Monitoring Reports
AoDM	Area of Detailed Modelling
APS	Annual Population Survey
AUC	Assignment User Class
BC	Buckinghamshire Council
BRES	Business Register and Employment Survey
BSTM	Buckinghamshire Strategic Transport Model
CB	Car Employers Business
CC	Car Commute
CO	Car Other
DfT	Department for Transport
Exc	Excluding
FC	Full Car
FH	From-home
FMA	Fully Modelled Area
FT	Full-time (employment)
GJT	Generalised Journey Time
HAM	Highway Assignment Model
HB	Home Based
HBEB	Home Based Employers Business
HBEd	Home Based Education
HL	Home Based Leisure
HBO	Home Based Other
HBPS	Home Based Shopping & Personal Business
HBW	Home Based Work
HGV	Heavy Goods Vehicle
IB	Inbound
ICA	Intersection Capacity Analysis
Inc	Including
IP	Interpeak
JTW	Journey-to-work

LAD	Local Authority Districts
LGV	Light Goods Vehicle
LSOA	Lower Super Output Area (Census geography)
MDVR	Model Development and Validation Report
ME	Matrix estimation
MSOA	Middle Super Output Area (Census geography)
MYPE	Mid-Year Population Estimates
NB	Northbound
NC	No Car
NHB	Non-Home Based
NHBEB	Non Home-Based Employers Business
NHBO	Non-Home Based Other
NTEM	National Trip End Model
NTS	National Travel Survey
OA	Census Output Area
OB	Outbound
O-D	Origin-Destination
OGV	Other Goods Vehicle
ONS	Office for National Statistics
ORR	Office of Rail Regulation
P/A	Production-Attraction
PC	Part Car
P&R	Park & Ride
PCU	Passenger Car Unit
PJT	Perceived Journey Time
PRPT	Public Transport Model
PrT	Private Transport
PT	Part-time (employment)
PuT/PT	Public Transport
RoFMA	Rest of the Fully Modelled Area
RD	Residential Dwelling
SEALR	South East Aylesbury Link Road
SDT	Short Distance Trips (those < 2 miles)
TAG	Transport Analysis Guidance
TfL	Transport for London
TH	To-home

TLD	Trip length distribution
TOD	Time of day
VDF	Volume/Delay Function
VDM	Variable Demand Model
VOC	Vehicle Operating Cost
VoT	Value of Time
WfH	Working from Home

1. Introduction

1.1 Purpose of this report

AtkinsRéalis, the framework consultants to Buckinghamshire Council (BC), has been commissioned to undertake the upgrade of the Buckinghamshire Strategic Transport Model (BSTM) which was developed by Jacobs in 2021. The new version of the model is the BSTM2, and it utilises the PTV VISUM 2021 software suite.

The BSTM is a highway assignment model (HAM) with fixed demand adopting the base year 2019. It was built following the Department for Transport's (DfT) Transport Analysis Guidance (TAG) but does not fully comply with its requirements for link validation, screenlines or journey times with enhancements needed in several key urban areas. In addition, the BSTM doesn't have components of public transport modelling and variable demand modelling.

Following the review of the BSTM by AtkinsRéalis, the below list of improvements was suggested:

- The addition of variable demand modelling (VDM);
- The addition of public transport elements; and
- The enhancement of the model validation in selected urban areas (Aylesbury, High Wycombe, Marlow, Bourne End and Buckingham).

The purpose of the model update is to develop a new version of the BSTM that better meets the relevant TAG standards in the above-mentioned urban areas and includes the provision of a VDM component.

Similar to the BSTM, the BSTM2 retains a 2019 base year and extends across the Buckinghamshire boundary, capturing movements on the unitary authority borders in areas including Milton Keynes, Bicester, Slough, and West Drayton. In order to better reflect traffic movements across and within key areas of Buckinghamshire, the coding of highway network and zoning elements has been enhanced in the BSTM2 specifically in Aylesbury, High Wycombe, Marlow, Bourne End and Buckingham. In addition, local model recalibration was undertaken in the above-mentioned areas to achieve better compliance to TAG for all highway counts, screenlines and journey time routes. Further information about the BSTM2 calibration and validation can be found in BSTM2 HAM Model Development and Validation Report.

In addition to the highway assignment element, the BSTM2 includes a proxy representation of a public transport model (PRPT) using fixed skim attribute matrices derived from TRACC¹ and a VDM component that enables more realistic estimation of demand responses to proposed schemes and developments in Buckinghamshire. A key shortcoming with PRPT is that only global parameters of public transport can be altered and tested (e.g., fares) while specific network attributes at a service or corridor level are fixed and assumed to be 'broadly' the same between a base case and a test scenario.

¹ TRACC is a travel time analysis tool developed by BaseMap which produces travel time catchments and contours for a range of travel modes. It can be used to analyse the effectiveness of proposed schemes and interventions, particularly with regards to those involving active Modes and PT where the location of walk/cycle routes and bus stops may be important.

The primary uses of BSTM2 will be testing the impact of:

- Highway network interventions.
- Changes in global factors affecting public transport services.
- New development proposals.
- Transport strategies.
- Growth resulting from the development of the Local Plan.

The HAM Model Development and Validation Report (HAM MDVR), which outlines the updates specific to the HAM, was originally submitted to BC on 23rd August 2024. This document serves as the VDM and PRPT report for BSTM2, providing a comprehensive description of the 2019 base model, the VDM and PRPT development process, and an overall verification presentation.

1.2 Report Structure

Following this introduction, the report is structured as follows:

- Chapter 2 - outlines the model's key features and elements.
- Chapter 3 - describes the guidelines and standards followed for developing the model.
- Chapter 4 - presents all the land use and travel demand inputs in the model.
- Chapter 5 - explains the land use and trip end calculations.
- Chapter 6 - defines the variable demand model structure, specifications, covering cost formulations and choice models.
- Chapter 7 - explains the demand model calibration process, ensuring the close replication of the demand distribution across different modes.
- Chapter 8 - this chapter presents the model's response to the different realism tests.
- Chapter 9 - concludes the summary and key findings.

2. Overview of Model Key Features

2.1 Modelling software

The BSTM2 is an integrated multi-modal model that integrates two transport model components as follows:

- A Variable Demand Model (VDM)
- A Highway Assignment Model (HAM)

The BSTM2 VDM has been developed using PTV VISUM (Version 21) transport modelling suite. PTV VISUM is a proprietary software suite able to encompass strategic transport modelling at a regional level. PTV VISUM is an industry respected modelling tool used widely for the assessment of forecast demand changes and infrastructure schemes and can provide robust analysis of small to large infrastructure developments.

The VDM interaction with the HAM was also developed in PTV VISUM (Version 21). While the HAM can operate independently from the VDM, in integrated running mode, it receives transport demand growth from the VDM and subsequently provides updated highway transport characteristics (skims) back to the VDM at each model iteration.

2.2 The integrated model structure

The design and structure of the model is intended to remain as close as practical to a conventional TAG design for a four-stage transport demand and assignment model.

The basic structure and principles of the model are summarised as follows:

- **Person trip ends:** In the base year model, trip productions and attractions by zone are calculated, separately by trip purpose and person type as detailed in sections 2.8.2 to 2.8.3. These trip ends are used as the basis for any model scenario tests, with changes input either as multiplicative growth or additive changes. The trip ends, and all the demand modelling, is carried out for a 24-hour neutral weekday.
- **Demand model (VDM):** A logit based variable demand model (VDM) is used to determine personal choices of travel mode and destination. These choices are informed by the generalised cost for each possible journey, calculated based on journey time, distance and money costs.
- **VDM/assignment interface:** The personal travel information calculated by the VDM is converted into highway vehicle trips by time period and used to apply changes to the base year assignment matrices for Car.
- **Freight and external matrices:** The highway assignment matrices include matrices of freight origin-destination trips in the base year. Forecast growth or other changes in freight trips is determined externally and applied within the model.
- **Assignment models (HAM):** Network assignment is carried out for highway to determine routeing and links flows, and to extract highway costs (distance, time and any toll charges) for O-D zone pairs by time period (AM, IP and PM).
- **Public Transport (PT) mode costs:** PT times are skimmed from TRACC separately for bus and rail. The fare skims for each OD pair are derived separately for bus and rail using a distance-based fare model developed based on sample routes.
- **Active mode costs:** Disutility for walk and cycle is based on travel distances, taken as the minimum between the unassigned highway distance and bus distance from TRACC. Where appropriate, localised estimates of distance can be adjusted to account for walking short-cuts and cycle paths. A fixed speed of walking and cycling is assumed.

- **Behaviour assumptions and economic assumptions:** These can be altered during scenario tests to assess their impact, such as changes in fuel costs or values of time.
- **Model iteration:** For scenario testing the model includes a supply-demand loop which allows for iteration of VDM choices and highway congestion levels.

It is noted that it is possible to use the HAM and VDM components independently from each other, for example to carry out fixed-demand assessments of infrastructure and service options.

2.2.1 Travel demand linkages

The travel demand in the model is, at the highest level, derived via trip rates applied to the zones land use, serving as an input to the VDM. The VDM and assignment models operate with different forms of demand: the VDM having what is termed a 'synthetic 24-hour person matrix of productions and attractions', while the HAM requires separate trip matrices by time period on an origin-destination basis measured in vehicle trips not persons. To link these, the 'VDM and HAM assignment model' interface involves several data transformations carried out as part of a model run. These include:

- Transforming the 24-hour production-attraction person trips output by the VDM into matrices of origin–destination personal trips for the morning, inter-peak and evening peak periods represented in the assignment model.
- Conversion of VDM person car trips to vehicle trips using occupancy factors.
- Mapping of the VDM travel demand segments into assignment user classes.
- A 'pivot' process to adjust the base year assignment matrices based on forecast changes in personal trips from the VDM.
- Road freight and car movements originating and destinating outside Buckinghamshire, calculated outside the main model, are added to the pivoted vehicle matrices before highway assignment.

2.2.2 Supply cost and networks

The highway network is integrated with the VDM model, where the highway skims generated after highway assignments are directly used to calculate generalised costs. For active travel modes, the minimum of the bus and car distance skims are used, as mentioned in section 2.2. Time period-specific skims from the HAM and PRPT, which include journey attributes such as journey time, distance, interchanges, and fares, are provided to the VDM. The VDM then processes this information to calculate generalised costs.

2.2.3 Forecasting functionality

For forecasting and iterative realism tests, the VDM and the HAM interact in iterative process allowing the congestion impact of changes in vehicle flows to feed back into the VDM. The supply/demand loop iterates to convergence with the HAM being re-run at each supply/demand iteration.

A pivoting process is used in any scenario test where changes from the VDM are to be applied in the assignment model. At the simplest level, the pivoting process uses percentage growth to adjust the base matrices. Formally, this approach is described as an Absolute Model Applied Incrementally (AMAI), as detailed in TAG unit M2.1, section 4.3.

The operation of the model differs for runs used in the base year model set-up and assignment calibration. These runs do not include any iteration between the demand model and the HAM. Fed by costs from a separate and single assignment of the validated base year vehicle matrices, a single pass of the demand model is used to create synthetic base year demand. Therefore, the VDM/HAM interface and feedback are not utilized.

2.3 Model base year

The BSTM2 has been built for a base year of 2019 like BSTM, which means that all model inputs are developed based on this year, including calibration of the highway assignment models. The decision to use 2019 is based on the availability of data for the pre-COVID period and the insufficiency of post-COVID data.

2.4 Model coverage, zoning and sector system

2.4.1 Model coverage

In determining the geographic coverage of the model, it is usual to consider a detailed inner area in which all transport behaviours are modelled, and outer area(s) in which there is progressively less detail, and few transport responses are represented. For the HAM, TAG unit M3.1 states that the geographic coverage generally needs to:

- Allow for strategic re-routing impacts of interventions;
- Ensure that areas outside the main area of interest, which are potential alternative destinations, are properly represented; and
- Ensure that the full lengths of trips are represented for the purpose of deriving costs.

From the Demand Model element, TAG unit M2.1 (section 2.4) advises that the model is divided into an internal area, in which all travel demand is modelled, and an external area, in which only trips to/from the internal area are considered.

Table 2-1 gives details of the model functionality by area type, and Figure 2-1 to Figure 2-2 show the extent of the Area of Detailed Modelling (AoDM) and Fully Modelled Area (FMA). The network density in Bulge Areas lying just on the edge of the Buckinghamshire unitary authority boundary is higher compared to Rest of Fully Modelled Area (RoFMA), enabling the movements to and from these areas into Buckinghamshire to be more accurately reflected.

Table 2-1 - Geographical coverage and model functionality by area type

Area Type	Areas Covered	HAM
Internal: Area of Detailed Modelling	Within the Buckinghamshire unitary authority boundary	This is the area over which significant impacts of interventions are certain and the modelling detail in this area would be characterised by: representation of all trip movements; small zones; very detailed networks; and junction modelling using Intersection Capacity Analysis (ICA);
Bulge Area	Milton Keynes, Bicester, Slough, West Drayton	Areas that lie on edge of AoDM and have higher network density than compared to RoFMA. The characteristics of network elements are same as RoFMA.
Rest of Fully Modelled Area	Outside and nearby the Buckinghamshire unitary authority boundary (average distance 20 km)	Area over which the impacts of interventions are considered to be quite likely, but relatively weak in magnitude and would be characterised by: representation of all trip movements; somewhat larger zones and less network detail than for the Area of Detailed Modelling; the traffic delay calculation is only based on volume delay function (VDF) at links;

Area Type	Areas Covered	HAM
Wider External Area	Rest of Country	Area where impacts of interventions would be so small as to be reasonably assumed to be negligible and would be characterised by a buffer network representing a large proportion of the rest of Great Britain, a partial representation of demand (trips to, from and across the Fully Modelled Area); large zones; skeletal networks and fixed speed modelling.

Figure 2-1 – BSTM2 Area of Detailed Modelling

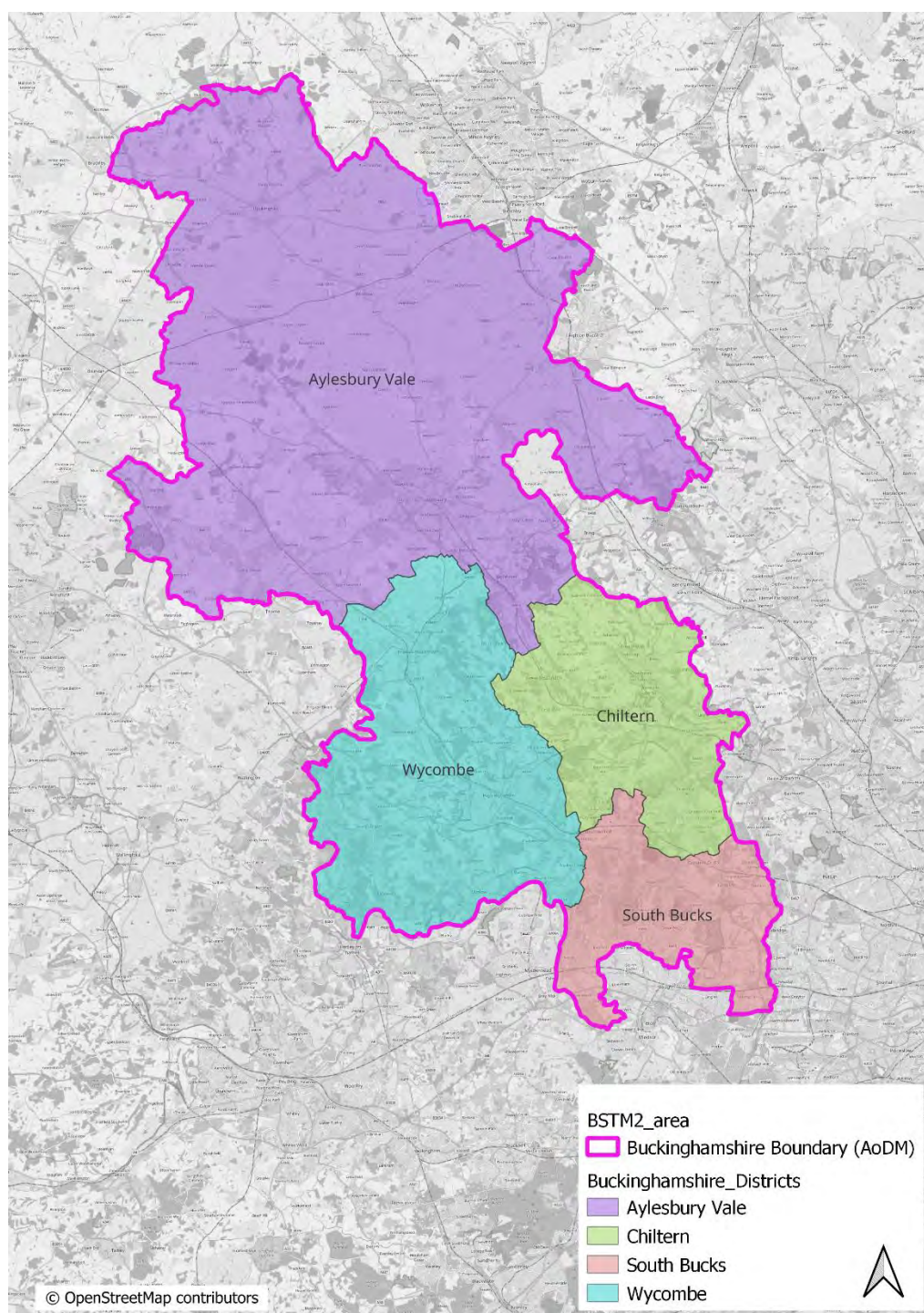
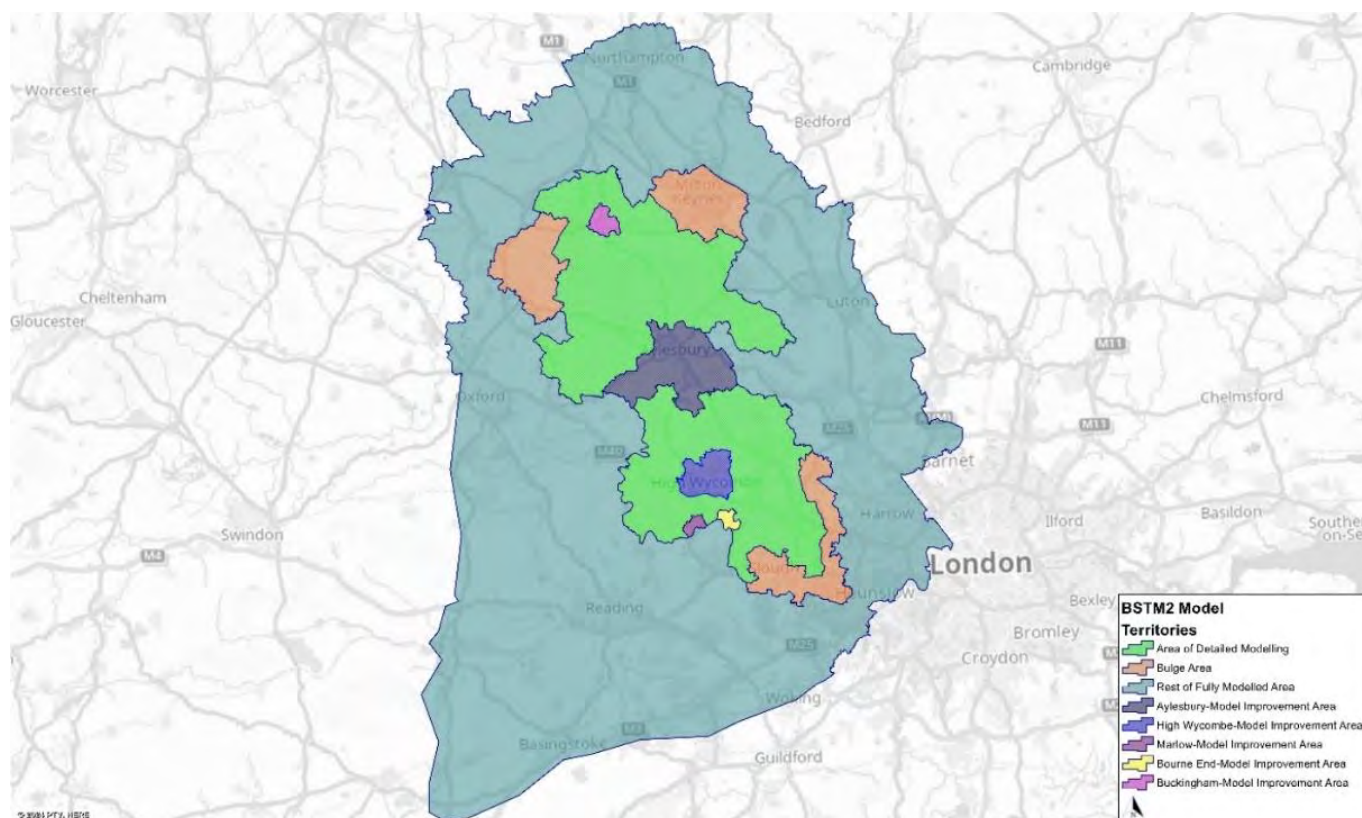


Figure 2-2 – BSTM2 Fully Modelled Area



2.4.2 Zoning system

The BSTM2 adopts the existing BSTM traffic zoning system for the FMA except for Aylesbury where the South East Aylesbury Link Road (SEALR) model provides more granular zoning. BSTM2 zones for Aylesbury have been taken from the SEALR model where trips were distributed as in SEALR but constrained to the BSTM demand. In addition, within the AoDM, 10 zones were split to generate 8 new zones representing park and ride(P&R) sites near to train or bus station to be used in modelling the Bus and Rail Park and Ride modes.

The BSTM2 zoning system is consistent across the HAM, PRPT, and VDM elements of the model. The zoning system of BSTM2 constitutes a total of 1050 zones divided into the model area types as shown in Table 2-2 and Figure 2-3 to Figure 2-5.

The zoning system includes 138 vacant zones which act as placeholders for future year developments. These are empty in the base year model, and not geographically assigned so that they can be located where needed.

Table 2-2 - BSTM2 zoning system

Model Area	Number of zones
Area of Detailed Modelling	738
Bulge Areas	28
Rest of Fully Modelled Area	84
External	62
Vacant Zones for Future Developments	138
Total	1050

Figure 2-3 – BSTM2 Model Zoning System- AoDM

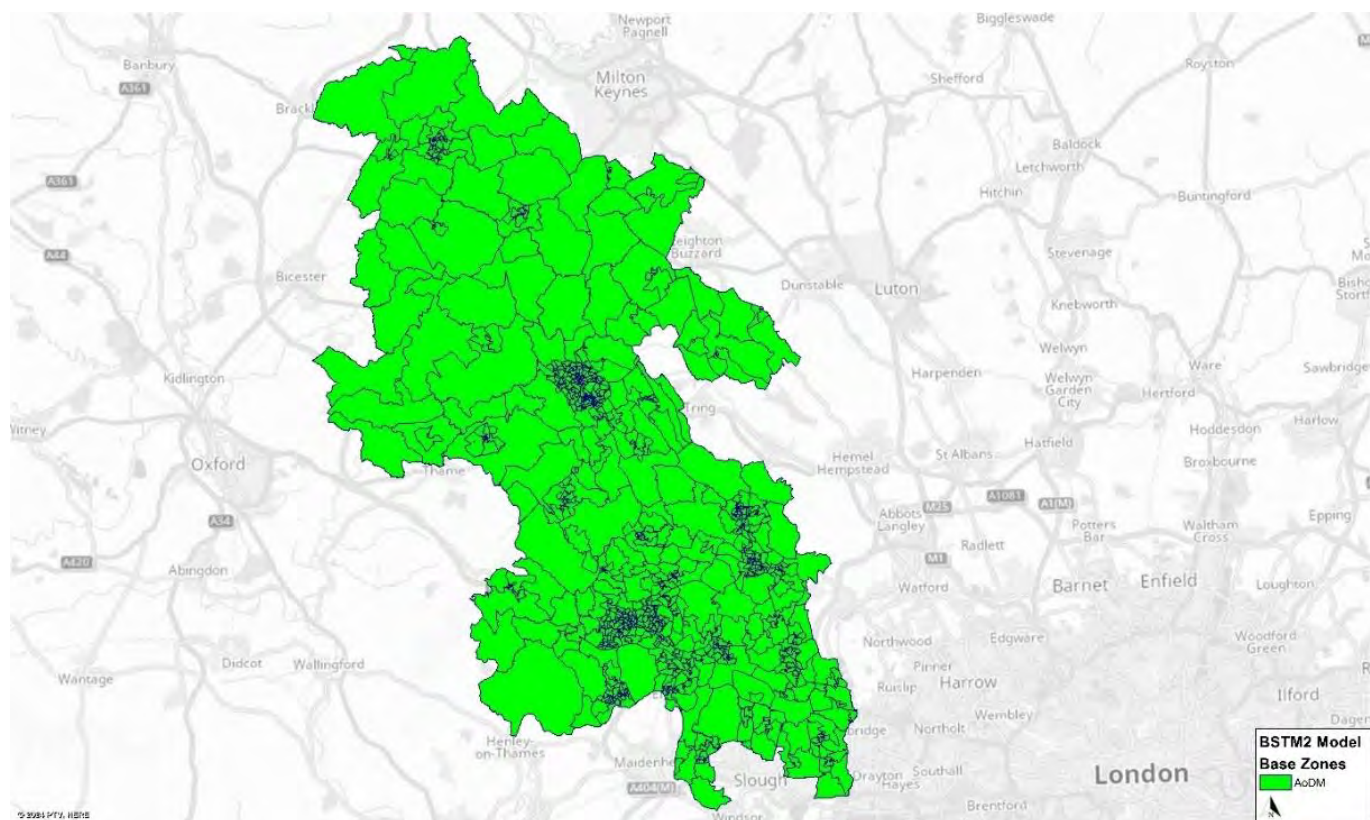


Figure 2-4 – BSTM2 Model Zoning System - FMA

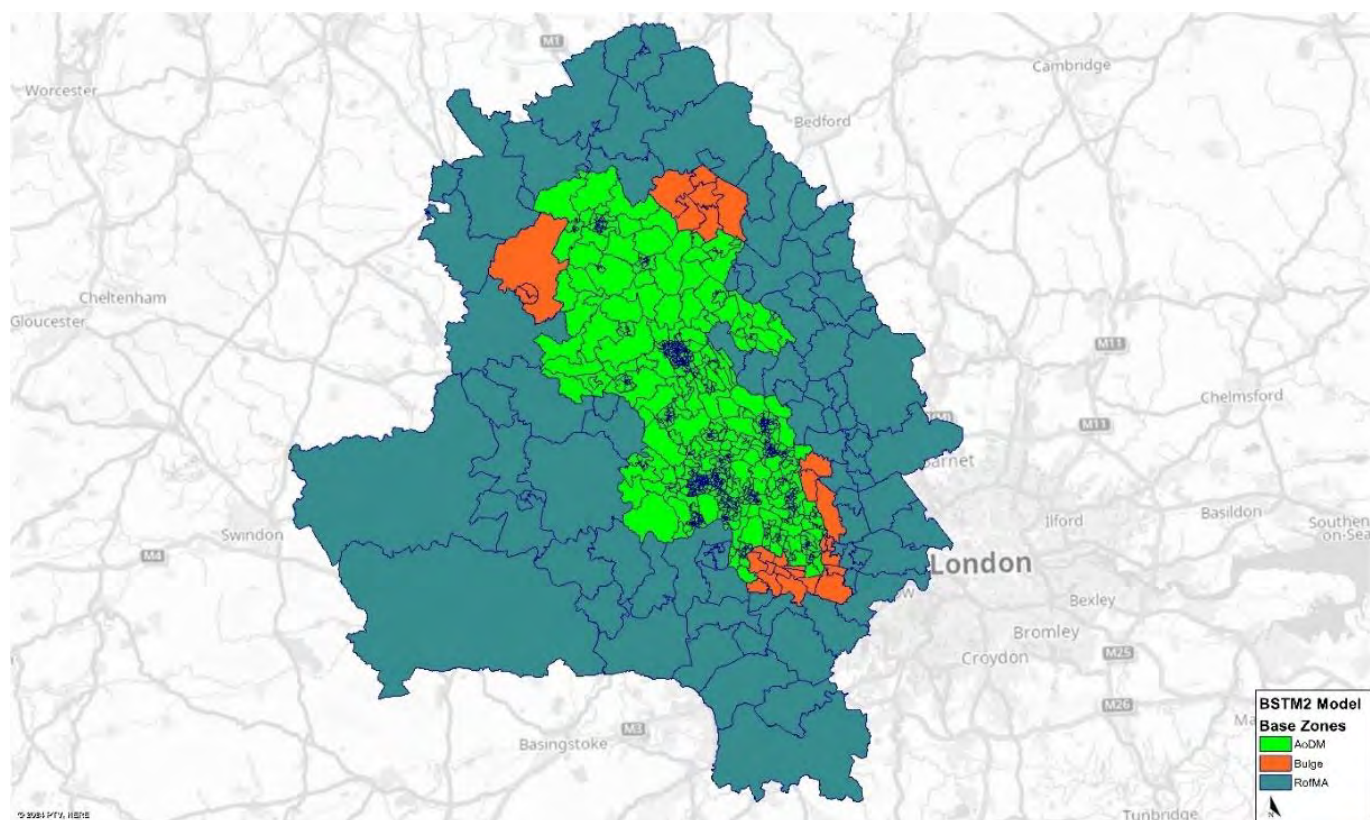
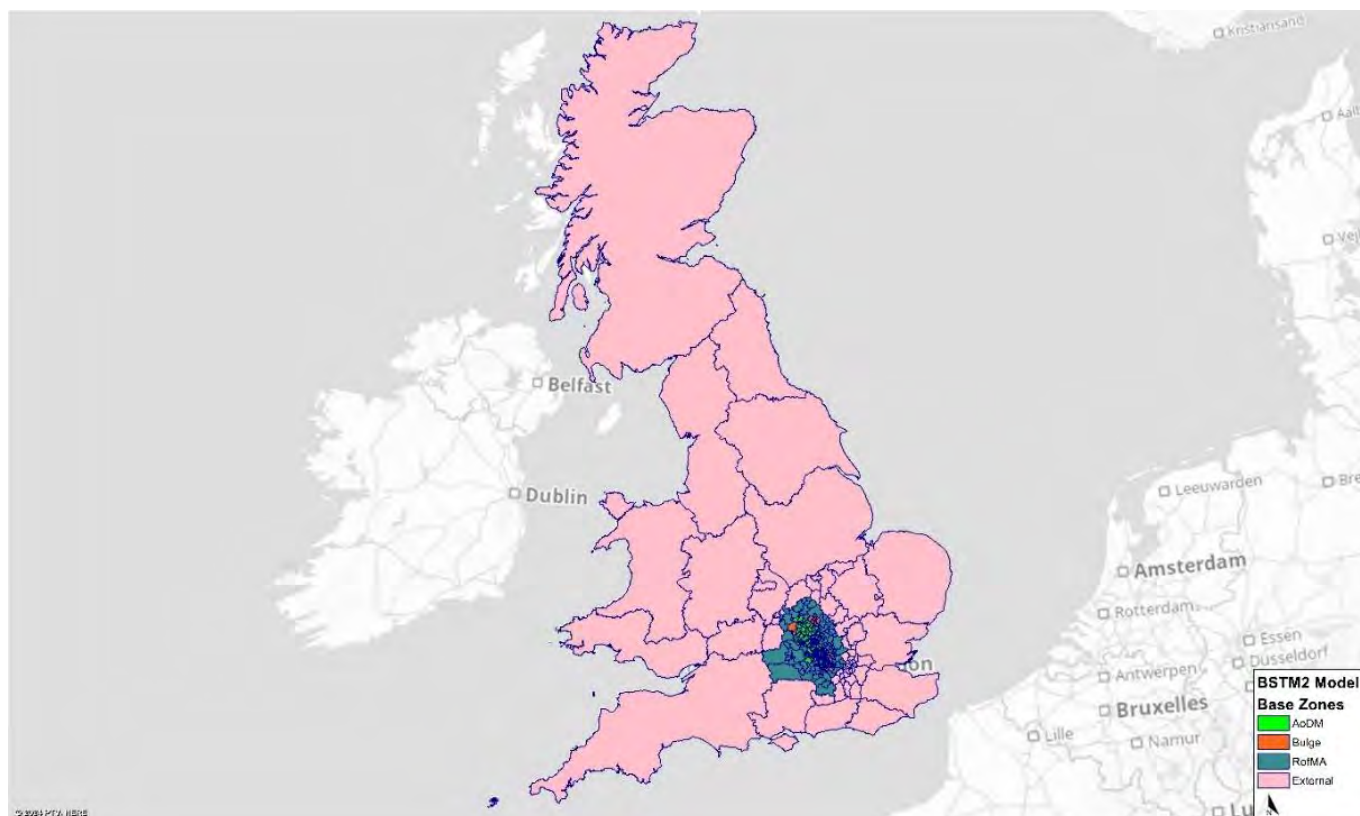


Figure 2-5 – BSTM2 Model Zoning System



2.4.3 Sector system

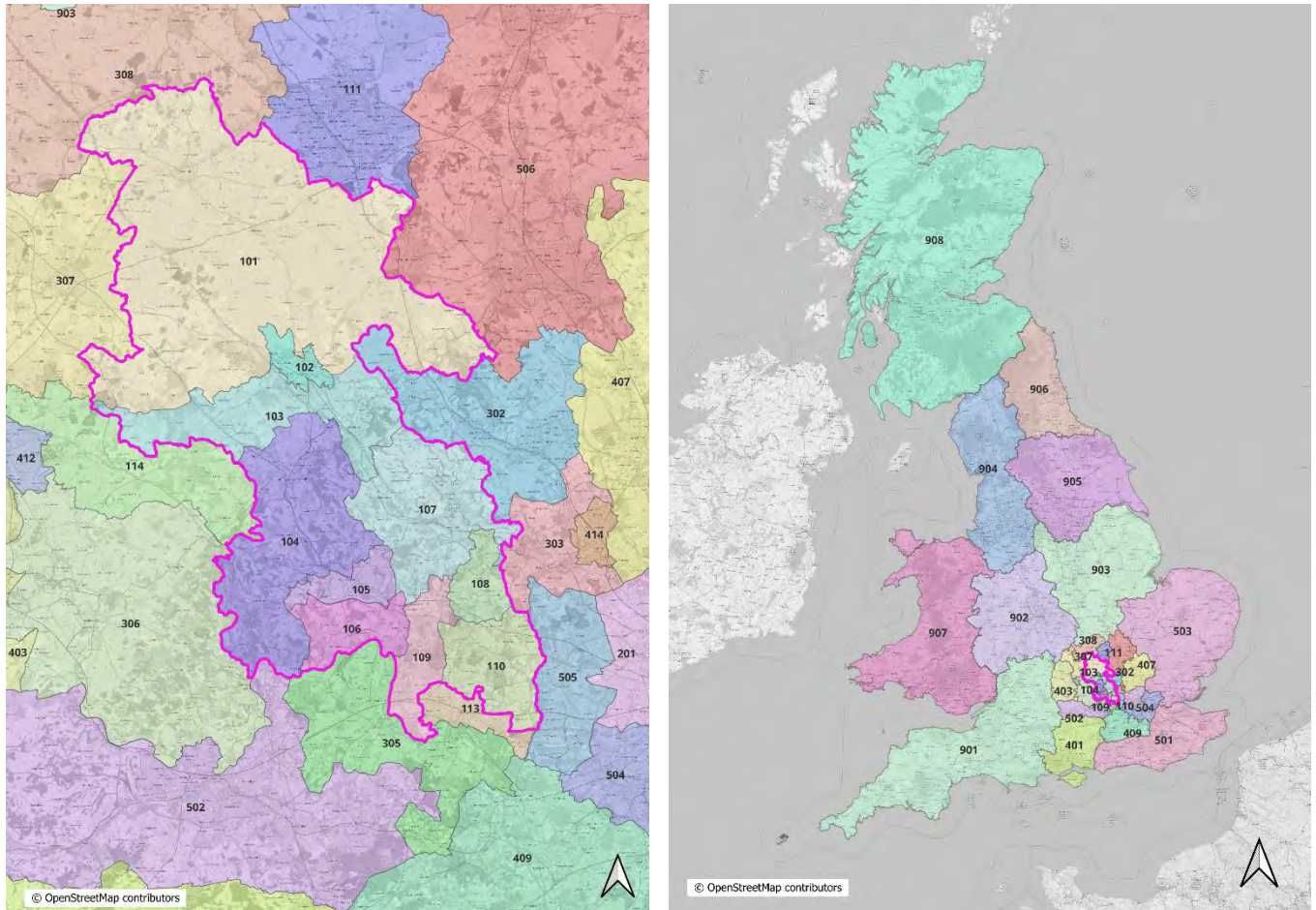
The 1050 zones are aggregated to form 40 sectors, out of which the first 10 sectors in the Table 2-3 are internal and 111 to 908 are the external sectors. The below Figure 2-6 shows the 40-sectoring system used in the BSTM2 VDM model.

Table 2-3 - Summary of BSTM2 Sector Systems

Sector No.	Sector Name	No. of Zones	Sector No.	Sector Name	No. of Zones
101	Aylesbury North	94	401	Hampshire	1
102	Aylesbury Central	91	403	Oxfordshire	2
103	Aylesbury South	71	407	Hertfordshire	7
104	Wycombe North-West	63	409	Surrey	11
105	Wycombe Central and East	123	412	Oxford	1
106	Wycombe South	64	414	Watford	2
107	Chiltern North	104	501	West Sussex and Kent	3
108	Chiltern South	34	502	Berkshire	6
109	South Bucks West	44	503	Cambridgeshire, Essex and East of England	4
110	South Bucks East	50	504	East and South-West London	10

Sector No.	Sector Name	No. of Zones	Sector No.	Sector Name	No. of Zones
111	Milton Keynes	8	505	Hillingdon South and Uxbridge	12
113	Slough	8	506	Bedfordshire and Bedford	15
114	Bicester	3	901	Southwest	2
201	Central and Northwest London	15	902	West Midlands	3
302	Dacorum	9	903	East Midlands	6
303	Three Rivers	7	904	Northwest	1
305	Windsor and Maidenhead	10	905	Yorkshire and The Humber	1
306	South Oxfordshire	5	906	Northeast	1
307	Cherwell	8	907	Wales	2
308	Northamptonshire	10	908	Scotland	1

Figure 2-6 – BSTM2 Sector System



2.5 Travel choices and hierarchy

The model assumes a TAG 'default' hierarchy, with the main mode choice being less sensitive (higher in choice hierarchy) than destination choice for all trip purposes. No estimation or experimentation with choice hierarchies was undertaken.

The travel choices included are as follows, and are considered in the order shown:

1. Main mode choice (private car, public transport, walk and cycle trips determined in VDM);
2. Destination choice (VDM);
3. Sub-mode choice (bus, rail, bus park & ride and rail park & ride determined in VDM);
4. Route choice (assignment in HAM).

The main mode, destination and sub-mode choices are determined in the VDM. The HAM considers route choice for private vehicle and road freight trips. Car legs of P&R trips are assigned in the HAM. It is noted that the VDM and HAM iterate so that road congestion impacts following highway assignment are fed back to the top of the choice hierarchy in the next loop of the VDM. The choice hierarchy is shown in more detail in section 6.3.

2.5.1 Choices not included

The model does not consider variations in trip frequency, which are considered less relevant where short trips and particularly active modes are considered. However, manual manipulation of trip rates is possible during policy tests. The model does not include choice of time of travel, whether between time periods (e.g., switching between AM and inter-peak period travel) or micro time period choices (e.g., switching between a trip at 8-9am or 9-10am). Instead, fixed out and return trip factors are applied as described in section 2.7 which vary by travel purpose and mode.

2.6 Travel modes

The VDM represents a full range of private, public and active travel modes. A 'main mode' choice divides trips first between private car, public transport, walk and cycle trips. These four main modes represent very different trip lengths and characteristics and separating them initially improves the next step of destination choice.

The model includes sub-mode choice covering bus, rail, bus park & ride and rail park & ride. The main mode and sub-mode choice are determined explicitly within the VDM, determining a 'dominant mode' for each O-D trip as input to the assignment models.

The model considers the most common set of mode choices for journeys, tailored to the travel trends and policy choices faced by Buckinghamshire. However, there are some travel combinations explicitly excluded or only implicitly included. These include:

- Return journeys where the outward and return legs use radically different modes, e.g., walk or bus in the morning, and then train home.
- Kiss & Ride is considered part of Park & Ride, with the onward journey by the driver not explicitly considered, due to a lack of data.
- Cycle to Bus and Cycle to Bus P&R sites are not included due to lack of observed data.

The base year model does not include any 'new modes' such as e-Bikes, autonomous vehicles or mobility as a service. However, it is anticipated that these can be added within the model should the need arise for forecast scenarios, and suitable definitions of the travel modes and their characteristics become available.

2.7 Time periods

As discussed in section 2.3, the model represents a 24-hour neutral weekday in 2019. The VDM considers choices at the 24-hour level. The HAM is divided into AM peak, inter-peak (IP) and PM peak models, representing the conditions during those time periods, based on differences in travel demand, road congestion and service schedules. Table 2-4 illustrates the out and return time period combinations which are considered in the model. The VDM produces 24-hour P/A which for home-based trips implicitly include all trips which travel out and back in a single 24-hour period. Hence any combination of trip travelling from home in the morning pre-peak period (midnight until the start of the AM period) and returning during a later period is included. This would include trips entirely within the pre-peak or post-peak periods known as off-peak (OP).

The assignment model includes only trip legs in the AM, IP or PM periods, which include return legs in those periods for journeys starting in the pre-peak, and outward legs of journeys ending in the post-peak.

Trips returning in a different 24-hour period to those in which they begin are included in non-home-based trips, i.e., the outbound and return legs are treated separately, and the non-home-based trip rates implicitly include them.

Table 2-4 - Out and return time periods in VDM and Assignment models (home-based trips)

		Return time-period (same day)					Key
		Pre-peak	AM	IP	PM	Post-peak	
Outward Period	Pre-peak						VDM and Assignment
	AM						VDM only
	IP						
	PM						
	Post-peak						

2.8 Demand segmentation

2.8.1 Overview

Travel demand segmentation is used within the model to represent differences in travel behaviour by trip purpose and type of traveller. This is helpful both for representing travel choices, and to allow for forecasting different rates of future growth for different traveller types and trip purposes.

The travel demand is segmented in the Person Trip Ends module and VDM by trip purpose and traveller type (termed 'demand strata' in VISUM). These demand strata are grouped into assignment user classes (AUCs) which are used in the HAM to represent differences in routeing choices. The sections below discuss the segmentation at each stage and the relationship between them.

2.8.2 Trip purposes

TAG unit M2.1, Table 1 states that there should be at least three categories of trip purpose (commuting, employer's business and other) as *"these categories are likely to have different elasticities and different distributions in both time and space, and substantially different values of time"*.

The Person Trip Ends and VDM segmentation is based on DfT's NTEM (National Trip End Model) v8.1 and hence the trip purpose definitions are aggregations of those within NTEM. NTEM includes eight home-based (HB) and seven non-home-based purposes (NHB) as set out in Table 2-5 below.

Table 2-5 - NTEM and BSTM2 trip purposes.

NTEM Home-based (HB) Purpose	NTEM non-home based (NHB) Purpose	BSTM2 Home-based (HB) Purpose	BSTM2 non-home based (NHB) Purpose
HB Work	NHB Work	HB Work (HBW)	NHB Others (NHBO)
HB Employer's Business	NHB Employer's Business	HB Employer's Business (HBEB)	NHB Employer's Business (NHBEB)
HB Education	NHB Education	HB Education (HBEd)	NHB Others (NHBO)
HB Shopping	NHB Shopping	HB Personal Business and Shopping (HBPS)	
HB Personal Business	NHB Personal Business		
HB Recreation / Social	NHB Recreation / Social	HB Leisure (HBL)	
HB Visiting friends & relatives			
HB Holiday / Day trip	NHB Holiday / Day trip		

The model combines the following trip purposes from NTEM:

- HB Shopping and HB Personal Business.
- HB Recreation / Social, HB Visiting friends & relatives and HB Holiday / Day Trip; and
- NHB Work, NHB Education, NHB Shopping, NHB Personal Business, NHB Recreation / Social and NHB Holiday / Day trip.

2.8.3 Traveller type and demand strata

The segmentation in NTEM consists of a combination of 11 person types based on gender, age and employment status as shown in Table 2-6; and eight household types, based on household size and number of cars available. These combine to provide 88 combinations of person and household types, which are termed traveller types.

Table 2-6 - NTEM population segmentation

Gender	Age	Employment status (16-74 age groups only)
Male	0 – 15 years	Full time (≥ 30 hours per week)
	16- 74 years	Part time (<30 hours per week)
Female	75+ years	Students (not working)
		Other non-working

For the BSTM2, the gender segments are removed but other person segments are retained, and education stages based on school education added. Modelling of primary, secondary and sixth form education stages allow trip-making to different school types to be considered individually which has benefits for development planning and distribution modelling to relevant education facilities.

Household types are combined into 3 separate categories denoting car availability as follows:

- No Car (NC): No cars available in the household;
- Part Car (PC): Fewer than one car per adult available in the household; and
- Full Car (FC): One or more cars per adult available in the household.

This led to eight person types and three levels of car availability, and hence 24 traveller types for trip generation in the BSTM2 person trip ends module. However, the VDM only considers valid combinations of traveller type and trip purpose, termed demand strata.

As the number of demand strata defined increases, the run times for the model also increase. To optimize this, education trips have been differentiated to include only school children. Consequently, further academic and vocational education trips are reclassified as HBPS trips in the VDM. This means that the education purpose is exclusively reserved for school related travel in the VDM. Thus, education travel for student segments with 19+ age groups is considered under HBEd purpose for the trip end calculation and later are added to the HBPS for VDM purposes.

Table 2-7 presents the demand segmentation used in the VDM, and highlights where, for example, children and those aged 75+ who do not make commuting or business trips are not considered due to insignificant trip numbers by definition; and where education trips have been reclassified as shopping and personal business.

Table 2-7 - VDM demand segmentation (for each car availability status)

Traveller types	Trip purpose						
	HBW	HBEB	HBEd	HBPS	HBL	NHBEB	NHBO
Primary (5-11)			✓				
Secondary (12-16)			✓				
Tertiary (17-18)			✓				
Children_0-15	n/a	n/a	(HBPS)	✓	✓	n/a	✓
Student_16-74	n/a	n/a	(HBPS)	✓	✓	n/a	✓
FullTime_16-74	✓	✓	(HBPS)	✓	✓	✓	✓
PartTime_16-74	✓	✓	(HBPS)	✓	✓	✓	✓
Other_16-74	n/a	n/a	(HBPS)	✓	✓	n/a	✓
75+	n/a	n/a	(HBPS)	✓	✓	n/a	✓

n/a – segments not considered as trip numbers small by definition

(PB) – HBEd trips generated by those aged under 5 and over 18 transferred to HBPS and excluded from demand strata for HBEd

The number of demand strata for each purpose are shown in Table 2-8 (note that there are three car availability levels for each entry).

Table 2-8 - Number of demand strata for each trip purpose

Trip Purpose	Description	Demand Strata
HBW	HB Work	6
HBEB	HB Employers Business	6
HBEd	HB Education	9
HBPS	HB Shopping & Personal Business	18
HBL	HB Leisure	18
NHBEB	NHB Employers Business	6
NHBO	NHB Other	18
Total		81



2.8.4 Assignment user classes (AUC)

The highway model segments trips into assignment user classes. For the highway model this follows standard TAG guidance to segment by commuting, business and other trip purposes (denoted by CC, CB and CO respectively).

The correspondence between the demand model trip purposes and the assignment user classes (AUC) for HAM is set out in Table 2-9. The HAM additionally includes AUCs for LGV and HGV vehicle trips.

Table 2-9 - Correspondence between VDM trip purposes and Assignment User Classes

No	Purpose	Code	Highway AUC
1	HB Work	HBW	CC
2	HB Employers Business	HBEB	CB
3	HB Education	HBEd	CO
4	HB Shopping & Personal Business	HBPS	CO
5	HB Leisure	HBL	CO
6	NHB Employers Business	NHBEB	CB
7	NHB Other	NHBO	CO

3. Guidance and Standards

3.1 Overview

The high-level requirements and objectives of the model are stated in Section 1. This chapter defines what guidance, and standards have been used to measure technical quality.

3.1.1 Key documents

The relevant key guidance documents from the Department for Transport Analysis Guidance (TAG), used to inform the approach and standards include:

- TAG unit M1.1 principles of modelling and forecasting.
- TAG unit M1.2 data sources and surveys.
- TAG unit M2.1 variable demand modelling.
- TAG unit M4 forecasting and uncertainty.
- TAG unit M5.1 modelling parking and park-and-ride.

3.2 Calibration

The model outputs are calibrated to ensure that the model is behaving as close as possible with the observed data like the Census travel to work and National Travel Survey (NTS). As per TAG unit M2.1, adjustments to the ASCs can be made iteratively, by running the VDM using the generalised cost or time equations for utility and by then examining how closely the mode shares are replicated. Adjustments can be added to the utility for each mode, until the predicted shares closely reproduce the observed shares.

3.3 Realism testing

Realism testing is used to ensure that the model responds to changes in travel costs rationally, behaves realistically and with acceptable elasticities. This involves changing various components of travel costs to check whether the response of the VDM is consistent with general experience and empirical data. Part of the calibration process involves adjusting the parameters in the VDM model until acceptable results are obtained from realism tests. It is recommended that these tests are started with initial logit parameters (i.e. the spread, sensitivity or scaling parameters – lambda and theta) based on median values provided in TAG unit M2.1, section 5.6.

A series of realism tests are recommended by TAG to assess the performance of the model. These tests are designed to confirm that the response to changes in key inputs are in line with that which has been observed in empirical studies. The TAG realism tests are:

- Car fuel cost elasticity: change in vehicle kilometres driven, in response to a change in the fuel cost;
- PT fare elasticity: change in PT trips, in response to a change in the PT fares; and
- Car journey time elasticity: Change in car trips, in response to a change in car journey times.

TAG unit M2.1 provides an indication of the demand responses which are a guide to the aggregate behaviour which would be expected across the UK. TAG also advises that it is important to check responses for different types of demand, e.g. comparing trip purposes and urban versus rural areas to ensure their relative responses are logical.

3.3.1 Car fuel cost elasticity

This is calculated as the percentage change in car vehicle-kms with respect to the percentage change in fuel cost. The calculations should be carried out for a 10% or a 20% fuel cost increase. Car fuel cost elasticities are established using both matrix vehicle kilometres and network vehicle kilometres and are based on an iterated supply-demand model result. TAG unit M2.1 indicates that fuel cost elasticity **within the range of -0.15 to -0.35 (overall, across all purposes)** is acceptable and suggests to provide reasons if the elasticity is weaker.

TAG states that target elasticities are considered more plausible if:

- the pattern of annual average elasticities shows values for employers' business trips near to -0.1, for long-distance discretionary trips near to -0.4, and for short-distance discretionary trips and commuting and education somewhere near the average
- the pattern of all-purpose elasticities shows peak period elasticities which are lower than interpeak elasticities which are lower than off-peak elasticities.

3.3.2 Public transport fare elasticity

The public transport fare elasticity required is the percentage change in public transport trips by all public transport modes with respect to the percentage change in public transport fares. The calculations should be carried out for a 10% or a 20% public transport fare increase, applied to all public transport modes equally. Public transport fare elasticities should be calculated on a matrix basis, by time period and trip purpose. Elasticities of public transport trips with respect to public transport fares have been found to lie typically in the range **-0.2 to -0.9** for changes over a period longer than a year. Values close to -0.2 are unlikely for the whole public transport market unless this includes a high proportion of concessionary fare trips with a significant number made free of charge.

The elasticities are considered more plausible if:

- Discretionary purposes expected to have a stronger response than non-discretionary purposes
- Stronger response expected for trips in interpeak period than in peak periods
- Stronger response expected for trips with car available than those without a car available.

3.3.3 Car journey time elasticity

The car journey time elasticity required is the change in car trips with respect to the change in journey time, i.e. as travel time increases it is expected to generate a reduction in car trips. Previously the advice for the car journey time elasticity was to run the demand model for a single loop because the target came from a stated preference exercise, however the benchmark evidence has changed and TAG now advises to run the model to full convergence. TAG states that:

"The output elasticities should be checked to ensure that the model does not produce very high output elasticities (stronger than -0.75)".

3.4 Demand/supply convergence

TAG unit M2.1 section 6.3 recommends that the convergence of the demand and supply models should be measured, using a cost-weighted gap statistic (known as %Gap). This allows the changes in the mode choice and distribution of trips, as well as the journey costs, to be monitored at a high level. Thus, for the BSTM2, a cost-weighted demand gap is used as a gap statistic but allowing a stopping criterion related to maximum number of iterations (whichever is reached first). Also, instead of a single demand gap, separate demand gaps are calculated in VISUM for each of the choice models.

4. Model Data Inputs

4.1 Introduction

This section of the report summarises the planning, land use and travel demand data collated for development of the BSTM2. The subsequent chapters of this report explain how this data has been used to develop the BSTM2 Base year model.

4.2 Data sources

Table 4-1 provides an overview of each planning, land use and travel demand dataset. Further detail regarding each source is provided in the following sub-sections.

Table 4-1 - Planning, Land Use and Travel Demand Metadata

Dataset	Dates	Geography	Units	Attributes	Source
NTEM 8.1	2011-2061	GB, MSOA Level	Persons/ Households/ Jobs	Population by NTEM person type No. households No. jobs by employment type	DfT
ONS Population estimates, Annual Population Survey	2011-2019	UK, LAD level	Persons	Provides various data at LAD level, including mid-year population estimates by age, no. employed individuals by SOC2010 (Standard Occupational Classification) and no. economically inactive individuals by reason.	NOMIS
BRES and Job density	2011-2019	GB, LAD level	Employee/ Employment	Estimated employment by Standard Industrial Classification.	NOMIS
Census	2011	GB, MSOA level and OA level	Persons	Method of travel to work. All Census JTW modes at MSOA, aggregated modes at OA level. Additional 2011 Census data on residents also used.	NOMIS
Addressbase	2019	Buckingham shire	Individual properties	Record of status of each residential and commercial property by: Location Type of commercial activity / dwelling	BC
National Travel Survey (NTS) – Household interview and travel diary	2002-2019	Great Britain (Residence within England)	-	Main topics of NTS data include: - Household variables. - Individual information (e.g. age, place of work, travel to work) - Vehicle information (e.g. type) - Trips (e.g. day, time, mode, purpose, origin/destination) - Stage (e.g. mode, distance)	UK Data Archive (owner DfT)

Dataset	Dates	Geography	Units	Attributes	Source
				Long-distance trips (over 50 miles) (e.g. mode, distance, purpose, origin/destination)	
School DfES Capacity Data	2018-2019 Academic year	England & Wales, individual school level	School places	School capacity data by location and school type (e.g. primary, secondary, sixth form).	DfES School Capacity
AMRs	2011-2020	BC Internal Area, LAD level	Households	Local authority's understanding of: - New households completed - Households demolished - Total households	AMRs from LADs.
Car Park data**	2019	BC Internal Area, LAD level	Various	List of car parks by location, space and charging**.	Respective LADs
PT skims	2019	Buckingham shire	-	PT distance and time skims	TRACC,
PT Fares	2019-2021	Buckingham shire		PT fares for different operators in Buckinghamshire	brfares and operators/ websites

**Data is downloaded from Mipermits scheme and therefore is not a completed list; only some car parks have provided information on space or parking charges or both.

4.3 Overview of land use activities and travel demand

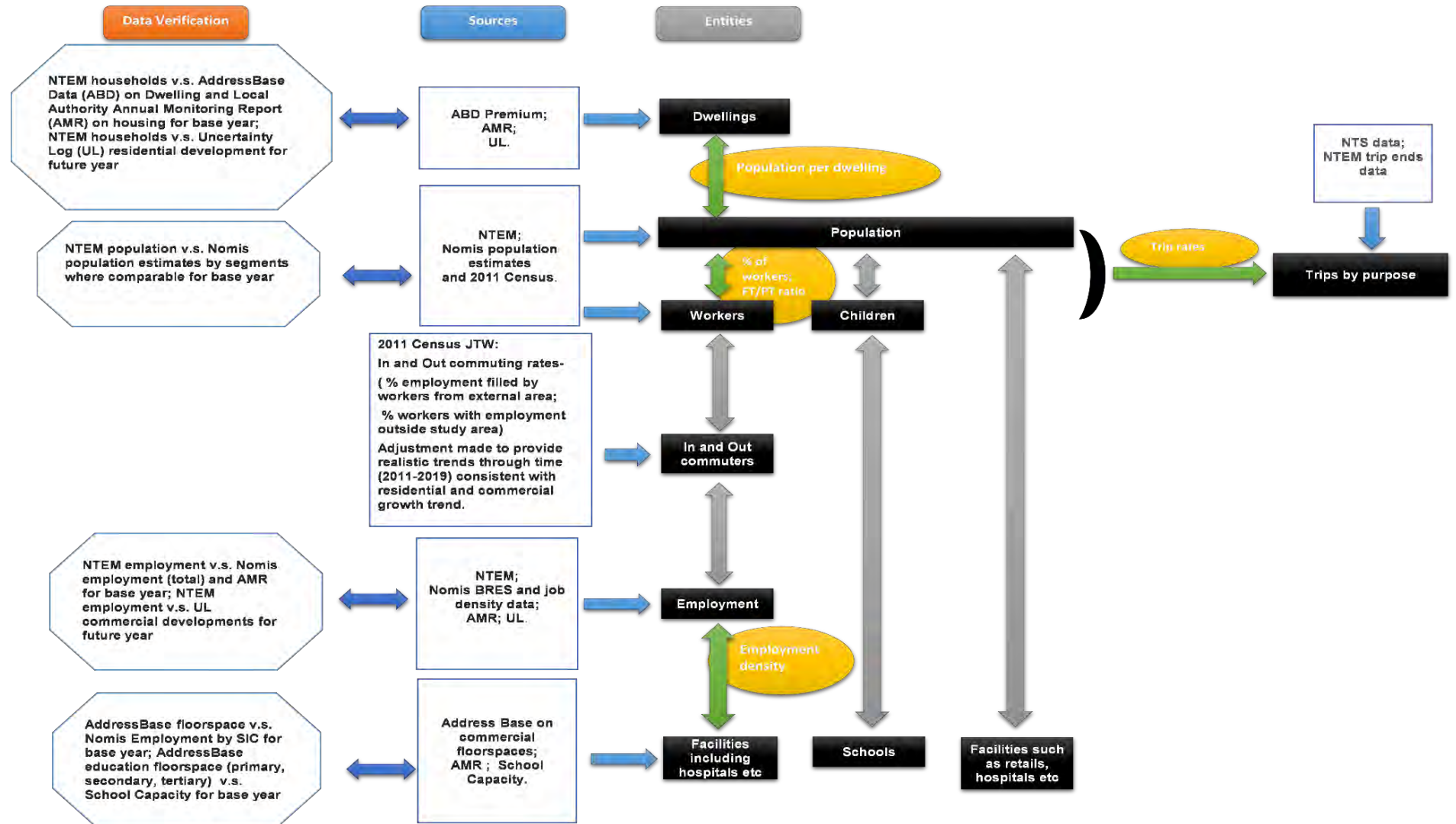
Figure 4-1 shows the relationships between key land use entities and the available data sources linked to these entities. As seen from the diagram, apart from premises (dwellings, facilities and schools), the entities are defined in terms of population. Employment is defined as measuring the workplace population in terms of workers.

Furthermore, following the usual convention the workplace population includes only the 'first job' of each worker as reported in the Population Census, and this therefore excludes second and other additional jobs from the totals.

The land use activities are the determinant of travel demand and are connected in the following way:

- The residential population requires dwellings in which to live;
- This residential population generates trips according to their main age/employment status. For example, employed residents (workers) generate daily commuting trips whilst children and students in full-time education generate daily education trips, and others generate shopping trips, etc;
- These different trip types require establishments (e.g. employment and school places) to provide these facilities;
- Some internal jobs (jobs available in BSTM2 AoDM) are taken by residents living externally (outside AoDM), and vice versa some external jobs are taken by internal residents, the in and out commuting trips are generated between internal (AoDM) and external areas.

Figure 4-1 – Overview of land use activities and data sources



4.3.1 National Trip End Model v8.1 (NTEM v8.1)

The NTEM 8.1 data is presented at MSOA level for Great Britain that has a total of 7,700 MSOAs. Based on 2011 Census data, it is run in 5-year increments from 2011 to 2061 with forecasts based on planning data. If data for a year other than the 5-year increments provided is required, interpolation is necessary.

NTEM is developed by DfT to provide a central definitive and consistent forecast of trip ends and planning data for transport studies at an average national trip rate level. This is primarily intended for forecasting future travel demand rather than as an absolute measure of the population, jobs or trips each year. Moreover, though 2011 data reflect observed information from the 2011 Census, all subsequent years are estimates based on a range of trends and planning information. To account for this, the planning data will be updated using recent observed data from other sources (described below). It will also be necessary to adjust to accommodate differences between national and local trip rates. NTEM is however a useful source of the initial 2011 segmented data, adjusted based on established trends in household size, age and proportion of population working, as well as trends in type of employment.

Data extracted from NTEM for the purposes of the BSTM2 base model build are listed in Table 4-1 above.

4.3.2 NOMIS statistics

NOMIS (accessed via the website [NOMISWEB](#)) provides a collection of population and labour market statistics maintained by the Office for National Statistics (ONS). The NOMISWEB site has been used to access:

- **Population Estimates:** Mid-year population estimates are the official source of population sizes in-between censuses, rolling forward the population found by the previous census, one year at a time by accounting for births, deaths, international migration and internal migration; to accomplish this multiple registration, survey and administrative data sources are used. It adopts census definition of people who are “usually resident” in the UK for 12 months, excluding short-term migrants, and counting students at their term-time addresses. It covers populations of local authorities, counties, regions and countries of the UK by age and sex.
- **Annual Population Survey (APS):** The APS is a continuous household survey, covering the UK. The topics covered include employment and unemployment, as well as housing, ethnicity, religion, health and education. It provides the estimates of the number of people in employment or unemployed.
- **Business Register and Employment Survey (BRES):** The BRES is an annual employer survey of the number of jobs held, broken down by industry. It is the official source of employee and employment estimates by detailed geography and industry and can be used as an observed comparator dataset for the forecast jobs growth provided by other datasets e.g., NTEM. It should be noted however that BRES is a sample survey and subject to some variation between years which is understood to be due to sample size. Therefore, it is important to analyse and observe trends before using the data and to use the data at a suitably aggregate spatial level.
- **Job density:** The total number of jobs estimated by Job Density is a workplace-based measure and comprises employee jobs, self-employed, government-supported trainees and HM Forces.

Population Estimates as well as APS estimate population and their economic activities at residence end whilst BRES and Job density measure jobs and employees at workplace end.

These are useful in helping to understand the change in population (either residents or workplace population) since the 2011 Census, as they are the only empirically based annual measures currently available and can be used to adjust both Census mid-year estimates and NTEM data. It is important to note, however, that NOMIS statistics are estimated from samples of the population, and as such cannot be considered a definitive, or completely accurate representation of patterns (and less representative than a full census dataset).

4.3.3 Census 2011

Data from the 2011 Census (also from NOMIS web) still provides an extensive source of data on the breakdown of population in the county, and economic circumstances that inform travel patterns.

The Census 2011 Journey-to-work (JTW) data is a vital component of the base year model building and calibration. This data provides a complete picture of the home and work locations of employed people, as well as the method of travel to work, for 2011. It is noted that the data represents where people live and where they work, thereby defining the typical journeys rather than actual volume of individual trips. The total volume of workers in the JTW data is greater than observed daily trips as on average workers make less than one trip per weekday. These are compiled to allow calibration of mode share, trip lengths and patterns of travel in the demand model as well as being used as a comparator dataset during base matrix development. Census 2011 is preferred over Census 2021 (being closer to BSTM2 base year), because the work commute patterns in Census 2021 are largely influenced by the COVID-19 pandemic.

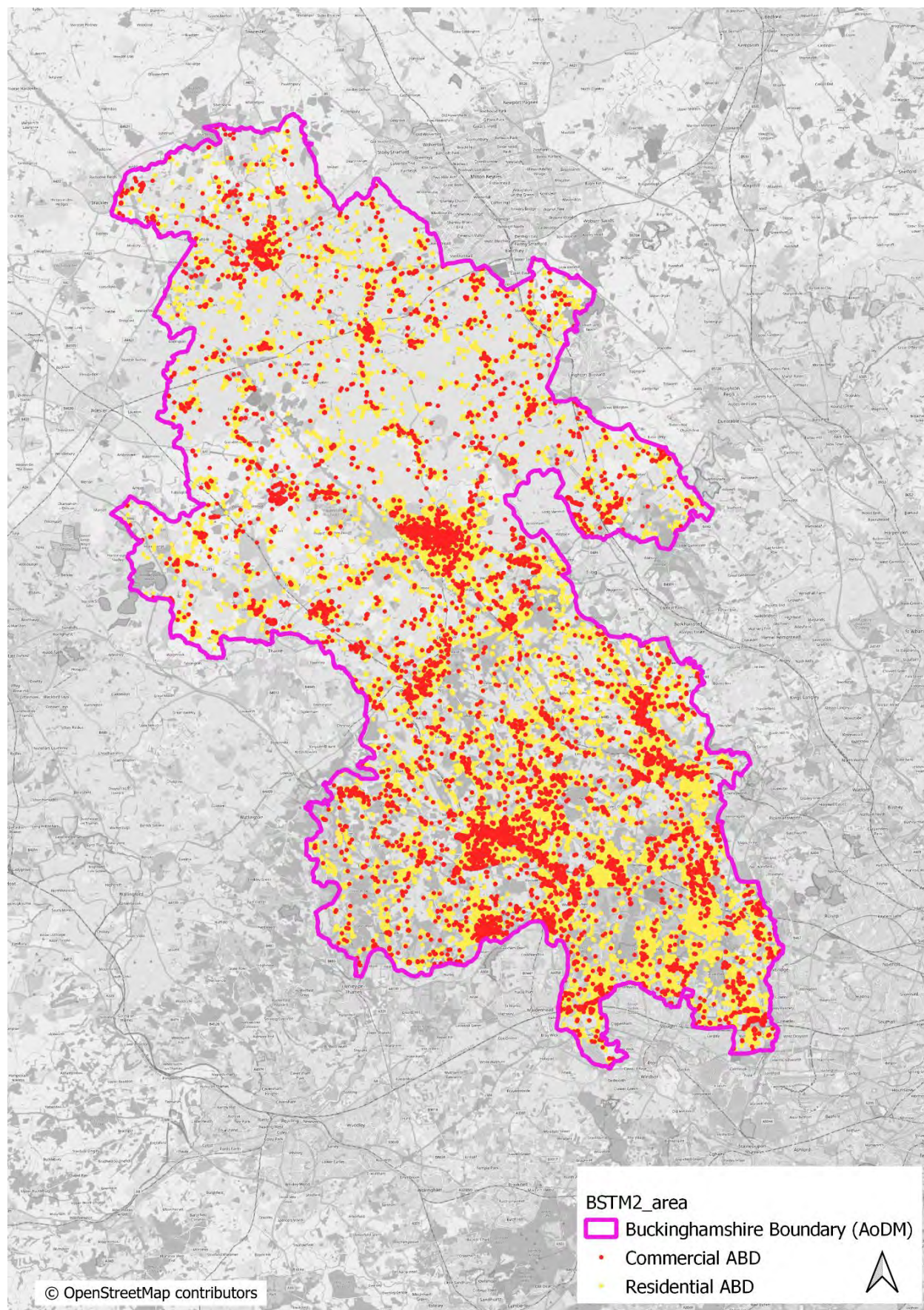
Census JTW data was downloaded for each MSOA within England and Wales and for each OA within England and Wales. This dataset details how individuals completing the 2011 Census stated that they travel to their regular place of work as described in Table 4-1 above.

4.3.4 AddressBase Data (ABD)

AddressBase Data (ABD) provides a source of residential and commercial property data which allows identification of individual properties, including year of first occupancy or change of use. This can be used to understand the change in land use (from 2011 to the BSTM2 2019 base year) at a spatially detailed level.

The ABD for use in development of the BSTM2 was supplied originally by BC in mid-2024, covering the BC internal study area. One issue with the data provided is that information on the year when the property was first built and in use was not available. To address this, further examination on the change of properties, i.e. growth of dwellings for period 2011-2019 has been carried out using figures from Annual Monitoring Report from each BC local authority district at that time.

Figure 4-2 – ABD 2019 data representation in BSTM2



4.3.5 National Travel Survey (NTS)

The NTS is an ongoing of travel diary survey designed to provide regular, up-to-date data on personal travel and monitor changes in travel behaviour over time. The survey provides detailed information on different types of travel: where people travel from and to, distance, purpose and mode. The NTS records personal and socio-economic information to distinguish between different types of people, and the differences in the way they travel and how often they do so.

Available NTS data ranges from 2002 to 2019 and covers personal travel by residents of England travelling within Great Britain, from data collected via interviews and a seven-day travel diary.

The Special Licence version (SN 7553) contains more detailed travel, demographic and socio-economic data, and the geographic level is Local Authority/Unitary Authority. This licence has been requested and obtained so that NTS data related specifically to the BSTM2 AoDM may be used, where sample sizes permit, to provide:

- Trip rates by district by person type;
- Time of day profiles by purposes, mode and traveller type, by home area type;
- Trip length profiles by purpose and mode; and
- Mode choice profiles by purpose and traveller type by home area type.

National aggregate statistics from NTS are published by the DfT online. This has been downloaded and further analysed in Section 5.5 to highlight key considerations for the BSTM2. Detailed analysis of the raw NTS dataset for Buckinghamshire was conducted as part of model development which are explained in the further sections. As a caveat it should be noted the sample size within Buckinghamshire may be limited. Accordingly, our use of the raw data will be limited to trip rates, mode shares, trip lengths and other useful aggregate measures.

4.3.6 School capacity data

The school census is conducted each year and every school is required to submit information, including capacity data, to the Department for Education. School capacity data for the academic year 2018-2019 was downloaded for all of England and Wales and then filtered to only include schools within Buckinghamshire.

The school capacity data provides data for each individual school as detailed in Table 4-1 above. Table 4-2 below provides a summary of the number of state-funded school places for each Local Authority District (LAD) in Buckinghamshire for the academic year 2018 – 2019 (before the Council became a unitary authority in 2020). The data shows the BSTM2 internal LAD with the highest levels of primary, secondary and sixth form school places is Aylesbury Vale.

Table 4-2 - School Capacity by Local Authority for Academic Year 2018 – 2019

Authority	No. of School Places (2018-2019)			
	Primary	Secondary	Sixth Form	Total
Aylesbury Vale	19,028	11,165	3,316	33,509
Chiltern	7,730	7,356	1,930	17,016
South Bucks	5,035	2,817	960	8,812
Wycombe	15,350	9,619	2,430	27,399
Total	47,143	30,957	8,636	86,736

4.3.7 Annual Monitoring Reports (AMRs)

Local Authorities produce Annual Monitoring Reports (AMRs) annually to review progress against their latest adopted Local Plan. A range of measures are reported on, including the number of dwellings that have been built out or demolished over the course of the year within the LAD. These provide a clear record of the residential growth (and demolitions) the Local Authority is aware of within their district and can be used as a comparator dataset, along with the AddressBase data, to validate the NTEM household data.

AMRs for the years 2011 to 2019 were obtained from each of the LADs within the BSTM2 internal area, i.e. the same LAD list as for the ABD.

4.3.8 Car park data

The list of car parks in Buckinghamshire operating under the Mipermits scheme were downloaded in August 2024 with most of the car parks in the list providing information on parking fees (either short stay or long stay or both) and parking spaces. Though data was downloaded in 2024, an agreement was made with BC to use the same parking fees for the base year 2019.

4.3.9 TRACC

TRACC, developed by Basemap Ltd in partnership with the Department for Transport (DfT), Local Authorities, and transport planners, is a prominent tool for multimodal transport accessibility analysis designed to generate travel times for a full range of transport modes between various origins and destinations. It replaced the previous “Accession” software, addressing various licensing issues often encountered with other platforms like Google Maps.

4.3.9.1 Key Benefits and Features

- **Accessibility Contours:** TRACC’s primary function is to generate accessibility contours, mapping the travel time and access from multiple origins to selected destination points.
- **Enhanced Visualization:** The software offers user-friendly visual outputs, which are highly valued by clients for clear accessibility analysis, especially for local authorities.
- **Low-Cost Efficiency:** After obtaining the necessary licenses, TRACC proves to be cost-effective and efficient, providing rapid accessibility analysis at a relatively low ongoing cost.
- **Familiarity with Stakeholders:** Many stakeholders, including government bodies, have experience with TRACC and its outputs, which facilitates adoption and reduces training needs.

TRACC’s role in accessibility analysis and transport planning makes it a popular tool, especially for public sector projects requiring reliable accessibility insights. For the VDM, non-car time skims (i.e. bus and rail) were generated from TRACC at zonal level and are given as input to VDM.

4.3.9.2 Specifications to TRACC

A set of specifications and inputs have been provided to TRACC for the extraction of bus and rail skims. The data is extracted for the year 2019 and for specific month of November.

Zoning and Railway Stations Data

- **Base Zones:** Base year zones, including designated park-and-ride facilities, are provided as input for TRACC. This setup allows for comprehensive coverage of the study area’s accessibility.
- **Network and Bus Stops:** TRACC incorporates the pre-built network and bus stop locations within the software, using them to create precise skim matrices (travel time and distance data) for multimodal accessibility. This ensures that bus accessibility is accurately reflected in the output.



- **Railway Stations:** A curated list of railway stations within and surrounding the BSTM2 AoDM is also provided as input. This addition enables TRACC to extract rail skims, which represent travel times and access measures for rail transport within the network.

Origin-Destination (O-D) Parameters

The following OD parameters presented in Table 4-3 are provided as inputs for TRACC for the generation of skims.

Table 4-3 - O-D Parameters

Parameters	Inputs
Public Transport Modes	Bus, Rail
Data Collection Day	Tuesday/Wednesday/Thursday
Time Periods	08:00 – 09:00; 10:00 – 16:00; 17:00 – 18:00
Walk Speed	4.8 kmph
Maximum walk distance between stops when interchanging	500m
Interchange penalty	5 mins
Accessibility to first stop	5 kms for Bus and Rail
Maximum number of interchanges	5
Interchange Parameters	For Bus only skims - Only Bus to Bus transfer is allowed. For Rail only skims - Only Rail to Rail transfer is allowed. For All Modes skims - Both Rail-Rail, Bus-Rail and Rail-Bus transfers are allowed (Used for infilling gaps in above skims).

5. Land Use and Trip Ends

5.1 Introduction

Land use and economic activity play an essential role in determining the nature and volume of trips produced from and attracted to certain desired locations or areas. The trip ends, estimated from land use activity, provide the travel demand inputs to the VDM.

Different segments of the population exhibit very different travel behaviours depending on their life stage, such as whether they are students or employed, and the structure of their household and car availability. Annual statistics that provide updates for population, housing, jobs, and economic activity do not offer the level of segmentation required for travel demand modelling. Segmented information can be obtained from sources such as the 2011 Population Census and other forecast datasets, such as the DfT's NTEM dataset.

The approach to building trip ends for the BSTM2 has been to collate information from 2011 data from NTEM v8.1 (which uses data from the 2011 Census) to pick-up the segmentation and update this to the 2019 base year using other aggregate observed information such as mid-year population estimates, AddressBase dwellings and Annual Monitoring Reports (AMRs). This chapter sets out the approach used to derive the 2019 land use and trip end inputs to the VDM for the base year.

NTEM planning data only forecasts residents living in households and therefore trips produced by trip end data are those generated by household residents only. People who live in communal establishments which include residential care homes, student halls of residence, military barracks and prisons are not included in NTEM. The same approach has been adopted for the BSTM2 VDM (noting that trips to/from these places would be reflected in the assignment model matrices).

5.2 Base year land use inputs

The NTEM 8.1 dataset is generally used as a starting point for base year land use and planning assumptions, as it essentially provides an update to 2011 Census data considering projected trends in housing, employment and demographics. NTEM is however a high-level projection with version 8.1 created in 2023 and can be complemented and enhanced using various other datasets available. The NTEM planning variables have thus been verified by looking at other available datasets and where appropriate adjusted to the observed data, for use in the BSTM2.

The variables covered with corresponding data sources, are:

- Dwellings / Households (Addressbase dwellings (ABD), Annual Monitoring Reports (AMRs), NTEM households);
- Population (2011 Census, Office for National Statistics (ONS) mid-year population estimates and NTEM);
- Jobs and Workers (ONS Job density and NTEM data);
- Journey to Work: Mode shares and Origin-Destination analysis (2011 Census);
- School spaces by education stages (school census).

This section presents detailed analysis of these datasets and concludes how they should be used to adjust the NTEM dataset. NTEM district level data is thus verified using growth of 2011-2019 derived from observed data covering the following:

- Population (2011 Census and ONS mid-year estimates);
- Dwellings (AddressBase data);



- Jobs (BRES and Job density);
- Economic activities (ONS annual population survey (APS));
- Job vs worker comparisons; and
- Journey to Work: Mode shares and in/out commuting analysis (2011 Census).

5.2.1 Population

Table 5-1 shows the population of Buckinghamshire council and its component districts according to Census 2011.

Table 5-1 - Census 2011 total populations within Buckinghamshire

Local Area District (LAD)	Population
Aylesbury Vale	174,137
Chiltern	92,635
South Bucks	66,867
Wycombe	171,644
Total	505,283

The population of the county is concentrated in the areas, with the Aylesbury Vale and Wycombe districts accounting for 68% of the total county population in 2011. The other two districts have similar population sizes, and the county as a whole had a population of 505,283 residents in 2011.

Table 5-2 compares two separate estimates of how the population has grown from 2011 to 2019 within each district: one based on forecasts from the NTEM dataset (using land use inputs to the National Trip End Model) and the other based on ONS population estimates (derived from labour market estimates carried out each year).

Note that the definition of NTEM's population differs from that of provided in the ONS mid-year population estimates, as NTEM planning data only forecasts residents living in households. Therefore, trips produced by trip-end data are generated solely by household residents. People who live in communal establishments, such as residential care homes, student halls of residence, military barracks, and prisons, are not included in the NTEM dataset, as the NTS is a household survey no trip rates from these establishments are captured. The ONS mid-year population estimate figures are total population and include both household residents and people living in communal establishments.

Table 5-2 - Population growth by local authority, 2011-2019, NTEM vs ONS

District	2011		2019		Abs Growth		% Growth	
	NTEM	ONS mid-year population estimate	NTEM	ONS mid-year population estimate	NTEM	ONS mid-year population estimate	NTEM	ONS mid-year population estimate
Aylesbury Vale	172,258	174,880	193,278	203,219	21,020	28,339	12%	16%
Chiltern	91,861	92,652	95,152	96,046	3,291	3,394	4%	4%
South Bucks	67,025	67,060	69,807	70,440	2,782	3,380	4%	5%
Wycombe	170,400	171,958	176,772	174,268	6,372	2,310	4%	1%
BSTM2	501,544	506,550	535,008	543,973	33,464	37,423	7%	7%



According to ONS mid-year population estimates, each LAD within Buckinghamshire has experienced different levels of population growth, with the largest increase seen in Aylesbury Vale (16%) and a relatively minor change in Wycombe (1%). The NTEM forecasts also show relatively higher growth in Aylesbury Vale (12%), while growth in other districts is 4%. When comparing the actual (estimated) growth from ONS estimates with the NTEM population growth forecasts, only the actual growth of Chiltern and South Bucks aligns closely between the two datasets, with greater variation observed in other districts.

Since the 2019 NTEM populations are forecast from the 2011 Census, it has been determined that, within Buckinghamshire, the district-level 2019 NTEM population will be adjusted according to the district growth estimated by ONS, while ensuring that all spatial details are maintained using NTEM patterns.

5.2.2 Dwellings/Households

In this section, a comparison between NTEM households (Hhs) and AddressBase data (ABD) dwellings has been conducted. Strictly speaking a dwelling is a property which could be empty or contain more than one individual household. However, when dealing with growth the two concepts are closely aligned, and it has been assumed that every dwelling contains precisely one household.

ABD data as supplied by BC has been further processed to filter the dwelling data classified into the following categories:

- RD: Residential Dwelling
- RD02: Detached
- RD03: Semi-Detached
- RD04: Terraced and
- RD06: Flats

Due to the lack of the information on start year and end year of each property in the received ABD shapefile, which was generated based on August 2021 data set (received from BC), it has been assumed that the properties recorded in the shapefile represent all existing properties in 2019. Since some properties may have emerged after 2019, this assumption could lead to a certain level of over-estimation of the total number of dwellings in 2019.

Accordingly, it has been very important to scrutinise the growth in housing from ABD against the housing growth documented in AMRs from each LADs within BCC from 2011 up to 2019. Census 2011 dwelling figures were used together with 2019 ABD dwelling figures to establish the growth in dwellings between 2011 and 2019. As seen from Table 5-3, percentage housing growth from AMRs based on 2011 Census total dwellings in general are either similar or slightly lower than those of ABD. Consequently, the level of housing growth from the AMRs has been used as the ultimate control per district for the 2019 model year, with the detailed spatial pattern derived from the ABD.

Table 5-3 - Housing growth, 2011-2019, ABD vs AMRs

Authority	2011 Census Dwellings	ABD Growth	AMR Growth	% ABD housing growth	% AMR housing growth
Aylesbury Vale	71,883	13,083	9,687	18%	13%
Chiltern	38,287	2,819	1,766	7%	5%
South Bucks	27,709	2,780	1,753	10%	6%
Wycombe	70,087	2,253	3,955	3%	6%
BSTM2	207,966	20,935	17,161	39%	30%

Furthermore, the comparison of NTEM household change versus ABD dwelling change (adjusted to be in line with AMRs district control) has been summarised in Table 5-4. According to both NTEM and ABD data, all districts within Buckinghamshire exhibit close growth patterns.

Table 5-4 - NTEM Households vs Address Base Dwellings Growth, 2011-2019

District	NTEM		Census and ABD		Ab growths (2011-2019)		% Growths (2011-2019)	
	2011 NTEM Hhs	2019 NTEM Hhs	2011 Census Dwellings	2019 ABD Dwellings (adjusted)	NTEM	ABD Dwellings (adjusted)	NTEM	ABD Dwellings (adjusted)
Aylesbury Vale	69,714	78,445	71,883	81,570	8,731	9,687	13%	13%
Chiltern	36,961	38,628	38,287	40,053	1,667	1,766	5%	5%
South Bucks	26,585	28,006	27,709	29,462	1,421	1,753	5%	6%
Wycombe	68,015	71,235	70,087	74,042	3,220	3,955	5%	6%
Total	201,275	216,314	207,966	225,127	15,039	17,161	27%	30%

The dwelling growths observed by ABD across LADs slightly vary by district when comparing with NTEM household growth with an overall 3% higher dwelling growth than NTEM household growth.

5.2.3 Jobs

Data concerning jobs and employment was collected from NOMIS (job density data as well as BRES data) and NTEM. Table 5-5 presents the growth of jobs in 2011-2019 between NTEM and NOMIS for the local authorities within BC.

Table 5-5 - Job growth by local authority, 2011-2019, NTEM vs NOMIS

District	2011			2019			Abs Growth			% Growth		
	NTEM	Nomis Job Density	Nomis BRES	NTEM	Nomis Job Density	Nomis BRES	NTEM	Nomis Job Density	Nomis BRES	NTEM	Nomis Job Density	Nomis BRES
Aylesbury Vale	81,462	80,000	71,500	90,575	100,000	80,600	9,113	20,000	9,100	11%	25%	13%
Chiltern	38,305	39,000	33,500	42,005	42,000	37,000	3,700	3,000	3,500	10%	8%	10%
South Bucks	35,830	37,000	33,500	39,357	46,000	38,000	3,527	9,000	4,500	10%	24%	13%
Wycombe	87,720	90,000	81,500	96,360	105,000	90,200	8,640	15,000	8,700	10%	17%	11%
BSTM2	243,317	246,000	220,000	268,297	293,000	245,800	24,980	47,000	25,800	10%	19%	12%

It is more difficult to compare these various employment data like-for-like due to differing definitions of employment:

- Job numbers estimated by NTEM are based on 2011 Census workplace population as well as 2011 BRES data for a base year of 2011; the numbers for years beyond 2011 are then forecast based on long-term trends. Therefore, total jobs for year 2019 are estimated figures.
- The total number of jobs from NOMIS Job Density (as explained in earlier section 4.3.2) is a workplace-based measure and comprises employees, self-employed, government-supported trainees and HM Forces. This could provide an over-estimated number of jobs as the BSTM2 will not consider jobs in Armed Forces and Government-supported traineeships.
- The BRES is an employer survey of the number of jobs held by employees broken down by full/part-time and detailed industry (5-digit SIC2007). The survey records a job at the location of an employee's workplace. As the definition indicates, self-employed people who are not working for employers are not included in the survey.

Even though the absolute figures of jobs from each of the sources are not comparable, the percentage growth of jobs for the period of 2011-2019 can shed light on the trend of job growth over this period. The NTEM growth pattern across districts is much less varied than those observed by either Job Density or BRES data from NOMIS. Checking the job growth per district, the following patterns are further observed:

- Both the BRES data and NTEM data indicate similarly lower job growth (10-13%) in the Aylesbury and South Bucks district, in contrast with NOMIS's Job Density data which reveals a substantially higher job growth rate (24-25%) in this area;

- Chiltern district has a comparable job growth rate of 8-10% according to the datasets from NOMIS and the NTEM dataset.
- The job growth in Wycombe, as provided by the BRES and NTEM, shows slightly different figures, with a lower growth rate (10-11%) compared to the growth shown by the NOMIS Job Density (17%) in this area.

The following percentage growths have been proposed and adopted in the model for each LAD:

Table 5-6 - Proposed Job Growth, 2011-2019

District	% Job Growth 2011-2019	Source
Aylesbury Vale	25%	NOMIS (Job Density)
Chiltern	8%	NOMIS (Job Density)
South Bucks	24%	NOMIS (Job Density)
Wycombe	17%	NOMIS (Job Density)
BSTM2	19%	NOMIS (Job Density)

5.2.4 Economic activity

A comparison of the proportion of workers over total population for year 2019 between NTEM forecast and ONS annual population survey (APS) is shown in Table 5-7. This demonstrates that the proportions of workers compared with total population forecast by NTEM for each district largely matches those observed by NOMIS (with the exception South Bucks being slightly more varied) leading to same overall countywide ratio of 50% for both sources.

Table 5-7 - Proportion of worker over total population, NTEM vs. ONS

District	NTEM 2019 Workers	ONS APS 2019 Workers	% of (NTEM 2019) Population	% of (ONS APS 2019 Workers) Population
Aylesbury Vale	101,359	104,100	52%	51%
Chiltern	45,209	46,100	48%	48%
South Bucks	34,119	32,100	49%	46%
Wycombe	87,779	91,100	50%	52%
BSTM2	268,465	273,400	50%	50%

To compare the accuracy of NTEM forecasts of workers against the actual (estimated) ONS APS figures, Table 5-8 shows the growth of working population (worker) between NTEM and ONS APS, since the last full Population Census.

Table 5-8 - Worker growth by local authority, 2011-2019, NTEM vs ONS APS

District	2011		2019		Abs Growth		% Growth	
	NTEM	ONS APS	NTEM	ONS APS	NTEM	ONS APS	NTEM	ONS APS
Aylesbury Vale	88,581	83,400	101,359	104,100	12,778	20,700	14%	25%
Chiltern	43,750	46,000	45,209	46,100	1,459	100	3%	0%
South Bucks	32,614	33,300	34,119	32,100	1,505	-1,200	5%	-4%
Wycombe	84,964	88,400	87,779	91,100	2,815	2,700	3%	3%
BSTM2	249,909	251,100	268,465	273,400	18,556	22,300	7%	9%

5.2.5 Journey-to-Work

The Census JTW data are used to understand levels of in and out commuting for the BSTM2 internal area, where:

- In-commuting represents the proportion of jobs in the internal AoDM filled by workers living in the external area; and
- Out-commuting represents the proportion of workers resident in the internal AoDM who have jobs based in the external area.

A summary of the in-commuting/out-commuting levels for the BSTM2 area is shown below in Table 5-9 including and excluding work from home (WFH) individuals. As WFH individuals do not make commuting trips, including them in the analysis gives a view on how in-commuting/out-commuting proportions apply to the total underlying population while excluding them gives a view on how in-commuting/out-commuting proportions apply to actual commuter trip-making. The figures demonstrate that the BSTM2 internal area has net out-commuting, i.e. there are more people out-commuting to jobs outside Buckinghamshire than in-commuting in 2011.

Table 5-9 - 2011 Census JTW In/ Out commuting proportions

Metric	Including WFH	Excluding WFH
% in-commuting (internal jobs filled by external workers)	27.8%	33.9%
% out-commuting (internal workers with external job)	36.8%	43.6%

5.3 Derivation of trip rates

National Travel Survey (NTS) data was used to calculate trip rates. NTS data consists of travel information for household residents between years 2002 and 2019 stored in a relational database of 13 tables. For the purposes of processing, data between 2011 and 2019 was used to have a considerable data pool. Out of 13 tables, four tables namely Trips, Individuals, Day and Households, were processed for this purpose. The processed trips and individuals were verified against published totals to validate the process.

The verified data was used to calculate home-based and non-home-based trip rates at three different geographical levels: (1) BSTM2 AoDM i.e. Buckinghamshire, (2) South East region and (3) national level, i.e. England. Thorough checks were conducted on segments with sufficient data, confirming minimal variation across the three geographical bases. Due to the limitations in NTS sample size for population categories in Buckinghamshire and South East region, the national level data has been used for both internal and external trip rates.

5.3.1 Home-based trip rates

The home-based trip rate required is the number of trips (productions) per person per (24 hour) neutral weekday. Trip rates were calculated for all home-based trip purposes for different population categories. The population categories were based on the purpose for making the trip and the household size, car availability and age of the individual making the trip. Trip rates were calculated for a neutral weekday for urban and rural areas, classified using area types, within the South-East region. For education-based trips, escort trips made by adults were also included in the trip rate calculations, meaning these escort trips are part of education trips.

The trip rates calculated for commute and business for those aged 16 to 74 in Full Time (FT) employment, Part Time (PT) employment, Student and Other categories are presented in Table 5-10. Trip rates values for those aged 75+ and child categories for these purposes are not used in the model as they make negligible numbers of commute and business trips. The correspondence between the population categories shown below and the model demand strata has been presented in Appendix C.

Table 5-10 - Daily trip production rates based on population category for HBW and HBEB

Population Category	HBW		HBEB	
	Rural	Urban	Rural	Urban
FT_1Adult_0Car	0.717	0.640	0.056	0.043
FT_1Adult_1+Car	0.538	0.604	0.112	0.087
FT_2+Adult_0Car	0.559	0.686	0.023	0.036
FT_2+Adult_1Car	0.633	0.702	0.072	0.050
FT_2+Adult_2+Car	0.554	0.620	0.097	0.083
PT_1Adult_0Car	0.448	0.439	0.019	0.064
PT_1Adult_1+Car	0.349	0.353	0.077	0.078
PT_2+Adult_0Car	0.575	0.484	0.006	0.020
PT_2+Adult_1Car	0.365	0.466	0.081	0.059
PT_2+Adult_2+Car	0.343	0.395	0.072	0.063

The rural and urban trip rate plots for HBW and HBEB purposed are also shown below in Figure 5-1 and Figure 5-2 respectively. The R² value in the plots below indicates that the urban and rural trip rates align closely with each other.

Figure 5-1 – HBW rural and urban trip rates

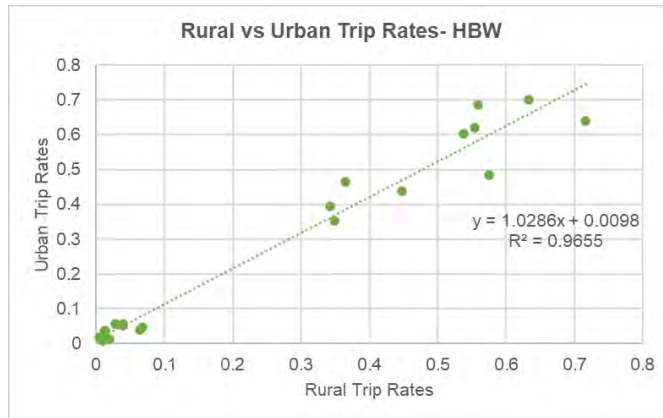
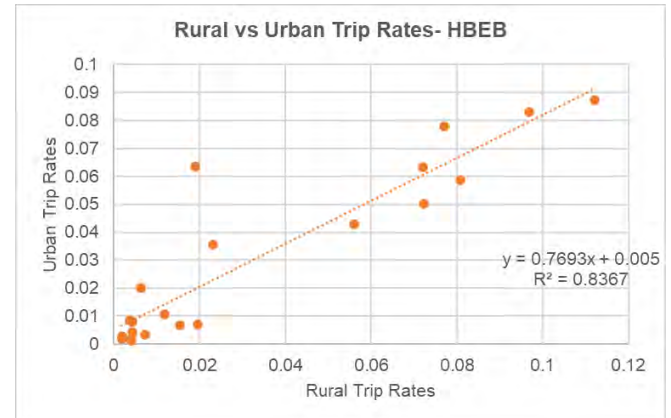


Figure 5-2 – HBEB rural and urban trip rates



The trip rates for home-based shopping and recreation for all population categories are presented in Table 5-11. People aged 75+ and the other working age group categories have highest trip rate for shopping. Recreation trip rates are similar across most of the categories.

Table 5-11 - Daily trip production rates based on population category for HBL and HBPS

Population Category	HBPS		HBL	
	Rural	Urban	Rural	Urban
Child_1Adult_0Car	0.292	0.263	0.198	0.195
Child_1Adult_1+Car	0.165	0.200	0.277	0.260
Child_2+Adult_0Car	0.169	0.241	0.143	0.151
Child_2+Adult_1Car	0.205	0.262	0.227	0.241
Child_2+Adult_2+Car	0.203	0.233	0.300	0.334
FT_1Adult_0Car	0.277	0.222	0.085	0.150
FT_1Adult_1+Car	0.237	0.238	0.276	0.288
FT_2+Adult_0Car	0.177	0.187	0.185	0.124
FT_2+Adult_1Car	0.241	0.238	0.191	0.207
FT_2+Adult_2+Car	0.209	0.219	0.246	0.256
PT_1Adult_0Car	0.252	0.316	0.136	0.214
PT_1Adult_1+Car	0.395	0.443	0.384	0.439
PT_2+Adult_0Car	0.287	0.343	0.132	0.149
PT_2+Adult_1Car	0.363	0.402	0.336	0.323
PT_2+Adult_2+Car	0.357	0.380	0.419	0.429
Student_1Adult_0Car	0.817	0.653	0.351	0.341
Student_1Adult_1+Car	0.321	0.394	0.213	0.271
Student_2+Adult_0Car	0.715	0.257	0.178	0.276
Student_2+Adult_1Car	0.135	0.187	0.264	0.319
Student_2+Adult_2+Car	0.140	0.174	0.224	0.295

Population Category	HBPS		HBL	
	Rural	Urban	Rural	Urban
Other_1Adult_0Car	0.519	0.614	0.538	0.556
Other_1Adult_1+Car	0.599	0.646	0.150	0.219
Other_2+Adult_0Car	0.458	0.555	0.375	0.397
Other_2+Adult_1Car	0.580	0.654	0.507	0.539
Other_2+Adult_2+Car	0.586	0.629	0.212	0.207
75+_1Adult_0Car	0.429	0.541	0.404	0.458
75+_1Adult_1+Car	0.619	0.651	0.054	0.143
75+_2+Adult_0Car	0.623	0.575	0.289	0.312
75+_2+Adult_1Car	0.640	0.714	0.372	0.387
75+_2+Adult_2+Car	0.658	0.663	0.372	0.387

The trip rate plots for HBPS and HBL presented in Figure 5-3 and Figure 5-4 show that the urban and rural trip making pattern for both the purposes are fairly similar. The students making home-based shopping and personal business trips show higher trip rates in rural areas compared to urban areas.

Figure 5-3 – HBPS rural and urban trip rates

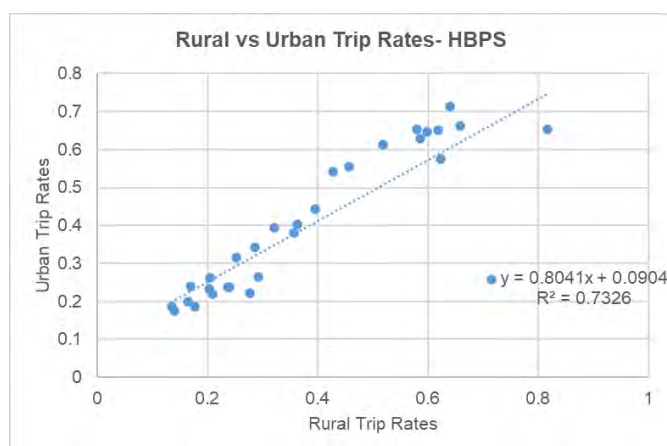
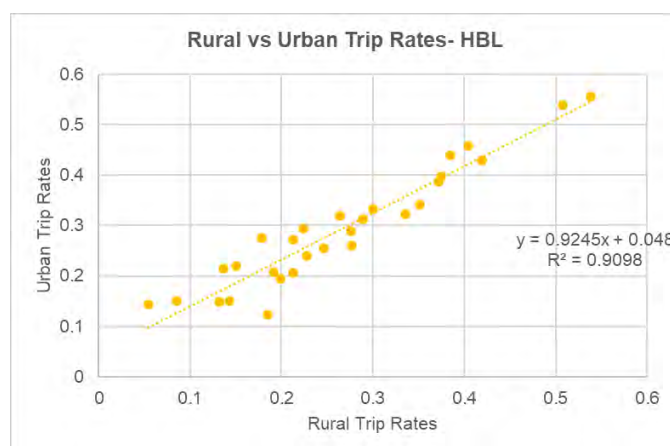


Figure 5-4 – HBL rural and urban trip rates



The education trip rates for all categories are presented in Table 5-12. Trip rates are highest for school children as they make regular trips and are often escorted by adults as well. It is noted that, once the trips are generated, the education trips generated by university students (ages 19+) are added to home-based shopping and personal business before input to the VDM as discussed in section 2.8.3.

Treatment of education escort trips

A high number of nursery and school trips are made by younger age groups who are usually escorted by adults. It is thus essential to capture these escort trips made by adults to truly reflect the trip making pattern made by children. Thus, for the population categories linked with education purpose, escort education trips made by adults (19+) have been extracted and redistributed amongst nursery, school and tertiary education categories.

The methodology adopted to capture escort trips for education is as follows:

- All education escort trips made by individuals up to the age of 18 were dropped.
- All adults above the age of 18 were extracted along with the household ID of the individuals making these trips. If the extracted households linked with these escort trips did not have an individual below the age of 18 making an education trip, the trips were dropped.
- For the trips from households where education trips were being made by children, adult escort trips were classified into 3 categories – nursery escort, school escort and tertiary escort, depending on the age of the child making education trip in the household. If a household has children in more than one category, the escort trips were assigned to the lowermost category.

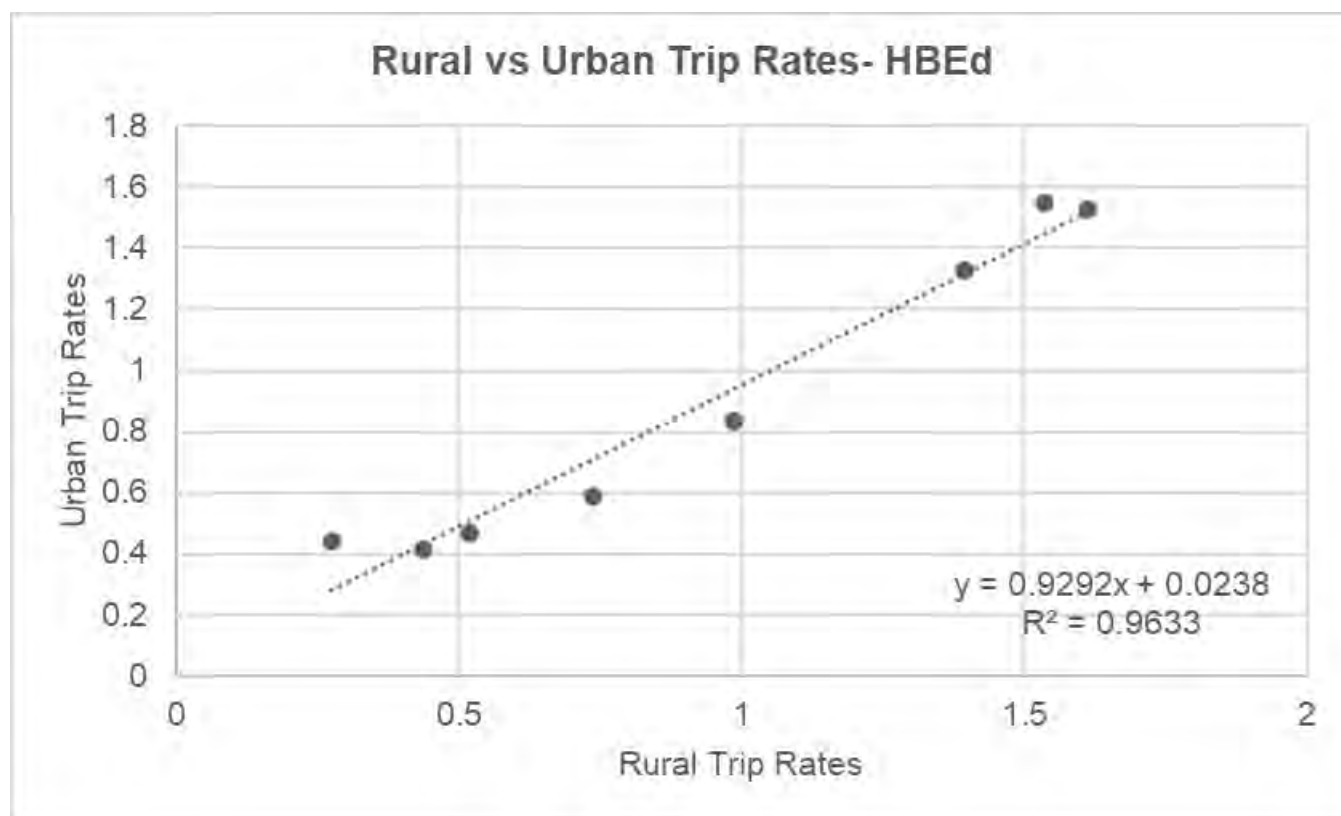
Thus, for the 3 education levels – nursery, school and tertiary, the total trips include trips made by the children themselves plus the education escort trip made by adults above age 18 in the same household category. In the university student category, the trips made by the adult themselves are only considered.

Table 5-12 - Trip rates based on population category for HBEd

Population Category	Rural	Urban
ChildNursery_1Adult_0Car	-	0.389
ChildNursery_1Adult_1+Car	0.737	0.589
ChildNursery_2+Adult_0Car	0.849	0.601
ChildNursery_2+Adult_1Car	0.438	0.417
ChildNursery_2+Adult_2+Car	0.519	0.469
ChildSchool_1Adult_0Car	1.149	1.358
ChildSchool_1Adult_1+Car	1.393	1.329
ChildSchool_2+Adult_0Car	1.323	1.566
ChildSchool_2+Adult_1Car	1.535	1.550
ChildSchool_2+Adult_2+Car	1.613	1.526
ChildTertiary_1Adult_0Car	-	0.223
ChildTertiary_2+Adult_0Car	1.123	0.766
ChildTertiary_2+Adult_1Car	1.049	0.782
ChildTertiary_2+Adult_2+Car	0.986	0.834
UniStudent_1Adult_0Car	0.458	0.650
UniStudent_1Adult_1+Car	0.420	0.263
UniStudent_2+Adult_0Car	-	0.676
UniStudent_2+Adult_1Car	0.204	0.546
UniStudent_2+Adult_2+Car	0.275	0.442

The below Figure 5-5 shows the trip rates plot for HBEd purpose which indicates both urban and rural areas in BSTM2 have similar educational trip making pattern.

Figure 5-5 – HBEd rural and urban trip rates



5.3.2 Non-home-based trip rates

Non-home-based trip rates (Gamma factors as termed in NTEM) were computed to estimate the number of non-home-based trips generated per home-based trip attraction across various purposes. All from-home based trips were classified into five categories – HBW, HBEB, HBL, HBPS, HBEd, and all non-home-based trips classified into two categories – NHBEB and NHBO. These seven categories of trips were summarised based on number of trips within the same tour and the non-home-based trips were attached to the preceding home-based trip categories within the same tour to determine the home-based trip purpose and calculate trip rates. Table 5-13 presents the NHB trip rates from national NTS data.

Table 5-13 - NHB daily trip rates per HB trip attraction (Gamma factors)

HB Purpose	NHBEB trip rate (gamma) per HB attraction	NHBO trip rate (gamma) per HB attraction
HBW	0.042	0.126
HBEB	0.229	0.093
HBEd	0.002	0.094
HBPS	0.010	0.166
HBL	0.008	0.159

The probability of generating non-home-based employer's business (NHBEB) trip is higher from a home-based employer's business (HBEB) trip. Non-home based other (NHBO) trips have a good probability of being generated from all the home-based trips with the highest trips generated from shopping and recreation trips.

5.4 Demand inputs to the VDM

5.4.1 Trip Productions

Home-based trip productions are calculated by multiplying the segmented resident population in each zone with the relevant trip rates for the area type of the zone. Workers derived from the population estimates are then used to calculate commute and business trip productions using NTS trip rates by area and purpose. Trip productions for discretionary purposes are derived by applying trip rates on entire segmented population.

Non-home-based trip productions are generated within the VDM by applying the NHB trip rates (gamma factors) to the modelled zonal home-based trip attractions by purpose. The trip productions for all the purposes are presented in Appendix D.

5.4.2 Trip Attractions

The base year trip attractions are primarily built up from 2019 NTEM v8.1 forecasts with some additional checks performed against known attractors. For the VDM, the absolute volumes of attractions are less important than the distributional weighting (attraction weights for modelling purposes) of these attractions.

Considering the good correlation of normalised growth between NTEM and ONS Job density data by district, it is assumed that the NTEM jobs have grown with the right distribution by MSOA from the 2011 NTEM base year to the 2019 BSTM2 base year.

Therefore, the NTEM jobs data by MSOA are used with adjustments at district level to develop BSTM2 base year home-based work and employers' business trip attractions across the entire BSTM2 model. The total jobs at district level are adjusted to meet target job growth from 2011-2019 based on observed Nomis Job Density data.

School capacity data is used as attractors for education trips by school stage. For discretionary purposes, NTEM attractions are directly used with zonal distributions applied based on 2011 Census OA level employment. The trip attractions for all purposes are presented in Appendix D.

5.4.3 External Trip ends

In terms of trips to and from the external area, only trips interacting with the internal area are considered by the VDM. For trip ends, this means that external trip productions are only considered where the attraction is within the internal area, and vice versa for trip attractions. The JTW proportions for the external attraction was only applied for the home-based work purpose. The external non-home base trip productions are estimated based on the gamma factors presented in the Table 5-13. The gamma factors are used to estimate the number of non-home-based trips generated per home-based trip attraction across various purposes. External trips for education purposes are not considered, as the majority of these trips (children going to nurseries and schools) occur within the same council area. Based on JTW data, the proportion of trips originating from Buckinghamshire to all external zones is within 29%. Therefore, the external attractions originating from the BSTM2 AoDM have been capped at 30%.

Table 5-14 - External Production Attraction for all purposes in VDM

Purpose	External Production	External Attraction
HBW	NTEM*JTW Proportion	NTEM*JTW Proportion
HBEB	NTEM*JTW Proportion	NTEM*30%
HBEd	NA	NA
HBL	NTEM*JTW Proportion	NTEM*30%
HBPS	NTEM*JTW Proportion	NTEM*30%
NHBEB	NA	NTEM*30%
NHBO	NA	NTEM*30%

5.5 Other NTS sources for calibration

NTS trip characteristics were also used to compute mode shares and trip length distributions by trip purpose used in the calibration of the variable demand model. Trips were summarised based on aggregated mode and trip length categories at National level. Figure 5-6 below shows the average mode share by for the whole weekday.

Car has the dominant share for all the home-based and non-home-based trip purposes except for education. For education purpose, car and walk both have equally significant shares. Rail has very small share for most purposes except for employer's-business and commute trips. Likewise, cycle too has a very small share of trips for most purposes except for commute. Bus shares are generally low for all trip purposes except education.

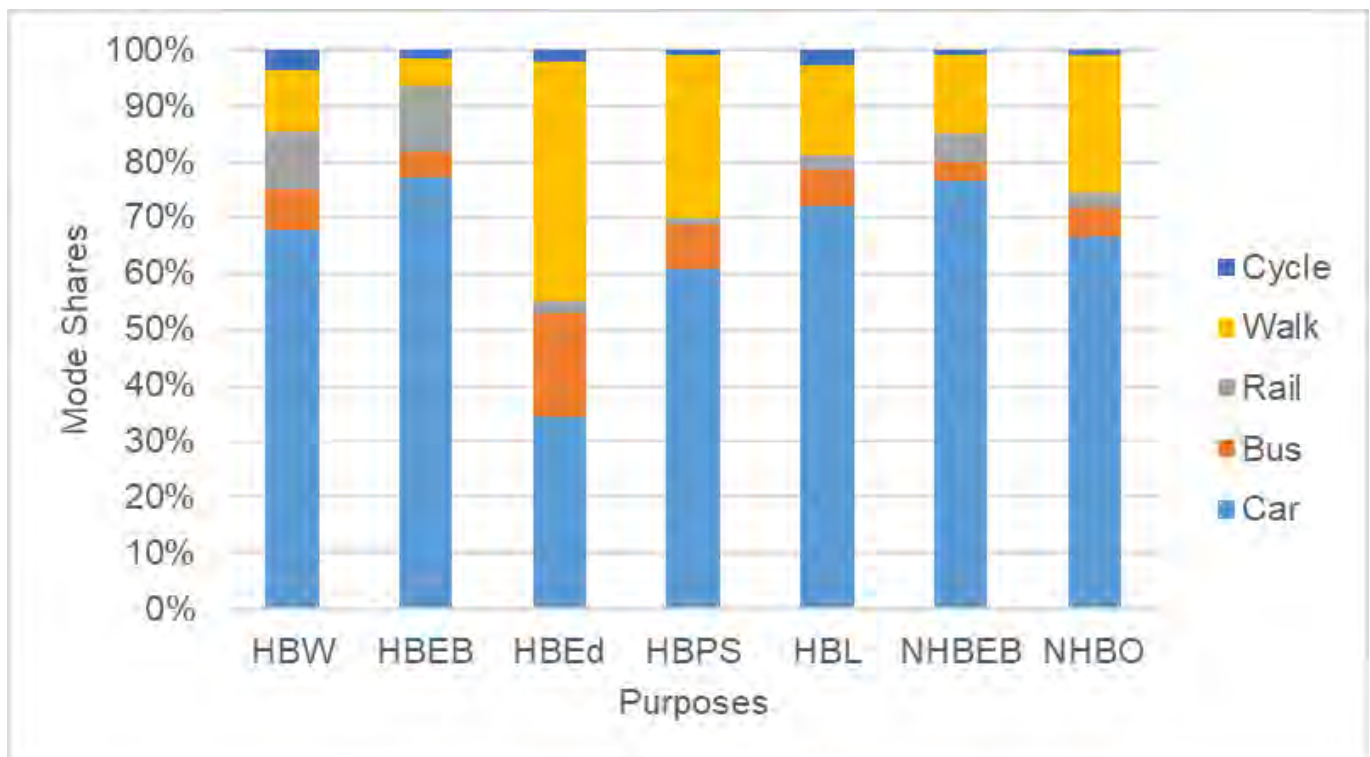
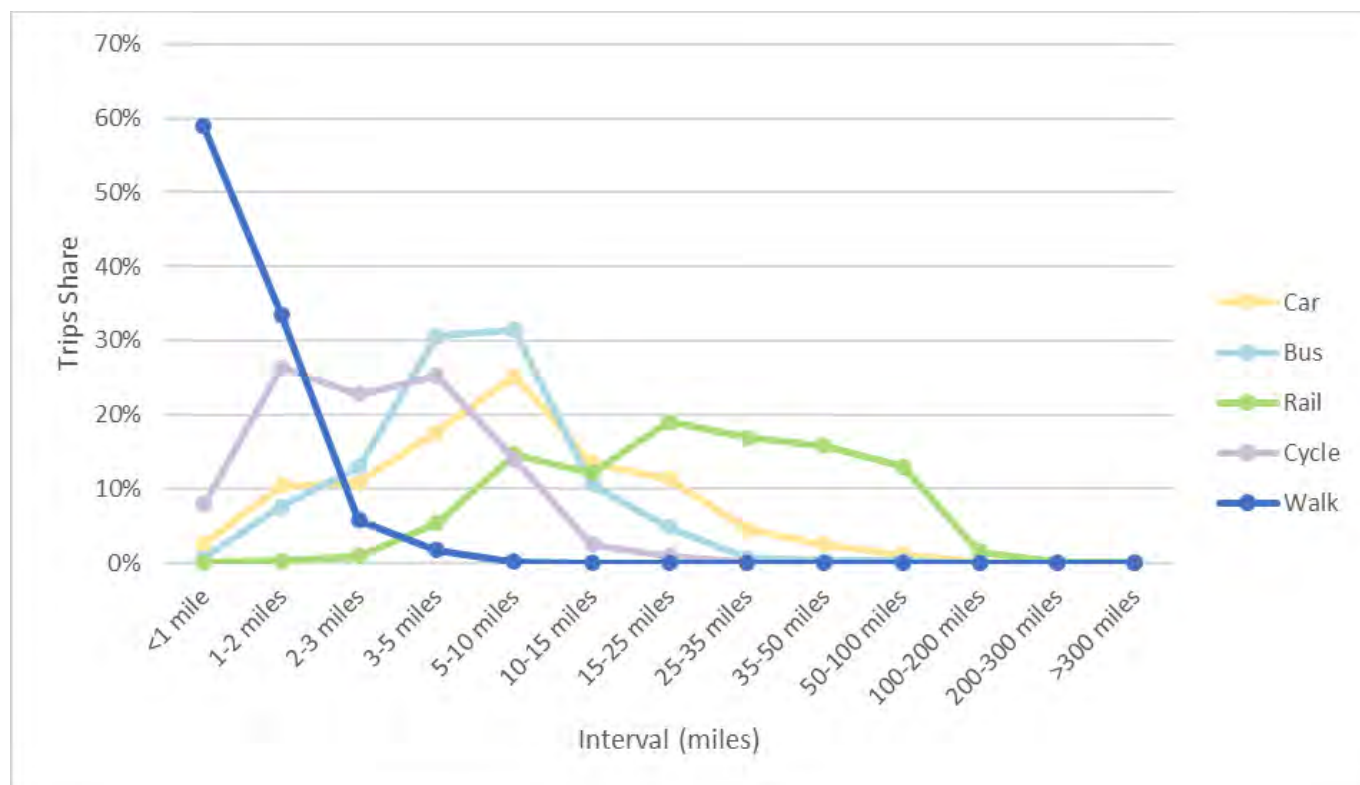
Figure 5-6 – Percentage trips by mode share across Trip Purposes - All day

Figure 5-7 shows the trip length distributions for all modes for commute trips. Work trips are accommodated mainly under the bands ranging from 2 miles to 15 miles which has the peak shares for car, bus and cycle. Walk trips are

dominant only under the <2-mile band and fall sharply thereafter. Rail peaks at 15-25 miles category which is due to commuters travelling outside the region.

Figure 5-7 – Percentage trips by distance bands for HBW trips – All day



6. Variable Demand Model Structure

6.1 Introduction

The basic structure of the variable demand model (VDM) was outlined in Chapter 2. This chapter expands on those details, providing a more in-depth explanation of the VDM's development. It specifically describes how the VDM, Highway Assignment Model (HAM), and Public Transport components are integrated through the exchange of demand and skim information. The chapter also covers key processes such as pivoting, supply/demand iteration, and model convergence checks.

6.2 Model form

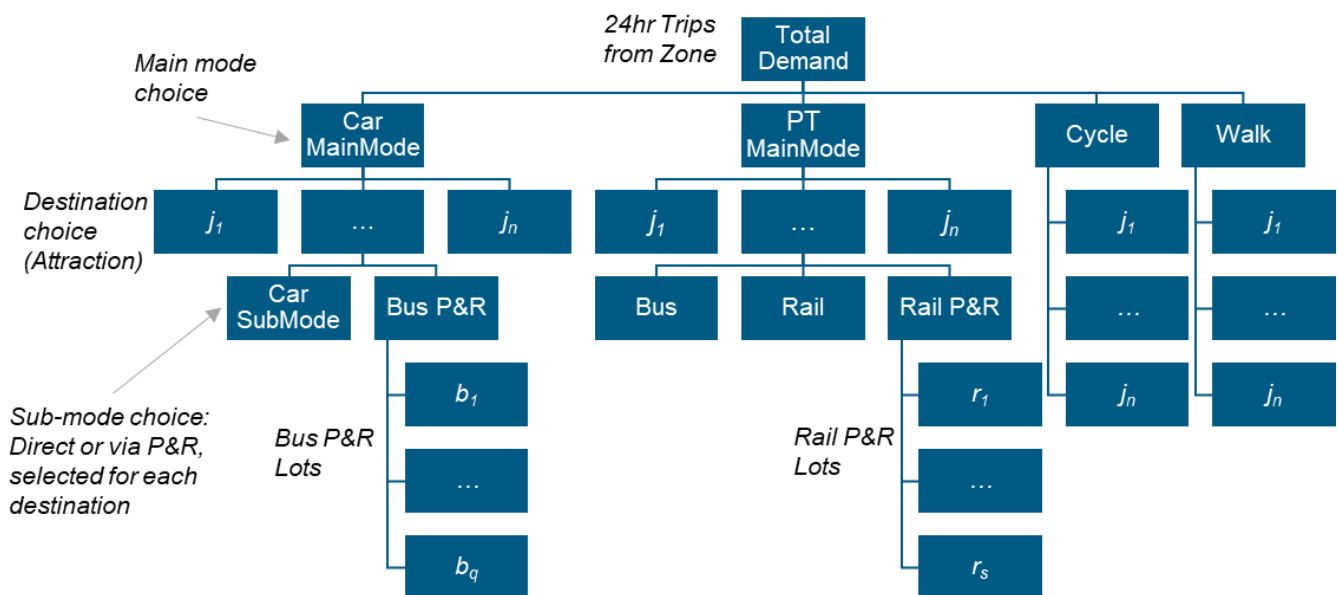
The VDM takes the form of an absolute model, applied incrementally (AMAI) using 24-hour P-A trips for a neutral average weekday, and is implemented in PTV VISUM. All input information, including trip ends, journey skims, and parameter settings, are stored in PTV VISUM at the beginning of a VDM model run, while the model results are stored as internal VISUM matrices.

The VDM process is implemented using the VISUM Nested Demand Model function, which is called from a VISUM Procedure Sequence that controls the entire iteration process of the VDM and assignment models. The demand segmentation for the VDM is detailed in section 2.8, and the choice structure for each segment is set out below. The calibrated choice model parameters are provided in section 6.10.

6.3 Demand model choice structure

The VDM includes mode and destination (attraction) choices but does not incorporate a macro time-of-day choice. In accordance with TAG guidance, it is assumed by default that the main mode choice is less sensitive than the destination choice and therefore is placed above it in the choice hierarchy. The sub-mode choices, which include Car and Bus Park & Ride (P&R), as well as Bus, Rail, and Rail P&R, are positioned below the destination choice. The lowest level of the hierarchy is the choice of the P&R site (referred to as P&R Lot choice in VISUM terminology), as illustrated in Figure 6-1.

Figure 6-1 – BSTM2 choice model hierarchy



6.4 Singly and doubly constrained distributions

TAG unit M2.1, section 4.9.3, states that “it is common to use doubly-constrained models for forecasting commuting and education trips, so that each zone attracts and generates a fixed total of work trip ends, and singly-constrained models for other purposes, where only the total number of trips generated in each zone is fixed.”

Doubly constrained distribution models ensure that a fixed number of attractions are allocated to each zone through balancing factors, which are derived via an iterative process during the choice modelling. In the BSTM2 VDM, home-based work (HBW) and home-based education (HBEd) trips are doubly constrained, as shown in Table 6-1 below.

All segments of HBW are collectively constrained to a single attraction, based on the distribution of total jobs across zones². HBEd is constrained by education stage, based on age bands to the total number of school places at that education stage, distinguishing between primary, secondary and sixth form stages. Education trips generated for students aged 19+ are added to shopping and personal business before VDM.

All other trip purposes are singly constrained with attraction weights derived from NTEM data for the specific purpose.

² PTV VISUM interprets all attraction weights and constraints as percentage distributions. Absolute values can be entered but only the relative size is considered. Hence the units are not relevant and there is no need to match trip productions to attractions as this is assumed.

Table 6-1 - Purpose wise trip distribution type

Purpose	Distribution Type
HBW	Doubly Constrained
HBEd	Doubly Constrained
HBPS	Singly Constrained
HBL	Singly Constrained
HBEB	Singly Constrained
NHBEB	Singly Constrained
NHBO	Singly Constrained

6.5 Representation of parking

In the BSTM2, parking is represented as an additional cost associated with travelling to a given zone by car. For instance, if a car trip travels from zone A to zone B, a parking cost penalty is calculated based on parking fees in zone B, as well as the availability and time required to search for a parking space. This parking charge is then added to the total generalised cost. The parking charges are applied to specific urban destination zones within the model's internal area, such as Aylesbury, Buckingham, High Wycombe, Amersham, and others.

The parking charge is implemented for:

- Urban areas: Individual zones with unique charges; and
- Park & Ride Lots: single zones used to represent Bus P&R sites or railway stations (see section 6.6.1 on Approach to P&R).

Parking costs for car parks, Bus P&R and railway stations (considered Rail P&R in the model) are sourced from BC through Mipermitt website, with the average parking cost determined according to the expected length of stay by trip purpose.

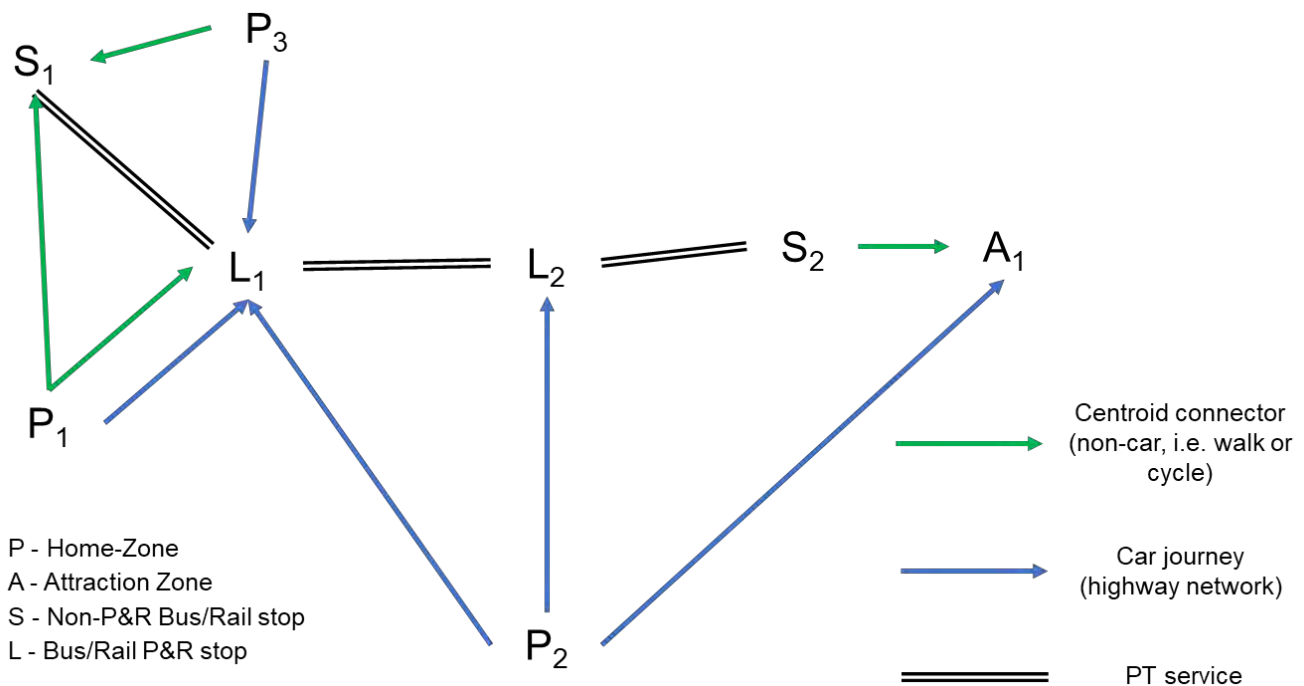
6.6 Approach to Park and Ride

6.6.1 Overview of P&R approach

Historically, park & ride (P&R) has often not been explicitly represented in the base year of multi-modal models. Instead, access to railway stations and bus P&R sites was represented through "access links" from specific zones. As a result, the P&R mode is typically absorbed into the general public transport category, with no explicit consideration of the access mode. This approach complicates the testing and appraisal of future P&R sites, often requiring workarounds and estimates to account for these elements.

PTV VISUM enables the modelling park & ride via 'Lots'. Any PT boarding point can be designated as a P&R Lot, whether bus or rail. Within the PT and highway models, each P&R Lot is treated as a zone: the drive leg to/from the P&R Lot and the PT leg between the P&R Lot and the destination are handled separately by VISUM, allowing them to be incorporated into the car and PT trips for assignment, respectively. Additionally, the option to use a walk/cycle leg to access the PT boarding point remains available where applicable. The functionality and connectivity provided in VISUM and implemented in BSTM2 is illustrated in Figure 6-2.

Figure 6-2 – Approach of park & ride for BSTM2



6.6.2 Key elements of P&R approach

TAG unit M5.1 provides guidance on the treatment of P&R trips within a VDM. It is recommended that P&R modes are treated as sub-modes of either car or PT, depending on the relative length of each leg of the trip. Accordingly, Bus P&R is treated as a sub-mode of Car, whereas Rail P&R is treated as a sub-mode of PT. This distinction is implemented by categorising the main modes for Car (comprising sub-modes for Car only and Bus P&R) and PT (comprising Bus, Rail, and Rail P&R sub-modes).

- The choice to use P&R is determined in the VDM as a sub-mode choice, rather than as a routeing choice
- Both bus and rail have separate P&R sub-modes, bus as a sub-mode of car and rail as a sub-mode of PT (default position, note it's easily reconfigurable, but each lot needs to be assigned to a sub-mode)
- Each P&R lot is assigned a zone number. This zone has ZERO or NULL trip ends and is not directly recognised by the VDM but is used by the HAM.
- VISUM handles the creation of the generalised cost for each P&R sub-mode by adding the costs of each leg of the trip.
- VISUM also then splits the P&R sub-mode demand into home->Lot and Lot->Destination by mode (car / bus / rail).

It is noted that TAG unit M3.2 specifies modelling the use of car access to PT services in two general forms, namely:

- **Kiss and Ride:** public transport user is driven to the stop / station and picked up again on the return journey
- **Park & Ride:** which may involve either the use of a designated park-and-ride site, parking at stations, or informal parking in streets surrounding stations

The P&R function within the model does not differentiate these two modes, so that implicitly any P&R trip could be in the form of Kiss and Ride. The cost-sharing aspect of this is dealt with via occupancy factors in the generalised cost equations. The next leg of the driver trip (onward to a further destination or home) is not explicitly handled

within the VDM but is assumed to be represented in the validated base year HAM assignment matrices. Hence using the pivot process growth in trips to/from the P&R zone should deliver growth in the appropriate vehicle trips in the HAM.

6.6.3 Implementation in VISUM

Park & Ride lot choice is implemented using the standard VISUM functionality as set out in section 4.2.12.1 of the VISUM manual. The procedure allocates given demand to each P&R lot via the following steps:

- A shortest path search for all O-D pairs on 24-hr P/A trips to find the most attractive route via the available park & ride lots
- An attraction weight is applied, based on the P&R capacity defined
- Another shortest path search is completed to find a second (now best) route:
 - a. Demand is shifted from one path to another until the costs of both routes are the same (for each O-D pair)
 - b. Further shortest path searches are performed, and costs updated until the gap is closer to zero, where the gap is calculated as follows:

$$Gap = \frac{\sum_p U_p}{\sum_p U_p^{SP}}$$

where U_p is updated cost of a path p once the demand has been shifted;

U_p^{SP} is the shortest path cost.

It is noted that as the impedances are altered until all paths between an O-D pair have the same impedance value, the resulting skim matrix doesn't require any averaging across paths.

6.7 Network skims

6.7.1 Overview

Network skims are available to the VDM from the highway assignment model (HAM) and TRACC Public Transport skims. The highway and public transport skims are provided by assignment user class (AUC), time period and Origin-Destination (O-D) pair, and hence relate to the individual out and return sections of a P/A trip.

6.7.2 Car

The HAM skims are available separately for distance, time and tolls of each O-D pair and period, skimmed directly from the HAM as a flow-weighted average across all paths between an O-D pair, AUC and time period.

Note whilst intra-zonal skims provided by the HAM are zero, these are re-calculated as half the zonal minimum row or column value for use in the VDM.

The HAM skims are refreshed in the VDM following each iteration between the assignment model and VDM, to allow for responses to highway congestion to be incorporated in the VDM.

6.7.3 Public Transport

6.7.3.1 Generation of Skims

Public Transport skims for each mode (i.e. bus and rail) are extracted from TRACC in the form of in-vehicle time, access and egress time, wait time, and number of interchanges for each origin-destination trip by time period. Based on interchange modes, public transport skims are extracted for bus (i.e. bus-bus interchange only) and rail (rail-rail, bus-rail and rail-bus interchange modes). It is to be noted that far external zone skims have been extracted for rail mode only. The outcomes of PT skims from TRACC are listed below in Table 6-5.

Table 6-2 - TRACC Skim Outcomes

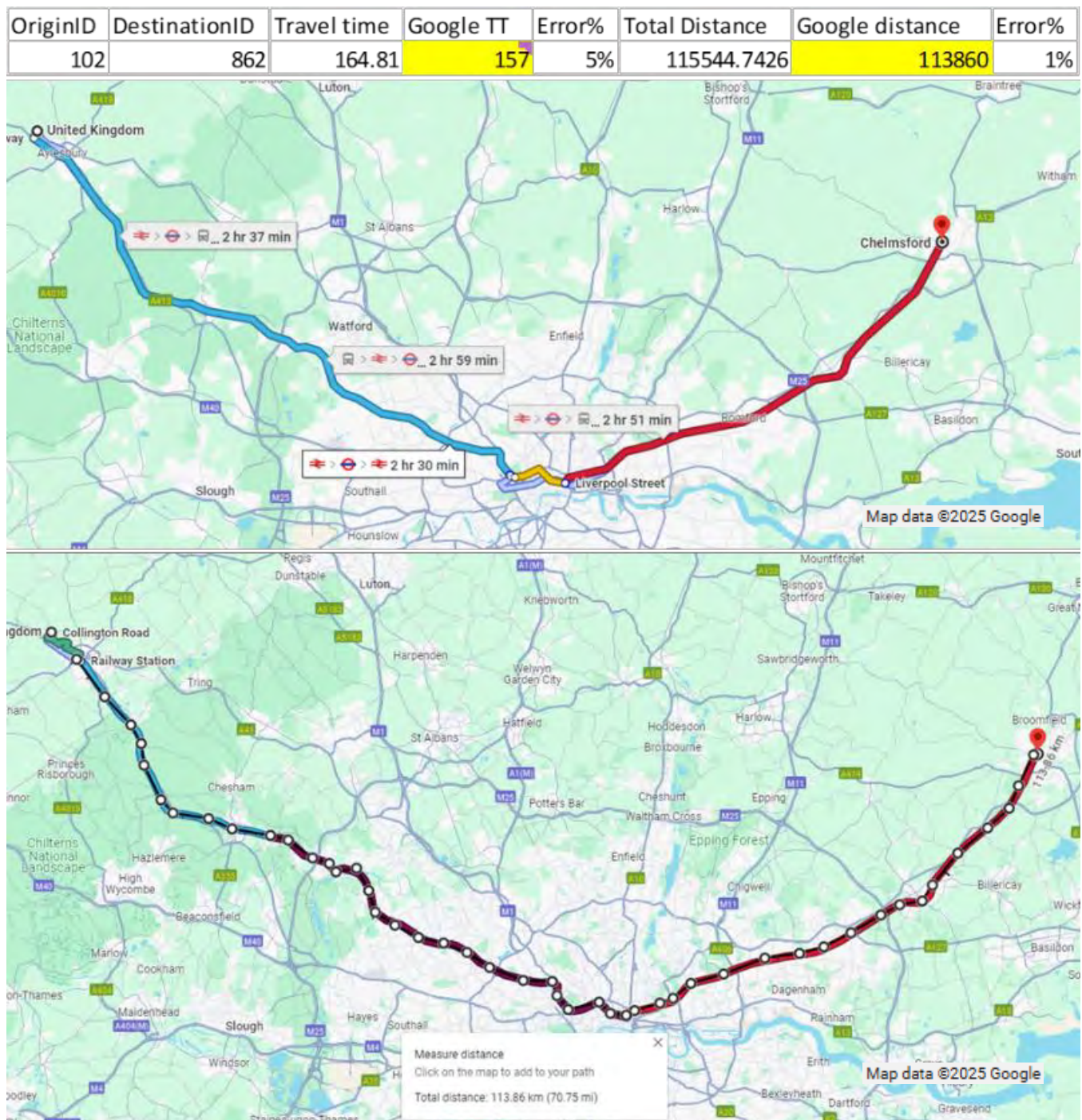
S.No	Components	Units
1	Number of services	number
2	Number of interchanges	number
3	Total walk time	minutes
4	Access walk time	minutes
5	Egress walk time	minutes
6	Interchange walk time	minutes
7	In-Vehicle ride time	minutes
8	Total wait time	minutes
9	Total distance	metres

6.7.3.2 Skims processing and checks

Once TRACC skims are generated for bus and rail, checks were made against the input assumptions for all the components presented in Table 6-2. A unique list of OD skim data was derived based on the dominant mode in the overall trip. This data has been used as input for VDM. It is to be noted that origin wait time cannot be extracted from TRACC, which assumes travellers arrive just in time for the first PT service for their journey. Origin wait time is therefore estimated based on headway assumptions as discussed in section 6.9.4 .

The accuracy of skims derived have been checked against alternative data (i.e. measured in google maps) for a sample of OD pairs in different time periods. The observed travel times for bus and rail are within $\pm 10\%$ when compared against TRACC skims. One example of the checks can be found in Figure 6-3.

Figure 6-3 – Snapshot for TRACC skim check with respect to Google maps



6.7.4 Walk and Cycle

Active travel skims derive distances by taking the shorter of two options: the interpeak uncongested highway distance for the 'car other' user class, or the bus distance skims from TRACC. A fixed speed of 4kph for walking and 12kph for cycling was assumed. Again, intra-zonal movements are re-calculated as half the zonal minimum row or column value for use in the VDM.

6.8 Monetary costs

6.8.1 Car

6.8.1.1 Vehicle Operating Costs

The base year vehicle operating costs (VOCs) are calculated in the VDM using the standard formulation set out in the TAG data book. In line with guidance, fuel costs are included for all trip purposes, whilst non-fuel costs are only perceived by the employer's business trips.

The VDM includes the VOCs for cars as part of the generalised cost formulation and uses speed (distance / time) for each zone pair to determine the VOCs by segment using the TAG data book (November 2023 v1.22) formula shown in equation (6.8.1). See Appendix A for information on the notation used in the equations shown.

$$VOC_{car,o,d,auc} = \left(\frac{a_{auc}}{v_{car,o,d,auc}} + b_{auc} + c_{auc} \times v_{car,o,d,auc} + d_{auc} \times v_{car,o,d,auc}^2 + a1_{auc} + \frac{b1_{auc}}{v_{car,o,d,auc}} \right) \times dist_{o,d,auc} \quad (6.8.1)$$

Where:

$v_{car,o,d,auc}$ is the average speed of travel from origin o to destination d for the assignment user class auc (based on the distance and time skims from the HAM)

a, b, c, d are parameters specific to assignment user class, auc , determining the fuel cost from the TAG data book

$a1, b1$ are parameters specific to assignment user class, auc , determining the non-fuel costs

$dist_{o,d,auc}$ is the distance skimmed from the highway assignment model for the auc .

The VOC parameters for car in the base year VDM are shown in Table 6-3. The choices of mode and destination made in the VDM hence consider differences in speed of travel between the alternatives available.

Table 6-3 - VDM vehicle operating cost parameters

Parameter to VOC	Non-work - TAG data book (v1.22) A1.3.13 (2019 prices and values)	Work - TAG data book (v1.22) A1.3.12 and A1.3.15 (2019 prices and values)
a	54.946	45.788
b	9.711	8.097
c	-0.103	-0.086
d	0.001	0.001
a1	0.000	5.704
b1	0.000	158.176

6.8.1.2 Parking costs

Parking costs are collated for car parks provided by the relevant local authorities within the BSTM2 internal area. Both long stay (all day) parking costs and short stay parking costs were collated and applied to each trip purpose as appropriate, as shown in Table 6-5. These costs are used to derive an additional penalty to be added to the overall

car generalised costs (maximum cost for long stay is all day, while for short stay is 2 hours). These parking costs are applied at zone level in the model, and the selection of zones where parking charges apply is shown in Figure 6-4 below. The charges applied to individual zones are listed in Appendix B. Additionally, since London is in close proximity to Buckinghamshire, car parking charges are applied in both inner and outer London in accordance with Transport for London's congestion charges. The car parking charges applied for London is shown in Table 6-5.

Table 6-4 - Parking charge applied by purpose

Purpose	Charge
HBW	Long stay
HBEB	Short stay
HBEd	No charge as education trips are largely 'drop-off' trips
HBPS	Short stay
HBL	Short stay
NHBEB	Short stay
NHBO	Short stay

Figure 6-4 – Model zones within AoDM with parking charges applied

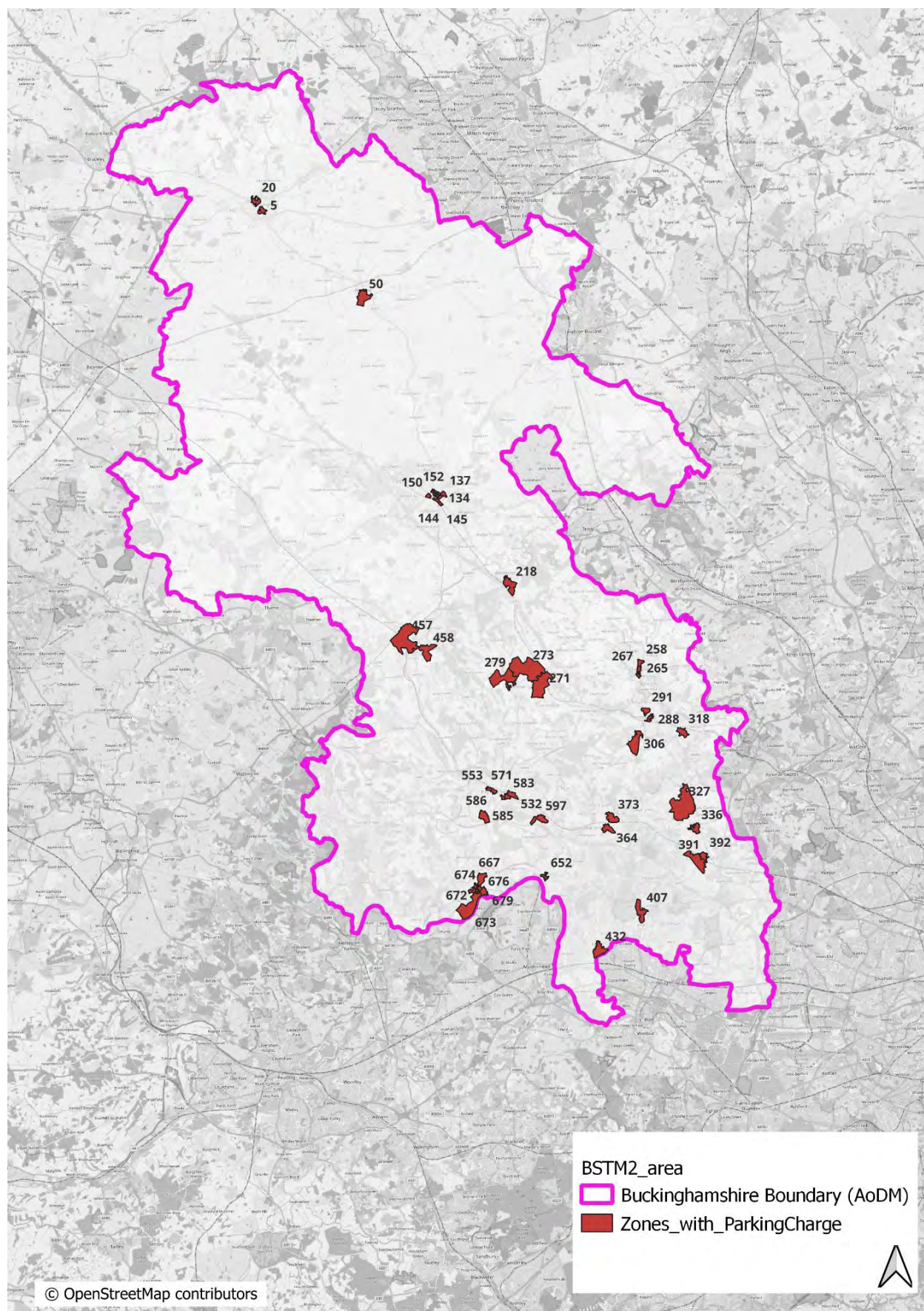


Table 6-5 - Parking charge applied for London

Parking Charges (in Pounds)	Inner London	Outer London
Long Stay	£15	£10
Short Stay	£10	£3

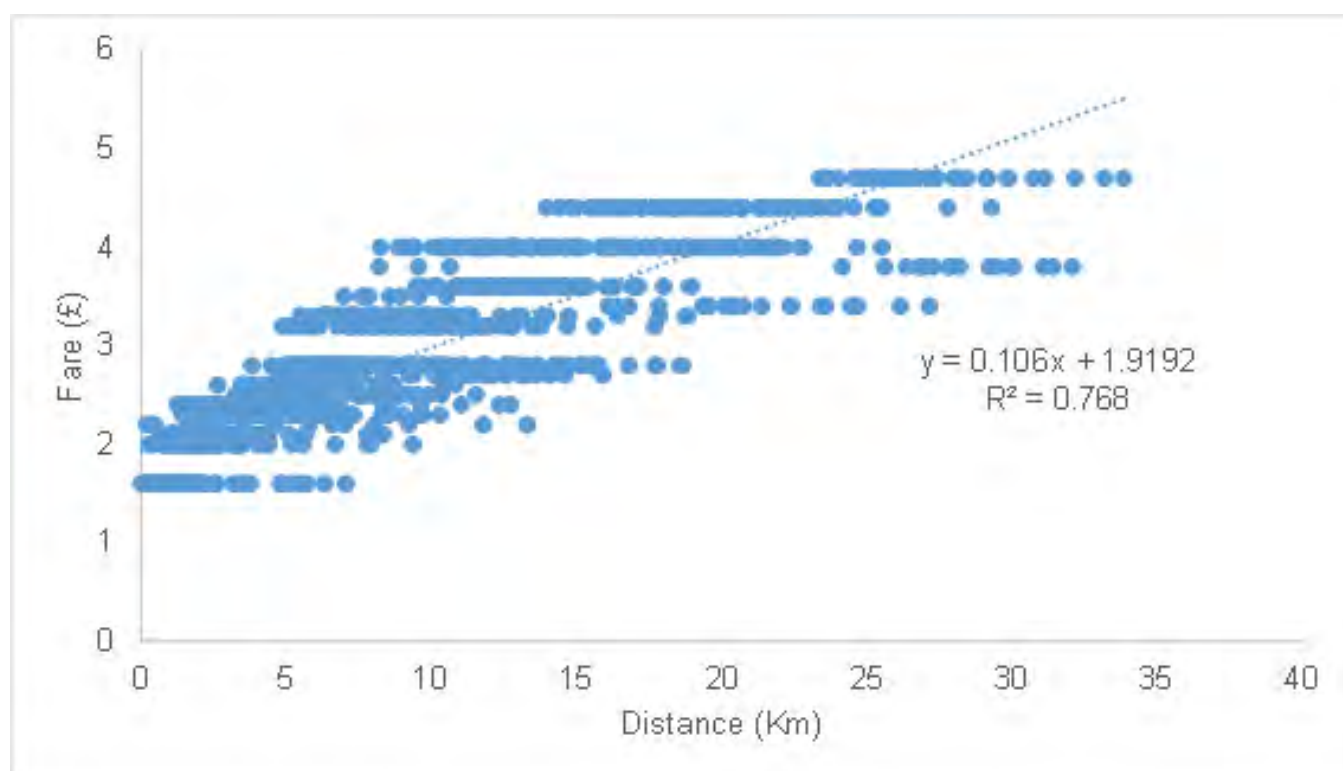
6.8.2 Public Transport

The fare skims for each OD pair are derived separately for bus and rail using a distance-based fare model developed based on sample routes. Fare data has been collated from operators/ website for the key destinations whereas distance skims are gathered from TRACC. Both fare and distance are used for developing fare models. There are no other explicit monetary costs that are considered within VDM.

6.8.2.1 Bus Fares

Due to the insufficiency of accurate bus fare data received for the base year 2019, fare model has been adopted from other region models in UK which was developed using bus fares against distance travelled. Figure 6-5 shows a good correlation of bus single ticket fare against distance travelled.

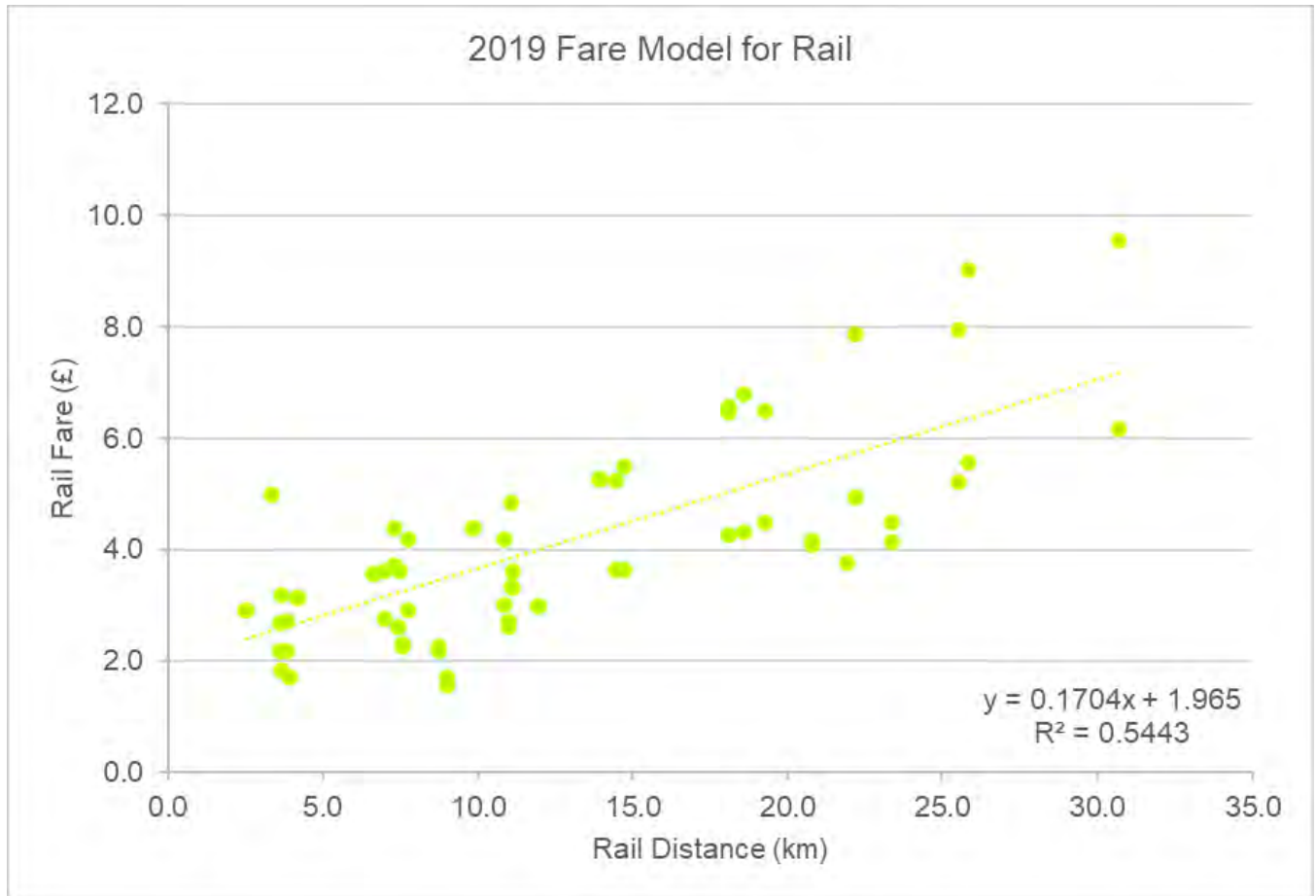
Figure 6-5 – Bus Fare Model



6.8.2.2 Rail Fares

Latest rail fare data (i.e. 2024) at station-to-station level (i.e. representative zone to zone level) is extracted from brfares website for these OD pairs. This rail fare data was then converted to 2019 base year using Retail Price Index conversion factor. Distance for these OD pairs is taken from TRACC skims. Fare model is a regression analysis arrived by plotting the rail fares against the distances. Figure 6-6 shows the correlation of rail single ticket fare against distance travelled.

Figure 6-6 – Rail Fare Model



6.9 Generalised cost

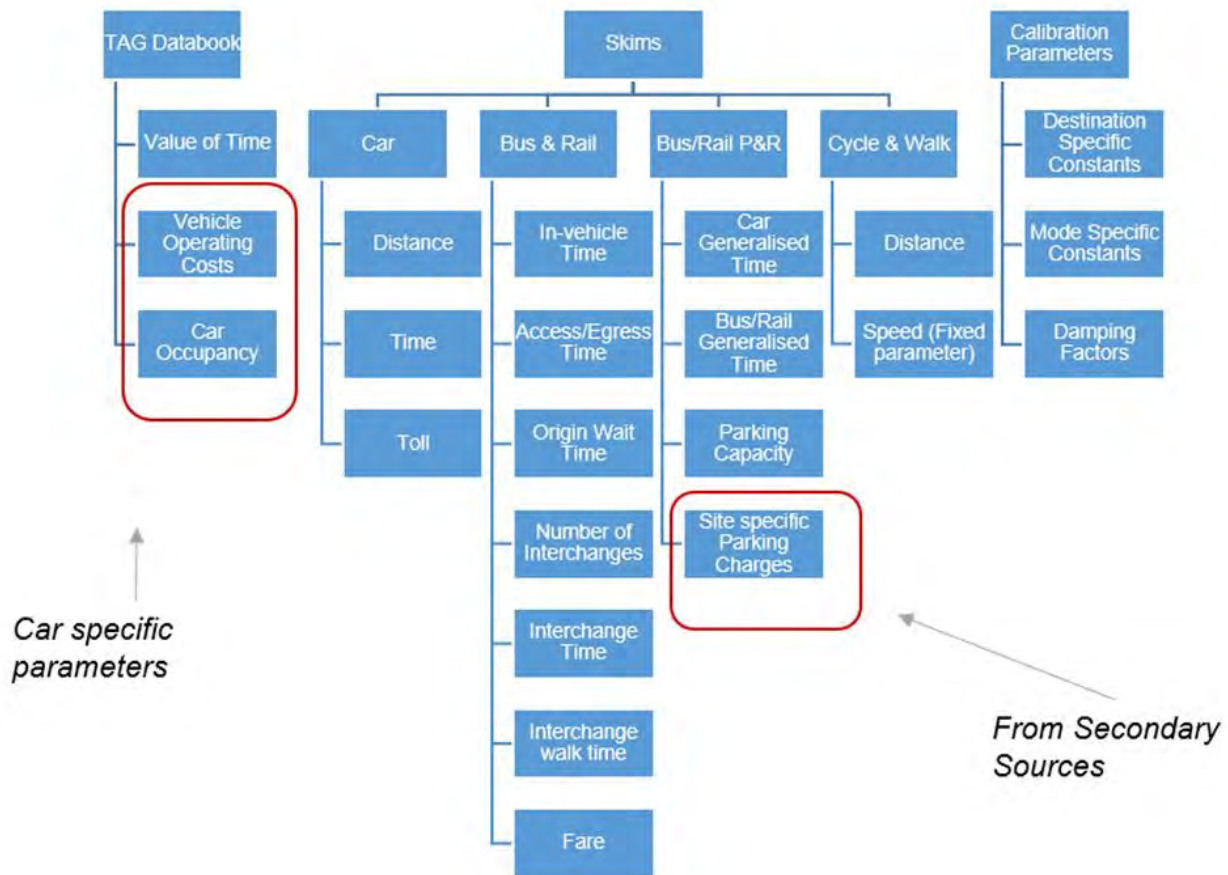
TAG unit M2.1 section 3.1 states that “*all transport modelling should recognise that people’s travel choices depend upon the cost, in both time and money. It is important to combine time and money into a single disincentive to travel (“disutility”), so that demand can be assumed to rise or fall with reductions or increases in either. To do so, it is necessary to apply appropriate weights to the time and money components of this combined cost so that travellers can trade money for time, such as in choosing between a faster but more expensive mode or a slower but cheaper option.*”

In the BSTM2, the disincentive to travel is represented by a generalised cost, G , in units of minutes. This generalised cost combines the time components of a trip with the monetary costs, which are converted into time units.

Figure 6-7 below shows the various components used in the generalised cost formulation. The figure is categorised based on the data type or source. TAG data book and calibration parameters are more generic and apply across all the modes, except for car specific TAG values. The generalised cost for car additionally includes the parking charge.

The remaining sections provide the mathematical formulation showing how the generalised cost is calculated for each mode. Further information on the notation used in the equations is provided in Appendix A.

Figure 6-7 – Components of generalised cost



6.9.1 O-D to P/A conversion

The skims input into the VDM to derive the generalised cost are primarily calculated during the assignment models and are therefore defined for peak hour origin-destination (O-D) trips for car and peak period O-D trips for bus and rail. For the VDM, typical P/A costs are required for travel on a neutral day, and thus a conversion process must be performed. For each home-based trip purpose, the 24-hour P/A costs are calculated by summing the out-and-return O-D costs. For each trip purpose, primary out and return time periods are defined based on the period in which the most trips occur, as outlined in Table 6-6.

Table 6-6 - Out and return time periods for P/A generalised costs

Trip Purpose	Car AUC	PT AUC	Outbound Time Period	Return Time Period
HBW	CC	PTC	AM	PM
HBEB	CB	PTB	AM	PM
HBEd	CO	PTE	AM	IP
HBPS	CO	PTO	IP	IP
HBL	CO	PTO	IP	IP
NHBEB	CB	PTB	IP	N/A
NHBO	CO	PTO	IP	N/A

* Note: PT represents both bus and rail.

6.9.2 Generalised cost damping

TAG unit M2.1 section 3.3 states that “there is strong empirical evidence that the sensitivity of demand responses to changes in generalised cost reduces with increasing trip length” and hence recommends that damping is applied. A variety of methods for damping are set out to either vary the value of time (VoT) by distance or raise the generalised cost to a power. Damping was tested during the calibration phase with the use of a power function as set out in equation (6.9.2).

$$G' = \mu G^{\kappa} \quad (6.9.2)$$

Here $0 < \kappa \leq 1$ and $\mu > 0$.

The values of κ and μ were calibrated during model development, initially set to 1 for each, meaning no damping was applied. The model calibration for car and bus modes worked well without damping, so damping is only applied to the rail mode. The damping parameters used in the model by mode are presented in Table 6-7.

Table 6-7 - Damping values for car and PT

Purpose	Car		Bus		Rail	
	κ	μ	κ	μ	κ	μ
HBW	1.00	1.00	1.00	1.00	0.87	1.82
HBEB	1.00	1.00	1.00	1.00	0.87	1.82
HBEd	1.00	1.00	1.00	1.00	0.87	1.82
HBL	1.00	1.00	1.00	1.00	0.87	1.82
HBPS	1.00	1.00	1.00	1.00	0.86	1.82
NHBEB	1.00	1.00	1.00	1.00	0.87	1.82
NHBO	1.00	1.00	1.00	1.00	0.87	1.82

6.9.3 Car generalised cost

The generalised cost of an O-D person car trip has the following form:

$$G_{car,ds} = k_{car,p} + k_{car,ds} + Time_{car,auc} + \frac{VOC_{car,auc}}{O_{car,p} \times VoT_{car,p}} + \frac{Toll_{car,auc}}{O_{car,p} \times VoT_{car,p}} + \frac{Parking\ Cost_{car,p}}{O_{car,p} \times VoT_{car,p}} \quad (6.9.3)$$

Where: $k_{car,p}$ & $k_{car,ds}$ are calibrated alternative specific constants, kept fixed in all forecast scenarios $Time_{car,auc}$ and $Toll_{car,auc}$ are skims from the highway assignment model for the O-D pair

$Parking\ cost_{car,p}$ for each trip purpose as described in Table 6-5

$O_{car,p}$ is the car occupancy as specified in Table 6-18

$VoT_{car,p}$ is the value of time as specified in Table 6-8

and $ds \in p \in auc$.

This can be re-written as:

$$G_{car,ds} = k_{car,p} + k_{car,ds} + Time_{car,auc} + \frac{Cost_{car,auc}}{O_{car,p} \times VoT_{car,p}} \quad (6.9.4)$$

$$Cost_{car,auc} = VOC_{car,auc} + Toll_{car,auc} \quad (6.9.5)$$

In addition to the time and monetary components of the generalised cost, there are mode and segment specific constants that are considered in the VDM. Furthermore, to represent the generalised cost for a P/A trip, the O-D generalised costs for both the out (from home) and return (to home) trips are considered as discussed in 6.9.1. Hence, the total generalised cost becomes:

$$G_{car,i,j,ds} = k_{car,p} + k_{car,ds} + \left(Time_{car,o,d,auc}^{Out} + Time_{car,o,d,auc}^{Return} \right)^T + \left(\frac{Cost_{car,o,d,auc}^{Out}}{O_{car,p} \times VoT_{car,p}} + \left(\frac{Cost_{car,o,d,auc}^{Return}}{O_{car,p} \times VoT_{car,p}} \right)^T \right) + \frac{Parking\ Cost_{car,p}}{O_{car,p} \times VoT_{car,p}} \quad (6.9.6)$$

Table 6-8 - VDM Value of Time (pence per minute, 2019 prices and values)

Purpose	Value of Time		
	Car	Rail	Bus, Walk & Cycle
HBW	21.64	21.64	21.64
HBEB	32.31	53.30	18.31
HBEd	9.88	9.88	9.88
HBL	9.88	9.88	9.88
HBPS	9.88	9.88	9.88
NHBEB	32.31	53.30	18.31
NHBO	9.88	9.88	9.88

Source: TAG databook (November 2023 v1.22) table no. A1.3.1

6.9.4 PT generalised cost

Equation 6.9.7 below gives the form of the generalised cost for a PT trip (*PT* representing either bus or rail):

$$G_{PT} = \alpha \times Access_{PT} + \beta \times Wait_{PT} + \gamma \times Interchange_{PT} + \varepsilon \times Ride_{PT} + \frac{Cost_{PT}}{VoT_{PT}} \quad (6.9.7)$$

The equation used to build generalised cost at 24-hr P/A is described below.

$$G_{PT,i,j,ds} = k_{PT,p} + k_{PT,ds} + PJT_{PT,o,d}^{out} + \frac{Fare_{PT,o,d,p}^{out}}{VoT_{PT,p}} + \left(PJT_{o,d,PT}^{Return} + \frac{Fare_{o,d,PT,p}^{Return}}{VoT_{PT,p}} \right)^T \quad (6.9.8)$$

Where: k are calibrated alternative specific constants, kept fixed in all forecast scenarios

$PJT_{PT,o,d}$ is the time element of the generalised cost as defined in equation 6.9.9

$Fare_{PT,o,d,p}$ is the fare calculated from the fare model derived using data from brfares website for the O-D pair

$VoT_{PT,p}$ is the value of time as specified in Table 6-8.

and $ds \in p \in auc$

$$PJT_{PT} = Invehicle\ time * Fac_{IVT} + Access\ time * Fac_{ACT} + Egress\ time * Fac_{EGT} \\ + Transfer\ walk\ time * Fac_{WKT} + Origin\ wait\ time * Fac_{OWT} + Transfer\ wait\ time \\ * Fac_{TWT} + Number\ of\ transfers * Fac_{TRN} + Number\ of\ operator\ changes * Fac_{OC} \quad (6.9.9)$$

Where the time elements are skimmed from the TRACC software and the Fac parameters are from TAG.

$$Origin\ Wait\ Time\ (OWT) = 3 * \sqrt{Headway} \quad (6.9.10)$$

Individual components for building generalised cost in the PT assignment model as described in equation 6.9.8 are supplied to VDM. The headway for PT to calculate the OWT as shown in equation 6.9.10 has been assumed to be 30 minutes for urban areas and 60 minutes for rural areas.

Additionally, PT trips with very short journey distance get assigned to purely walk legs during the PT assignment and therefore the skim received by VDM won't have PT travel elements included. To account for such PT trips, PT cost elements are added to the generalised cost input to the VDM for any trips less than 2 mile in length in the form of an origin wait time, a boarding penalty and a fare component (£1.1 for education bus, £1.60 for bus all other purposes and £5.00 for rail) as shown in Table 6-9 (note all units are generalised minutes). Table 6-9 shows the Short Distance Trip (SDT) penalty applied to PT trips below 2 mile distance.

Table 6-9 - Additional PT cost elements added for short distance trips

Purpose	Bus			Rail		
	Origin wait Penalty (min)	Boarding penalty (min)	Fare Penalty (min)	Origin wait Penalty (min)	Boarding penalty (min)	Fare Penalty (min)
HBW	15.00	10.00	7.40	20.00	20.00	23.11
HBEB	15.00	10.00	8.74	20.00	20.00	9.38
HBEd	15.00	10.00	11.14	20.00	20.00	50.63
HBL	15.00	10.00	16.20	20.00	20.00	50.63
HBPS	15.00	10.00	16.20	20.00	20.00	50.63
NHBEB	15.00	10.00	8.74	20.00	20.00	9.38
NHBO	15.00	10.00	16.20	20.00	20.00	50.63

6.9.5 Walk and cycle generalised cost

Given that there are no monetary costs associated with walk and cycle trips, the generalised cost equation has a simplified form to take account of the segmentation and purpose mode-specific constants as well as the travel time matrix as set out in equation 6.9.11.

$$G_{m,i,j,ds} = k_{m,p} + k_{m,ds} + (Time_{o,d,m}^{Out} + Time_{o,d,m}^{Return^T}) \quad (6.9.11)$$

Where, m represents walk and cycle and $ds \in p$.

6.9.6 Park & Ride Generalised cost

The generalised cost for Rail P&R and Bus P&R is a combination of generalised cost from both the car and PT legs of the journey. Capacity restraints are not considered for this study and parking capacities are input as attraction weights to the model, so sites with larger car parks will attract more trips all other things being equal. A pictorial representation of costs for P&R is shown in Figure 6-8. It takes the form of a minimised cost function, computed by the VISUM lot choice module as shown in equations 6.9.12 & 6.9.13 below.

$$G_{BusPR,i,j,ds} = k_{BusPR,p} + k_{BusPR,ds} + \min_b (G_{car,i,b,ds} + G_{Bus,b,j,ds}) \quad (6.9.12)$$

$$G_{RailPR,i,j,ds} = k_{RailPR,p} + k_{RailPR,ds} + \min_r (G_{car,i,r,ds} + G_{Rail,r,j,ds}) \quad (6.9.13)$$

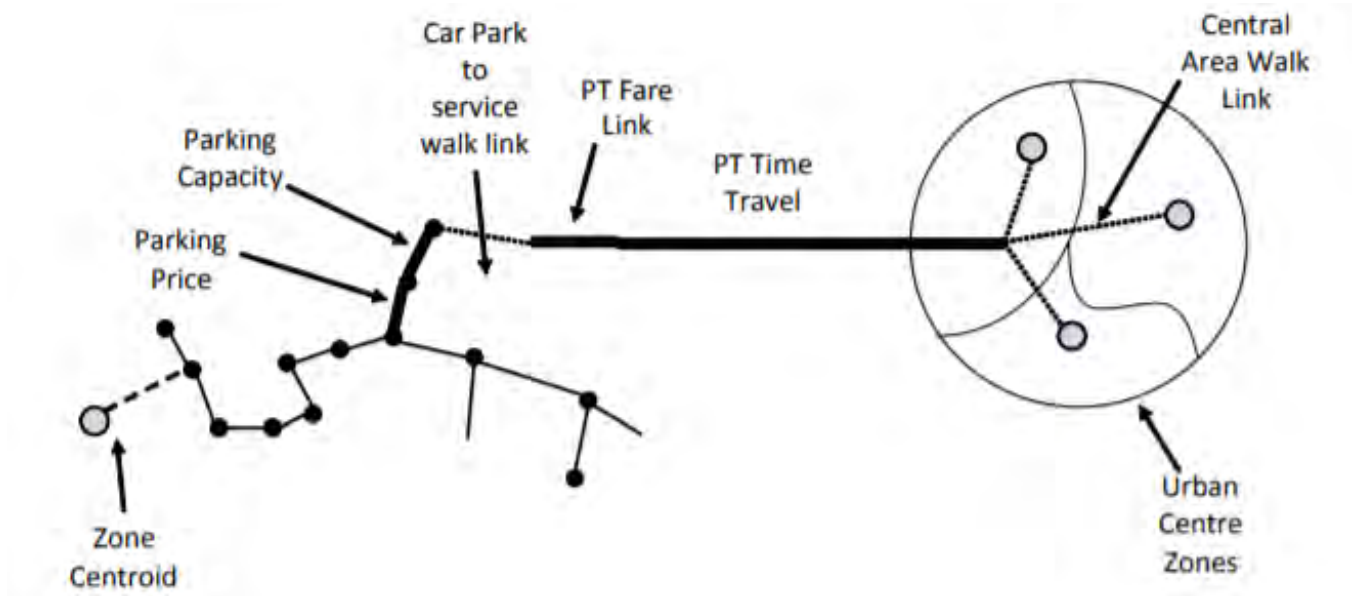
Where: k represents the alternative specific constant being added.

$G_{car,i,b,ds}$ is car generalised cost from origin i to lot b which includes the additional penalty for parking.

$G_{PT,b,j,ds}$ is PT generalised cost from lot b to destination j .

All the costs until the parking capacity shown in Figure 6-8 are included in the car generalised time and all further costs shown are included in the PT generalised time.

Figure 6-8 – Representation of park & ride components



6.9.7 Mathematical specification

6.9.7.1 Generalised cost compositing

Within the choice hierarchy, generalised costs are composited from the lowest level upwards with the removal of dimensions at each stage before these are used to allocate trips working downwards through the choice hierarchy.

At the lowest level, Park & Ride lot choice is carried out by considering the combination of generalised costs from both the car and PT legs of the journey in addition to any delays related to the capacity of the park & ride site included in the form of a parking constraint function.

Hence the cost generated for P&R lot choice in VISUM is:

$$G_{BusPR,i,j,ds} = \min_b (G_{car,i,b,ds} + G_{Bus,b,j,ds}) \quad (6.10.14)$$

$$G_{RailPR,i,j,ds} = \min_r (G_{car,i,r,ds} + G_{Rail,r,j,ds}) \quad (6.10.15)$$

The composite generalised costs for sub mode and destination choice are given by:

$$\text{Sub mode choice: } G_{m,i,j,ds} = \frac{1}{\lambda_{sm,p}} \ln \left(\sum_{sm} e^{\lambda_{sm,p} \times G_{sm,i,j,ds}} \right) \quad (6.10.16)$$

$$\text{Destination choice: } G_{m,i,ds} = \frac{1}{\lambda_{m,p}^{Dest}} \ln \left(\sum_j A_{p,j} e^{\lambda_{m,p}^{Dest} \times G_{m,i,j,ds}} \right) \quad (6.10.17)$$

Where λ are the calibrated choice model parameters

$A_{p,j}$ are the trip attraction weights (or constraints) by purpose p and zone j

6.9.7.2 Allocation of demand

The demand at each choice level is then calculated according to the equations:

$$\text{Main mode choice: } T_{m,ds,i} = P_{ds,i} \times \frac{e^{\lambda_p \times G_{m,i,ds}}}{\sum_m e^{\lambda_p \times G_{m,i,ds}}} \quad (6.10.18)$$

Where: $T_{m,ds,i}$ are the trip productions by mode m for demand strata ds in zone i

$P_{ds,i}$ are the input trip productions by demand strata ds in zone i

λ is the main mode choice parameter

$G_{m,i,ds}$ is the composite generalised cost of travel as defined above

$$\text{Destination choice (singly constrained): } T_{m,i,j,ds} = T_{m,i,ds} \times \frac{A_{p,j} \times e^{\lambda_{m,p}^{Dest} \times G_{m,i,j,ds}}}{\sum_j (A_{p,j} \times e^{\lambda_{m,p}^{Dest} \times G_{m,i,j,ds}})} \quad (6.10.19)$$

$$\text{Destination choice (doubly constrained): } T_{m,i,j,ds} = T_{m,i,ds} \times \frac{P_{p,i} \times A_{p,j} \times e^{\lambda_{m,p}^{Dest} \times G_{m,i,j,ds}}}{\sum_j (B_{p,j} \times C_{p,j} \times e^{\lambda_{m,p}^{Dest} \times G_{m,i,j,ds}})}$$

Where $B_{p,j}$ is calculated iteratively to adjust the intermediate number of attractions $A_{p,j}$ on each iteration until the target constraint value $C_{p,j}$ is met.

$$\text{Sub-mode choice: } T_{sm,i,j,ds} = T_{m,i,j,ds} \times \frac{e^{\lambda_{sm,p} \times G_{sm,i,j,ds}}}{\sum_{sm} e^{\lambda_{sm,p} \times G_{sm,i,j,ds}}} \quad (6.10.20)$$

6.9.7.3 Mode and sub-mode choice

As standard within the VISUM Nested Demand software, it is only possible to have one choice of each type (i.e., mode, destination, and time-of-day). This means that it is not possible to implement the hierarchy set out in Figure 6-1 directly, and instead multiple-choice hierarchies must be set up for each purpose. The sub-mode choice models have been separated out such that for each trip purpose, there are 3 hierarchies:

1. Main mode and destination choice.
2. Car / Bus P&R sub-mode choice; and
3. PT / Rail P&R sub-mode choice.

Each of the sub-mode choice models is run twice: once before and once after the main mode and destination choice model. During the first run, there is no demand to distribute. However, the logsum results from the generalised cost compositing are output, allowing them to be used as the main mode generalised costs in the main mode and destination choice models. These models are then executed, including both cost compositing and demand allocation, before the main mode matrices are fed into the sub-mode choice models. This process splits the demand for each main mode (car and PT) into their relevant sub-modes.

6.9.7.4 Park & Ride lot choice

Similar to the sub-mode choice models, the P&R models are run twice. The first run calculates the generalised costs across sites, and the second run distributes the trips after the sub-mode choice has been completed.

The objective of the P&R lot choice procedure is to determine the optimal P&R lots (p) and their proportionate demand (R) for each demand segment (n) and P/A pair (i,j), in order to balance the distribution of demand across the lots. This is done while considering demand-dependent capacity utilization and skim data. The procedure is iterative, adjusting the demand for each demand stratum and O-D pair, based on the input parameters, until a

balanced distribution is achieved. The capacity-dependent costs for P&R lot usage are calculated based on the total usage of the P&R lot across all demand strata included in the procedure.

Within the procedure, the first step is to identify all nearby P&R lots for each O-D pair and demand stratum through a shortest path search. Following this, the iteration process begins, where the proportionate demand for each demand stratum, O-D pair, and parking lot is treated as a variable that is continuously adjusted during each iteration. At the start of each iteration, a shortest path search is performed for each O-D pair, and its total demand is distributed across the available P&R lots. Initially, this distribution may not represent the optimal balance. The demand distributed across a single path is then scaled by a factor λ and incorporated into the formula for distribution from the previous iteration, as follows:

$$\tilde{R}(\lambda) = (1 - \lambda)R + \lambda\Gamma \quad (6.10.22)$$

Where:

$\tilde{R}$ is the new distribution calculated with this iteration step

R is the distribution according to the previous iteration step

Γ is the distribution of total demand according to shortest path search

λ is the scaling parameter (set to 0.5 by default)

6.9.7.5 Park & Ride Leg Split

Based on the P&R path sequence sets and the distribution of demand across the P&R lots, the procedure for P&R leg splitting calculates demand matrices for private (car) and public (PT) transport, denoted as PrT and PuT in VISUM, respectively. For the first path leg, the transport system used ends at the P&R lots and begins at the origin zone. For the second path leg, all paths begin at zones designated as P&R lots and lead to the destination zone.

6.10 Model parameters

Illustrative sensitivity parameters to the choice models are provided in TAG unit M2.1 section 5.6 as follows:

- Mode choice thetas
- Destination choice lambdas

The VISUM Nested Demand procedure is coded such that the sensitivity parameters that must be input are lambdas rather than thetas (relative to choice level immediately below), when providing the procedure with a generalised cost. However, for the Main Mode and Destination choice, we instead provide a Main Mode theta (with Destination lambda as 1) and provide the Destination cost compositing with a utility instead of a generalised cost. Therefore, equations 6.10.16 and 6.10.17 above can be rewritten as follows:

$$\text{Destination choice cost compositing: } G_{m,ds,i} = \frac{1}{\lambda_{m,p}^{Dest}} \ln(\sum_j A_{p,j} e^{U_{m,i,j,ds}})$$

$$\text{Where } U_{m,i,j,ds} = \lambda_{m,p}^{Dest} \times G_{m,i,j,ds} \quad (6.10.22)$$

$$\lambda_{m,p}^{Dest} = 1 \text{ for all purposes}$$

$$\text{Main mode choice: } T_{m,i,ds} = P_{i,ds} \times \frac{e^{\theta_p^{Mode} \times G_{m,i,ds}}}{\sum_m e^{\theta_p^{Mode} \times G_{m,i,ds}}} \quad (6.10.23)$$



Where $\theta_p^{Mode} = \frac{\lambda_p^{Mode}}{\lambda_{m,p}^{Dest}}$, $\lambda_{m,p}^{Dest} = 1$ for all purposes

Destination choice (singly constrained): $T_{m,i,j,ds} = T_{m,i,ds} \times \frac{A_{p,j} \times e^{U_{m,i,j,ds}}}{\sum_j (A_{p,j} \times e^{U_{m,i,j,ds}})}$

Destination choice (doubly constrained): $T_{m,i,j,ds} = T_{m,i,ds} \times \frac{P_{p,i} \times A_{p,j} \times e^{U_{m,i,j,ds}}}{\sum_j (B_{p,j} \times C_{p,j} \times e^{U_{m,i,j,ds}})}$ (6.10.24)

Where $U_{m,i,j,ds} = \lambda_{m,p}^{Dest} \times G_{m,i,j,ds}$

Table 6-10 below gives the mode choice thetas that have been implemented in the VDM and the range of illustrative parameters set out in TAG. The TAG specified median theta values were retained in the model for all the purposes.

Table 6-10 - Mode choice thetas for all purposes

Purpose	TAG Main Mode Scaling Parameters			Model Theta
	Minimum	Median	Maximum	
HBW	0.51	0.70	0.83	0.70
HBEB	0.19	0.46	0.78	0.46
HBEd				
HBPS	0.27	0.47	1.00	0.47
HBL				
NHBEB	0.73	0.73	0.73	0.73
NHBO	0.43	0.62	1.00	0.62

The destination choice sensitivity parameters implemented in the VDM are shown below from Table 6-11 to Table 6-13. Note that they are quoted as positive in this notation. Values within the given TAG ranges have been used for Car and PT, whilst nominal lambdas taken from a similar study are used for active modes and adjusted during model calibration. The TAG illustrative destination choice parameters have been halved for home-based tours as the model uses tour (out plus return) rather than trip (O-D) generalised costs. For car median lambda values as per TAG has been used for home based education, shopping and leisure purposes, whereas for all the other purposes the median value has been increased by 10%. For PT TAG specified median lambda values have been used for all the purposes.

Table 6-11 - Destination choice lambdas for Car

Purpose	TAG Destination Choice Parameters (per P/A trip)						Model Lambda
	2-way			1-way			
	Min	Med	Max	Min	Med	Max	
HBW	0.054	0.065	0.113	0.027	0.033	0.057	0.036
HBEB	0.038	0.067	0.106	0.019	0.034	0.053	0.037
HBEd							
HBPS	0.074	0.09	0.16	0.037	0.045	0.08	0.045
HBL							
NHBEB	-	-	-	0.069	0.081	0.107	0.089
NHBO	-	-	-	0.073	0.077	0.105	0.085

Table 6-12 - Destination choice lambdas for PT

Purpose	TAG Destination Choice Parameters (per P/A trip)						Model Lambda
	2-way			1-way			
	Min	Med	Max	Min	Med	Max	
HBW	0.023	0.033	0.043	0.012	0.017	0.022	0.017
HBEB	0.030	0.036	0.044	0.015	0.018	0.022	0.018
HBEd							
HBPS	0.033	0.036	0.062	0.017	0.018	0.031	0.018
HBL							
NHBEB	-	-	-	0.038	0.042	0.045	0.042
NHBO	-	-	-	0.032	0.033	0.035	0.033

Table 6-13 - Destination choice lambdas for Cycle and Walk

Purpose	Cycle	Walk
HBW		0.039
HBEB		0.061
HBEd		0.078
HBPS		0.061
HBL		0.029
NHBEB		0.122
NHBO		0.132

Illustrative sensitivity parameters for sub-mode choice are not provided by TAG. Therefore, initial sub-mode sensitivity parameters have been sourced from a separate study with limited adjustment during model build. The sensitivity parameters implemented in the VDM are shown below in Table 6-14.

Table 6-14 - Sub-mode choice parameters

Choice	Car vs Bus P&R	Bus vs Rail vs Rail P&R
HBW	0.07	0.07
HBEB	0.07	0.07
HBEd	0.07	0.07
HBPS	0.07	0.07
HBL	0.07	0.07
NHBEB	0.12	0.13
NHBO	0.12	0.13

6.11 P/A to O-D conversion

The matrices output by the VDM are in 24-hour P/A format by demand strata and mode ($T_{i,j,m,ds}$), while the car assignments require hourly O-D vehicle matrices by AUC ($D_{o,d,auc,tod}$).

For the car mode, the conversion is a 5-step process:

- Aggregation of demand strata matrices retaining segmentation by purpose and mode (Car);
- From home trips by time period – to split daily P/A trips into P/A trips by outward time period;
- To home trips by time period (for HB trips only) – to create return (to home) trips in appropriate time periods; and
- From home and to home trips are combined with NHB trips and summed by AUC and divided by occupancy convert into vehicles.
- Peak period matrices are further factored by peak period to peak hour factor to arrive at matrices at peak hour level for assignment.

Further details on this process are outlined below.

6.11.1 Aggregation of demand strata

The first step is to aggregate the matrices by demand strata retaining the car mode and purpose segmentation.

$$T_{i,j,m,p} = \sum_{ds \in p} T_{i,j,m,ds}, m = car \quad (6.12.26)$$

6.11.2 24-hour P/A to peak period matrices

6.11.2.1 From home trips by time period

Factors to calculate from home proportions are derived from the NTS data. The below equation shows the formulation used to split the 24-hr P/A into from home (FH) trips by time period.

$$T_{i,j,m,p,TOD}^{FH} = T_{i,j,m,p} \times \rho_{TOD,p}^{FH} \quad (6.12.27)$$

The Table 6-15 below provides the from-home factors used for converting the 24-hour P/A matrices to peak period matrices.

Table 6-15 - BSTM2 car P/A 24-hour to time period factors by purpose

Purpose	Car P/A Time Period Factors				
	AM	IP	PM	OP	Total
HBW	59%	11%	24%	6%	100%
HBEB	55%	22%	16%	8%	100%
HBEd	96%	3%	0%	1%	100%
HBPS	32%	51%	4%	13%	100%
HBL	17%	39%	16%	29%	100%
NHBEB	22%	57%	16%	5%	100%
NHBO	20%	53%	21%	6%	100%

6.11.2.2 To-home trips by time period

To-home time of day (or the phi) factors give the proportion of from-home (FH) trips by time period that have the corresponding to-home (TH) trip in each time period. The contributions from each FH time period are then summed to give the total TH matrix for TOD.

$$T_{i,j,m,p,TOD}^{TH} = \sum_{TOD} (T_{i,j,m,p,TOD}^{FH} \times \phi_{TOD,p}^{TH}) \quad (6.12.28)$$

The Table 6-16 below summarises the phi factors used in the BSTM2 which are derived from the NTS data.

Table 6-16 - BSTM2 Car To-Home Time of Day Factors by Purpose for each From-Home time period

Purpose	Car To-Home Factors					
	Out Period	AM	IP	PM	OP	Total
HBW	AM	3%	13%	75%	9%	100%
	IP	0%	18%	35%	47%	100%
	PM	0%	0%	50%	50%	100%
	OP	2%	28%	51%	19%	100%
HBEB	AM	3%	32%	56%	10%	100%
	IP	0%	46%	38%	17%	100%
	PM	0%	0%	23%	77%	100%
	OP	5%	21%	44%	30%	100%
HBEd	AM	1%	69%	29%	1%	100%
	IP	0%	49%	43%	8%	100%
	PM	0%	0%	73%	27%	100%
	OP	0%	27%	61%	13%	100%
HBPS	AM	27%	52%	19%	2%	100%
	IP	0%	76%	22%	2%	100%
	PM	0%	0%	63%	37%	100%
	OP	4%	2%	4%	90%	100%
HBL	AM	8%	56%	25%	10%	100%
	IP	0%	49%	39%	12%	100%
	PM	0%	0%	21%	79%	100%
	OP	4%	1%	2%	93%	100%

6.11.2.3 Aggregation to AUC

The FH and TH matrices by time period are then combined to give the O-D matrices and converted to peak hour O-D trip matrices using period-peak factors (shown in Table 6-17). This is completed by dividing the period trips by the factors shown in the equation 6.12.29 and 6.12.30. These factors are sourced from counts used in the development of BSTM2 Highway assignment model.

$$D_{o,d, auc, p, TOD} = \frac{(T_{i,j,m,p,TOD}^{FH} + (T_{i,j,m,p,TOD}^{TH})^T)}{h_{TOD}} \quad (6.12.29)$$

Where, h_{TOD} is the factor to convert from peak period to peak hour.

These matrices are then summed to AUC level:

$$D_{o,d, auc, TOD} = \sum_{p \in auc} D_{o,d, auc, p, TOD} \quad (6.12.30)$$

Table 6-17 - BSTM2 Car peak period to peak hour factors

Purpose	AM	IP	PM
HBW	2.818	6.000	2.819
HBEB	2.818	6.000	2.819
HBEd	2.818	6.000	2.819
HBL	2.818	6.000	2.819
HBPS	2.818	6.000	2.819
NHBEB	2.818	6.000	2.819
NHBO	2.818	6.000	2.819

6.11.2.4 Occupancy

An occupancy factor is applied to the car demand matrices to convert them from units of person trips to vehicles, as required for the highway assignment model.

$$D_{o,d, auc, tod} = \sum_{p \in auc} \frac{D_{o,d, auc, TOD}}{O_p} \quad (6.12.31)$$

BSTM2 occupancy factors were used as per TAG databook November 2023 v1.22 unit 3.5.6 (Tables 4, 5 and 6) presented in Table 6-18.

Table 6-18 - BSTM2 Car average weekday occupancy factors by purpose

Purpose	AM	IP	PM
HBW	1.132	1.151	1.136
HBEB	1.131	1.159	1.147
HBEd	1.712	1.823	1.793
HBPS	1.712	1.823	1.793
HBL	1.712	1.823	1.793
NHBEB	1.131	1.159	1.147
NHBO	1.712	1.823	1.793

6.12 Incremental approach and model iteration

TAG unit M2.1 section 4.3 provides advice on the different forms of VDM and the use of VDM results from an “absolute” model form, to apply growth in the assignment models and recommends an incremental approach. The model applies a method of incremental modelling known as an Absolute Model Applied Incrementally (AMAI). The basic calculation procedure is given in equation 6.14.32:

$$F = B \times \frac{S_f}{S_b} \quad (6.14.32)$$

where:

S_f is the modelled matrix, i.e. ‘synthetic’ trips for a future year from the VDM;

S_b gives the equivalent synthetic trip matrix for the base year from the VDM;

B is the base trip matrix from the validated HAM, built from observed data sources.

F is the resulting forecast assignment matrix for input to the HAM

Any of the three input components can be zero as the pivot is implemented for each of zone pair, time period and user class. To implement AMAI, the base year matrix process is required to produce base matrices (B) for each user class and time period for Car demand. The VDM demand strata matrices are aggregated to HAM AUCs prior to pivoting using the correspondences discussed in section 6.9.1. This means that Car is pivoted for individual user classes viz., business, commute and other. Table 6-19 presents the various pivot cases that are possible for applying synthetic growth on the validated base matrices.

Table 6-19 - The 7 cases used in the AMAI pivot process

Case	Base (B)	Synthetic base (S_b)	Synthetic forecast (S_f)	Forecast (F)	
1	≥ 0	0	0	B	
2	≥ 0	0	≥ 0	$B + S_f$	
3	≥ 0	> 0	0	0	
4	> 0	> 0	> 0	$B \times \frac{S_f}{S_b}$	Normal growth $B \approx S_b$
5	> 0	> 0	> 0	$B + S_f - S_b$	Extreme growth
6	$= 0$	> 0	> 0	$Max(0, S_f - S_b)$	Normal growth
7	> 0	> 0	> 0	$B + S_f - S_b$	Normal growth $B \ll S_b$

The principles adopted in setting these calculation rules aim to use the basic multiplicative equation whenever possible, but switch to an additive function when multiplication becomes unreasonable. The functional forms are chosen so that small changes in the inputs do not result in large changes in the outputs, especially when one of the components takes on a small positive value instead of zero. For instance, an additive equation is used to represent new developments where absolute forecasts should be applied, and when demand growth is modest, a proportionate change is applied. Additionally, the additive equation is used when synthetic and absolute demand do not align, and control is needed, though the synthetic demand growth remains modest to ensure the forecast values are reliable.

The use of normal growth and extreme growth regimes in cases 4 and 5 (i.e., when all three matrices are non-zero) is particularly useful for handling extreme growth cells. The distinction between extreme and normal growth is determined by the ratio of the synthetic forecast to the synthetic base matrices. Following previous conventions, this ratio is set at 10, though it can be adjusted by the user for a specific scenario if needed.

6.12.1 Normalisation and checking

6.12.1.1 Requirement for normalisation

When pivoting is carried out solely at the cell (individual zone-pair) level, there are several reasons why the aggregate result may differ from what would occur if the matrix totals were simply scaled. This discrepancy naturally arises when non-scalar growth is used, as in Cases 1-3 and 5 in Table 6-19.

Moreover, small mismatches between the Assignment Base (B) and Synthetic Base (S_b) can also compound to produce uneven growth. The example below illustrates this with a simplified case involving two zones. Although the synthetic and assignment base matrices have identical row and column totals, their patterns of movement differ slightly, with proportionally fewer intra-zonal trips in the assignment matrix. If the intra-zonal trips grow more rapidly in the synthetic matrix, it results in disproportionate overall growth in the assignment matrix (F). In this example, this leads to an excess of 6 trips in total.

The issue can be corrected by scaling the whole matrix (F_n) so that the matrix total returns to the correct target value, in this case 48.

$$B = \begin{bmatrix} 12 & 6 & 18 \\ 6 & 12 & 18 \\ 18 & 18 & 36 \end{bmatrix}, \quad S_b = \begin{bmatrix} 10 & 8 & 18 \\ 8 & 10 & 18 \\ 18 & 18 & 36 \end{bmatrix}, \quad S_f = \begin{bmatrix} 20 & 4 & 24 \\ 4 & 20 & 24 \\ 24 & 24 & 48 \end{bmatrix}$$

$$\Rightarrow F = \begin{bmatrix} 24 & 3 & 27 \\ 3 & 24 & 27 \\ 27 & 27 & 54 \end{bmatrix}$$

$$\Rightarrow F' = \begin{bmatrix} & & 24 \\ & & 24 \\ 24 & 24 & 48 \end{bmatrix}$$

$$\Rightarrow F_n = \begin{bmatrix} 21.3 & 2.7 & 24 \\ 2.7 & 21.3 & 24 \\ 24 & 24 & 48 \end{bmatrix}$$

Hence, normalisations of this kind are applied after the pivoting process to correct for both of these issues.

Normalisations are carried out by summing the zone-zone matrices to a suitable sector-sector level and then repeating the pivot process at this level. The results of the zone-level pivoted matrices are then scaled so that the sector-sector totals match the results of the sector-level pivot. The 40-sector system, as presented in section 2.4.2 was used for the pivoting approach.

6.12.2 Iteration and smoothing

The VDM iterates with updated travel times from the assignment models due to changes in highway congestion feeding back and influencing travellers' choices. The travel times from the highway congestion supplied in every loop will alter the demand generated in VDM until demand-supply equilibrium is achieved.

When significant perturbations are made which impact on congestion, the levels of demand and resulting congestion tend to oscillate from demand-supply iteration to iteration. Smoothing is intended to reduce oscillation in

the demand-supply iterations by reducing the scale of changes being introduced. This could potentially be achieved by smoothing attributes (like distance, cost and time) that are fed into the demand model or smoothing the numbers of trips which are fed into the assignment models. The BSTM2 uses the latter approach, with the smoothing process applied to the numbers of trips.

The smoothing function takes the form:

$$T_{i,j}^{N+1} = \tau Y_{i,j}^N + (1 - \tau) T_{i,j}^N \quad (6.14.38)$$

where: N is the iteration (demand-supply loops)
 τ is the smoothing factor
 $Y_{i,j}^N$ is the initial (unsmoothed) estimate of trips on iteration N
and $T_{i,j}^N$ is the best (smoothed) estimate of trips on iteration N

A constant value for the smoothing parameter, $\tau = \frac{1}{2}$, is currently implemented. Note the method of successive averages (MSA), which varies τ by iteration as $\tau = \frac{1}{N}$, can be implemented if further smoothing is needed (but this has not been found to be necessary for the base model).

6.12.3 Convergence

The convergence criterion is based on the nested demand gap values calculated for each choice models. The equation used to calculate the gap value as set out in TAG unit M2.1 section 6.3.4 is presented in equation 6.14.39.

$$\text{Percentage Gap} = \frac{\sum_a - U_a |D_a^{\text{new}} - D_a^{\text{old}}|}{\sum_a - U_a D_a^{\text{old}}} \times 100 \quad (6.14.39)$$

Where,

U_a is the costs specified in referenced nested demand procedures (i.e., negative utility)

D_a^{old} is the saved demand from last iteration used to create the costs U_a

D_a^{new} is the saved demand from current iteration which results from applying the VDM using the costs U_a

a runs through all matrix entries, demand strata, modes and times of the day

TAG suggests a gap value of less than 0.2% for complex models to achieve convergence. Thus, for the BSTM2, the weighted gap value across all sub-modes must be less than 0.15% to achieve convergence.

7. Variable Demand Model Calibration

7.1 Approach to calibration

This section presents the calibration results for the BSTM2 VDM. The calibration process has been carried out in accordance with TAG unit M2.1. TAG recommends that, ideally, local data should be used to calibrate the parameter values within the VDM to create a model that closely replicates observed base year data. However, no strict criteria are provided for this, and it is noted that this is less of an issue for incremental models such as BSTM2. The guidance also suggests that the effort required for calibration should be proportional to the quality and relevance of the available data. As such, the goal has been to calibrate the model parameters to produce a reasonable match with observed local data. While a fair representation of demand in the base year, as described in this chapter, is important, the key requirement is to ensure that the model's responses in realism tests meet the recommended standards, which are addressed in Chapter 8.

The approach taken in the development of BSTM2 is an iterative process of reviewing model outputs against observed data and using judgment to adjust model parameters for a better fit. All the data presented below is considered "independent" in the sense that it has not been directly used in the modelling (e.g., for the statistical estimation of model parameters) but has been used to inform judgment during the calibration of the model parameters discussed previously.

Presented here are the results most relevant to the overall patterns of demand within the model. This covers comparison of the demand model results against available comparators including National Travel Survey, 2011 Census Journey to Work data and the validated base year car assignment matrices.

Mode shares and trip length distributions have been compared against both Census (only for HBW) and NTS data. P-A distributions for HBW have been compared against the Census for all modes. These comparisons show that the model is performing broadly as expected.

7.2 Calibration data

Many of the datasets available have been used to implement and calibrate the VDM. The remaining data available for comparison against the variable demand model results is as follows:

- Readily available Journey to Work (JTW) tables from the 2011 Census of Population were used to check the output mode shares and trip length distributions for commuting trips; and
- The national level National Travel Survey (NTS) data were used to validate the output mode shares by purpose, and the trip length distributions for all purposes. (The trip length distribution for commuting trips were compared against the locally focused Census data, to provide a baseline for interpreting the other purposes against this national dataset).

There are several sensitivity parameters viz., mode and destination choice parameters, generalised cost damping values, mode, purpose and demand segment specific constants that have been calibrated to derive synthetic demand that is aligned with the observed demand. The sensitivity parameters calibrated are discussed in Chapter 6.

7.3 Mode shares

As set out above, mode share information is available both from the NTS and the Census (2011). Table 7-1 below shows the comparison between NTS mode shares and trip production level mode shares from BSTM2 by purpose



for trips to/from the BSTM2 AoDM. Table 7-2 provides the mode shares for HBW in BSTM2 alongside the Census equivalent. These values are all day productions/attractions covering I-I and I-E trips.

Table 7-1 - Main Mode Shares (BSTM2 vs NTS) by Purpose

Purpose	Car		PT		Walk		Cycle	
	BSTM2	NTS	BSTM2	NTS	BSTM2	NTS	BSTM2	NTS
HBW	73%	75%	12%	10%	8%	11%	7%	4%
HBEB	79%	85%	12%	9%	6%	5%	4%	1%
HBEd	39%	36%	17%	18%	39%	43%	6%	2%
HBPS	67%	64%	7%	8%	24%	27%	2%	1%
HBL	70%	75%	3%	7%	19%	15%	8%	3%
NHBEB	78%	81%	4%	6%	17%	13%	0%	1%
NHBO	65%	70%	6%	6%	29%	23%	0%	1%
Total	64%	68%	9%	9%	23%	21%	5%	2%

Table 7-2 - Main Mode Shares (BSTM2 vs Census) for HBW Purpose

Purpose	Car		PT		Walk		Cycle	
	BSTM2	Census	BSTM2	Census	BSTM2	Census	BSTM2	Census
HBW	73%	80%	12%	11%	8%	8%	7%	2%

Table 7-1 and Table 7-2 suggest the model broadly matches to NTS and Census data for different purposes at 24-hr P/A level. As per TAG's guidelines, mode shares should closely replicate the observed data. In this context, the mode shares derived from the BSTM2 model for all travel purposes fall within a +/- 6% range when compared to both the NTS and Census data.

The sectoral mode shares are helpful to understand the areas in which the model may be less accurate. The model overall shows a sensible variation in mode shares by sector, and a reasonable fit with the Census. The sector wise production and attraction totals are presented in Appendix E.

7.4 Trip length distributions

As well as mode shares, trip length information is also available from Census and National NTS. Census distances are calculated by attaching HAM skims to the Census matrix volumes whereas NTS distances are extracted from the reported values from the survey. Useful inferences can be drawn using the two datasets. A full set of trip length distribution (TLD) comparisons is presented in Appendix F.

Figure 7-1 to Figure 7-5 compare the home-based work synthetic trip length shares by distance with Census JTW, SE region and national NTS for all the main modes. Note these plots are for the 24-hour production/attraction trips. It is to be noted that the accuracy of designating a modelled trip to a distance band under 3 miles (<1 mile, 1-2 miles, 2-3 miles) is considered low due to the limitations of the representation of the modelled zone and network structure.

The home-based work plots suggest that there is a similar share of trips in majority of distance bands between synthetic and observed demand for all modes. The walk and cycle demand also show a good fit against Census

JTW and National NTS, except for an additional peak in 1-2 miles band for cycle which is higher than both Census and NTS.

Figure 7-1 – Trip Length Distribution Comparison for HBW (Car Mode)

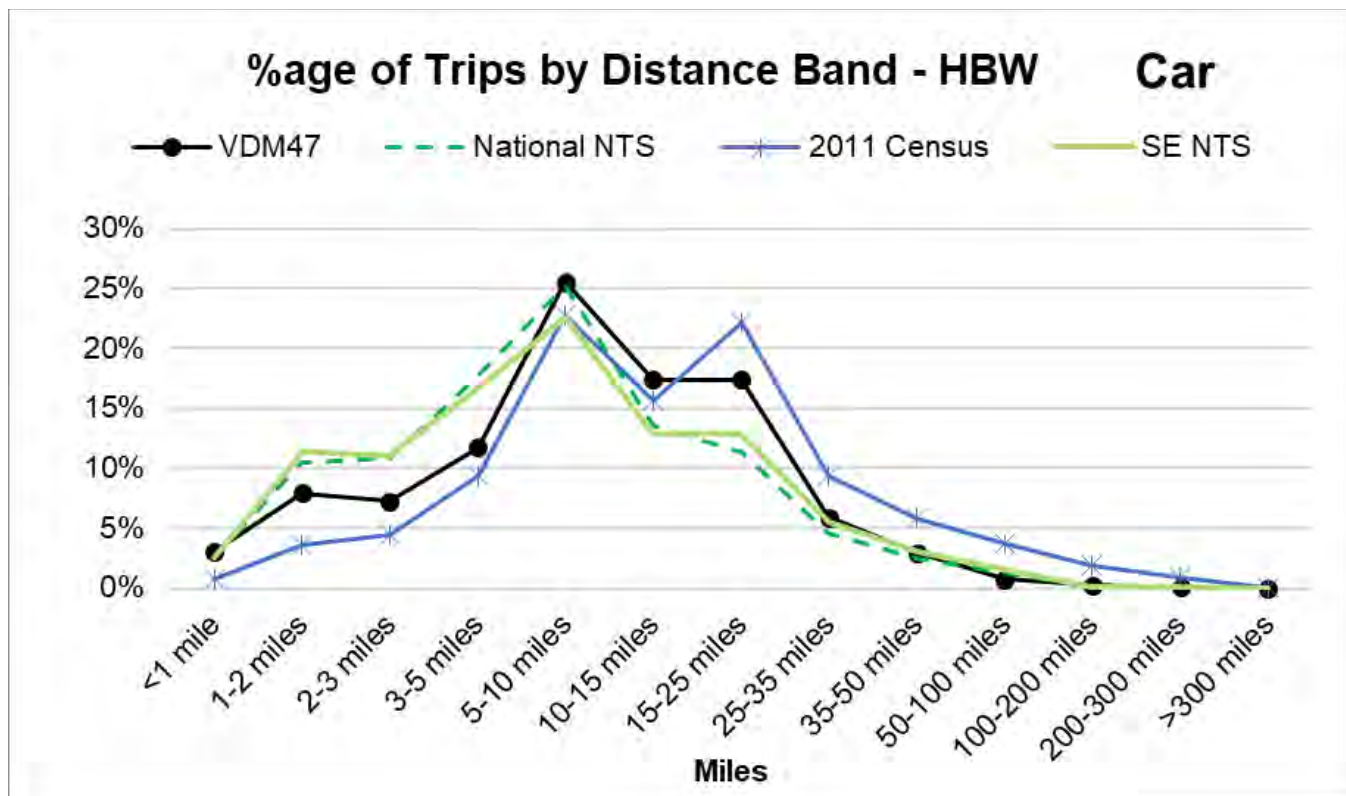


Figure 7-2 – Trip Length Distribution Comparison for HBW (Walk Mode)

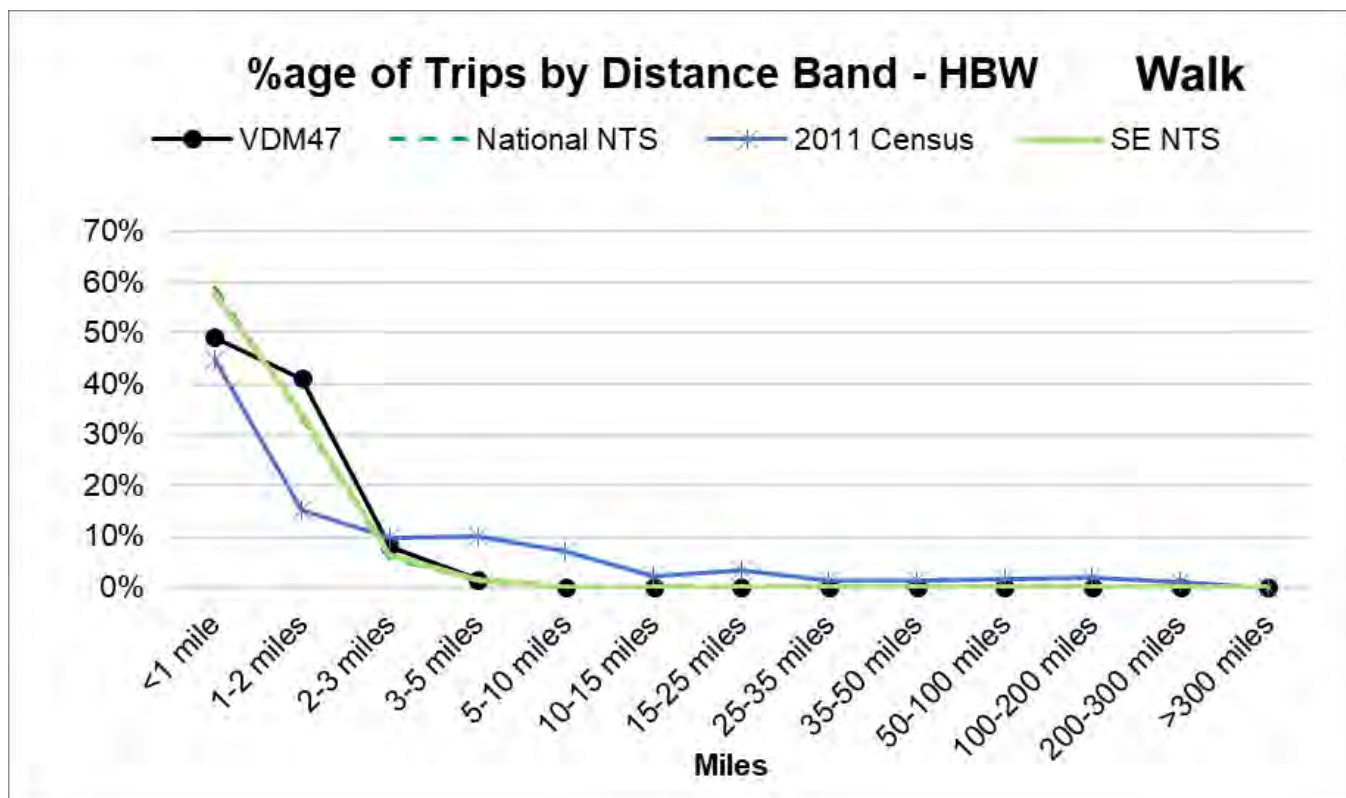


Figure 7-3 – Trip Length Distribution Comparison for HBW (Cycle Mode)

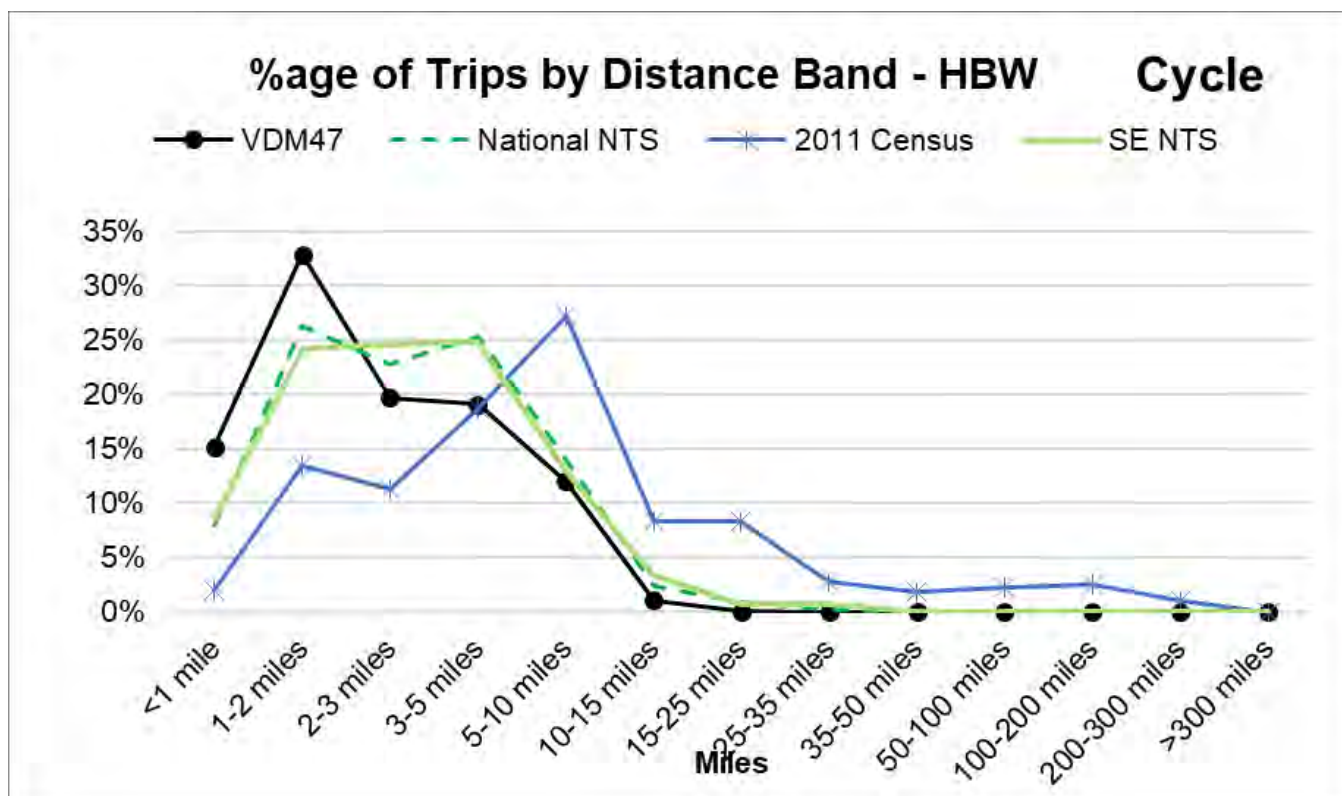


Figure 7-4 – Trip Length Distribution Comparison for HBW (Bus Mode)

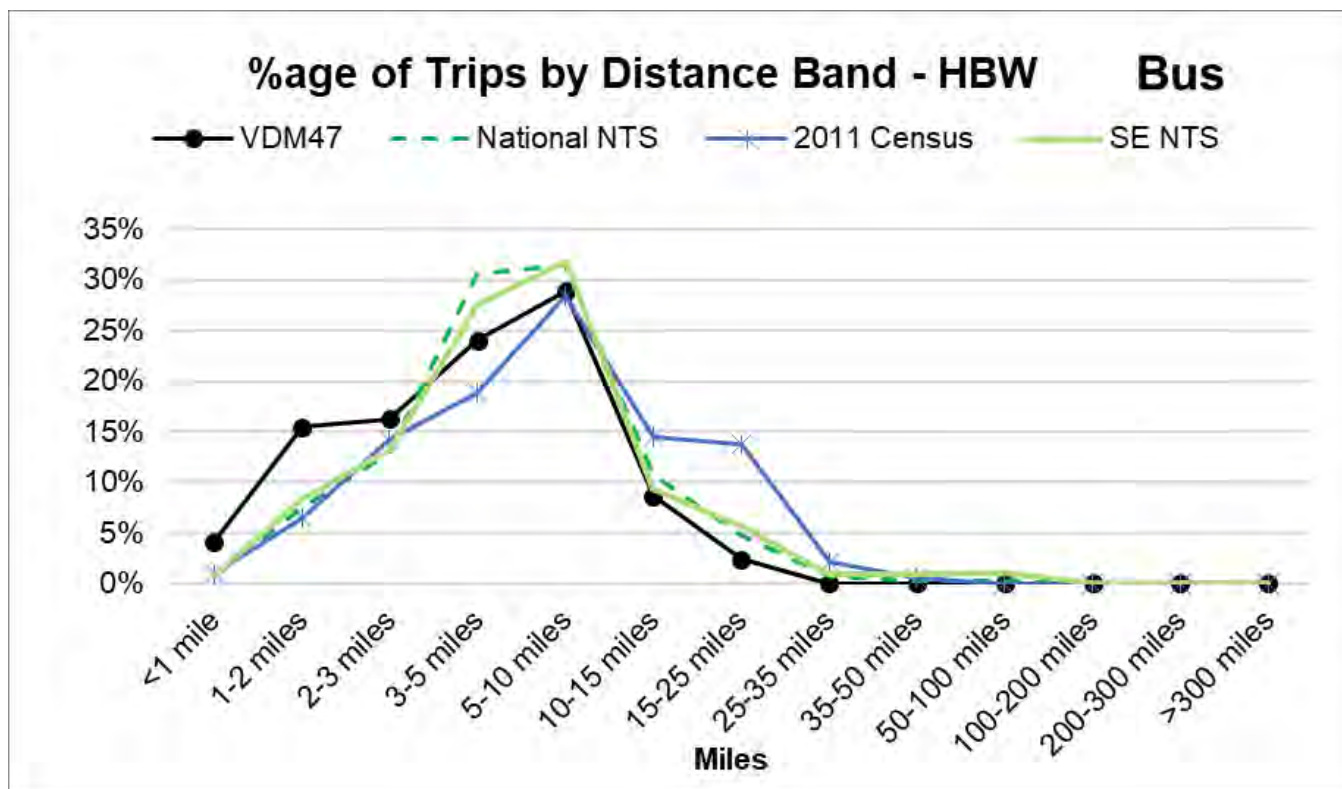


Figure 7-5 – Trip Length Distribution Comparison for HBW (Rail & Rail PR Mode)

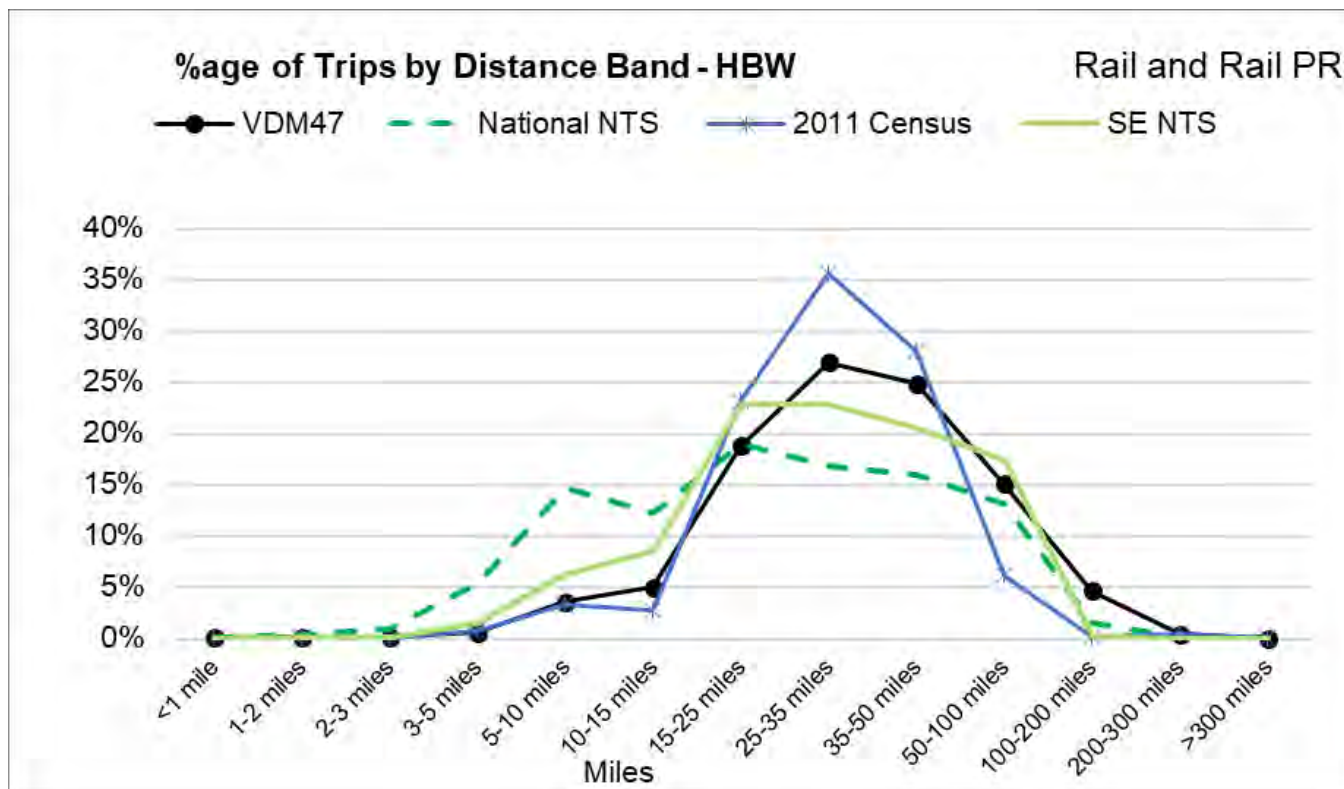


Figure 7-6 to Figure 7-10 compare the synthetic demand trip length shares by distance for home-based other trips (which included HBEd, HBL and HBPS) with National and SE NTS for all modes. Again, the accuracy of designating a trip to a distance band under 3 miles is considered low due to the modelled zone and network structure. It can be observed that VDM underestimates <3 miles trips and generally overestimates > 5 miles car trips. For other modes, synthetic trip distribution follows similar pattern as SE and National NTS, the only notable mismatch being the rail trips in which the 5-35 miles band trips are higher than longer distance bands.

Figure 7-6 – Trip Length Distribution Comparison for HBO (Car Mode)

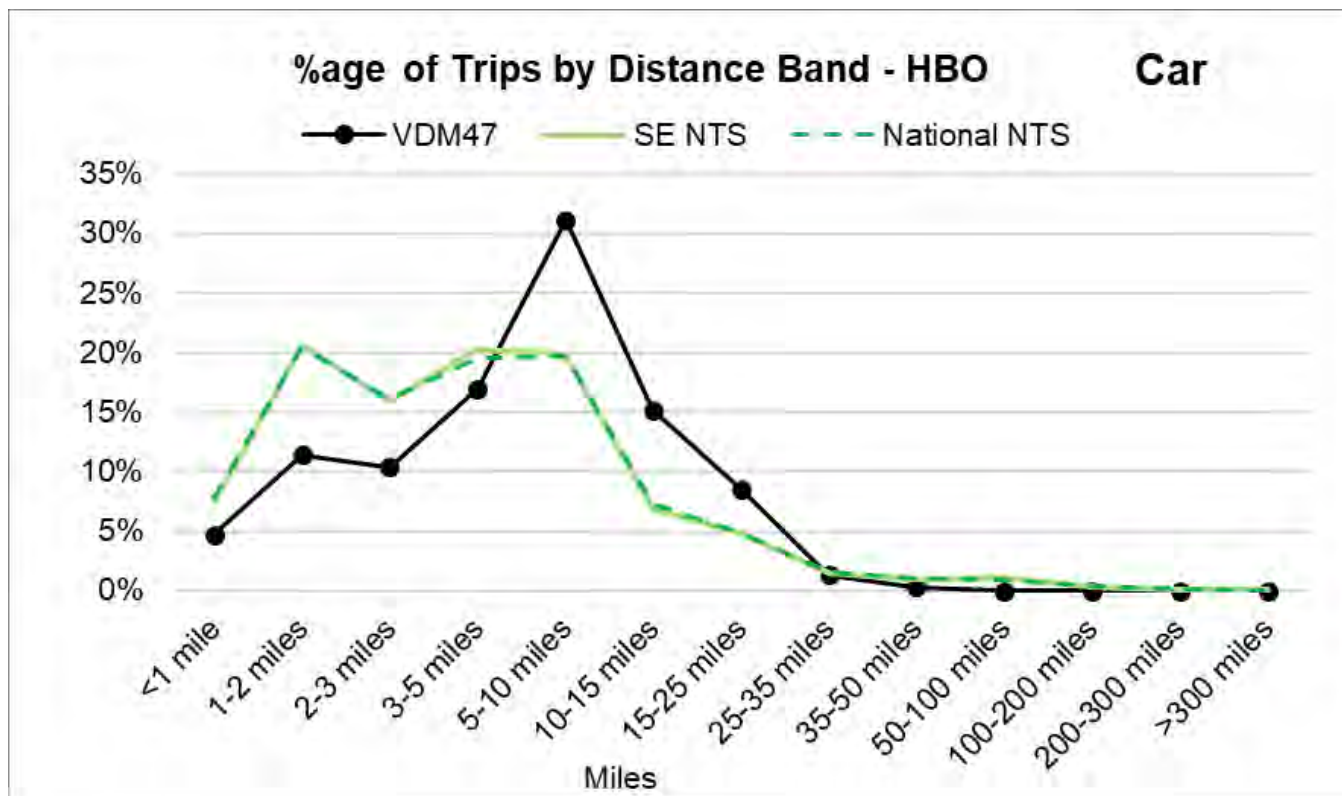


Figure 7-7 – Trip Length Distribution Comparison for HBO (Walk Mode)

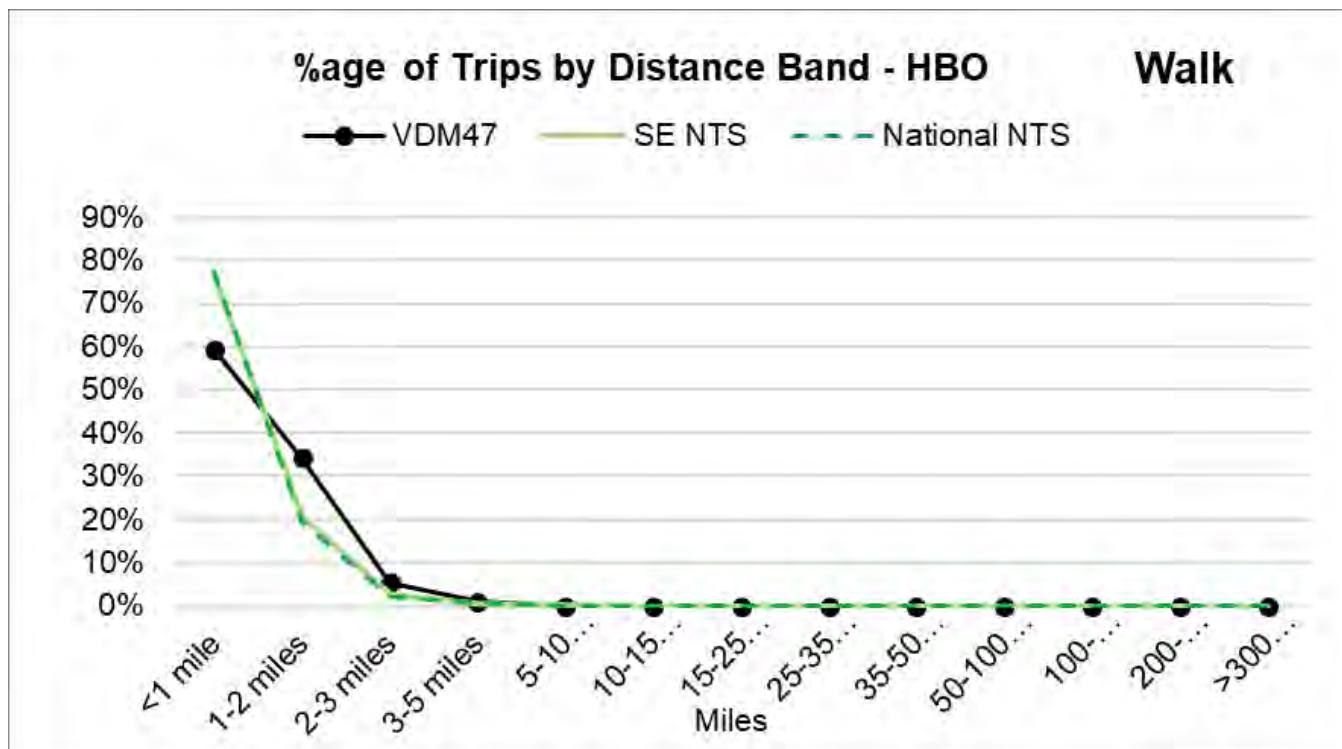


Figure 7-8 – Trip Length Distribution Comparison for HBO (Cycle Mode)

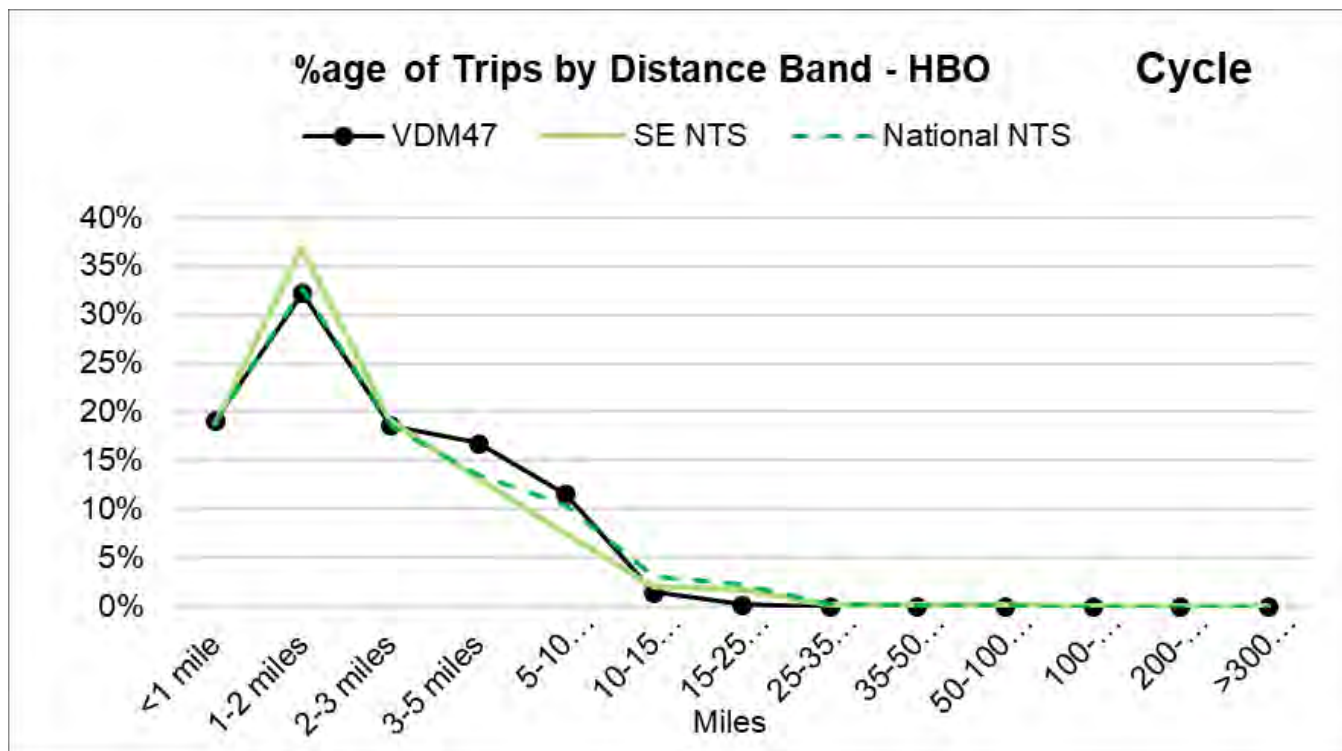


Figure 7-9 – Trip Length Distribution Comparison for HBO (Bus Mode)

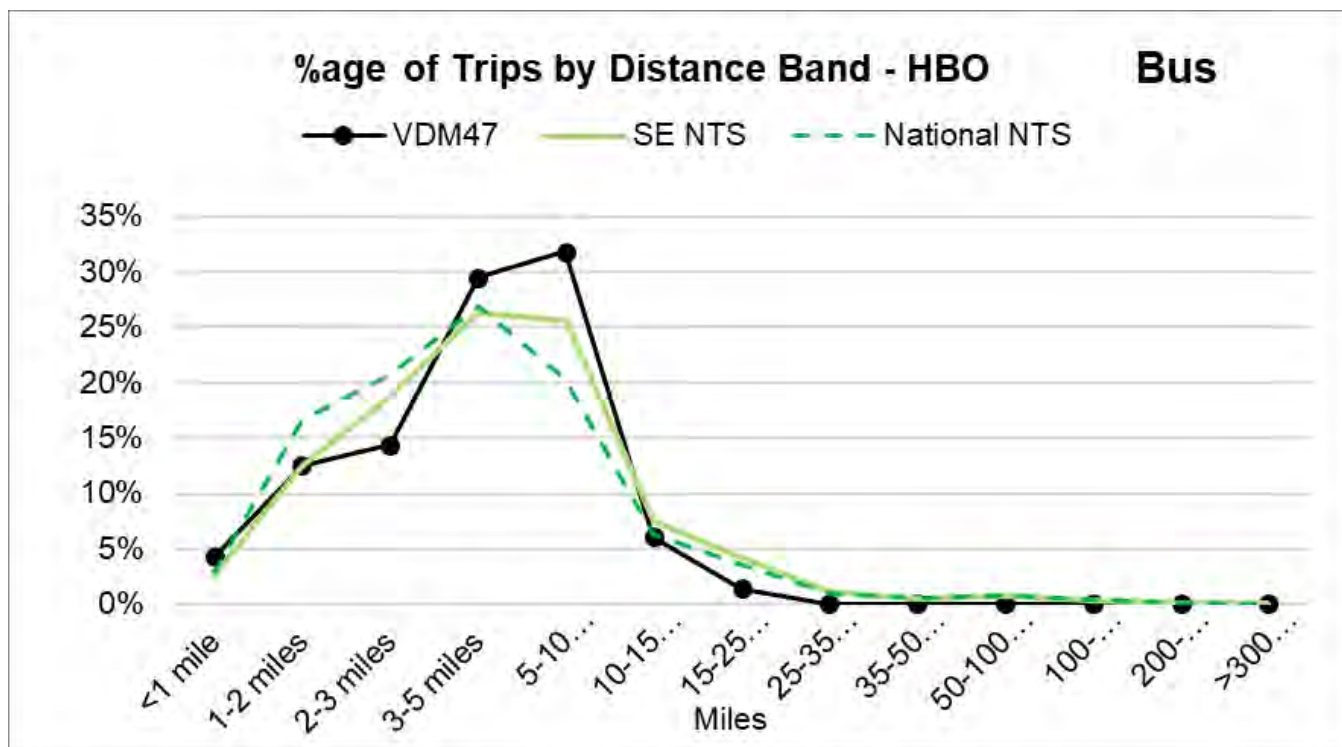
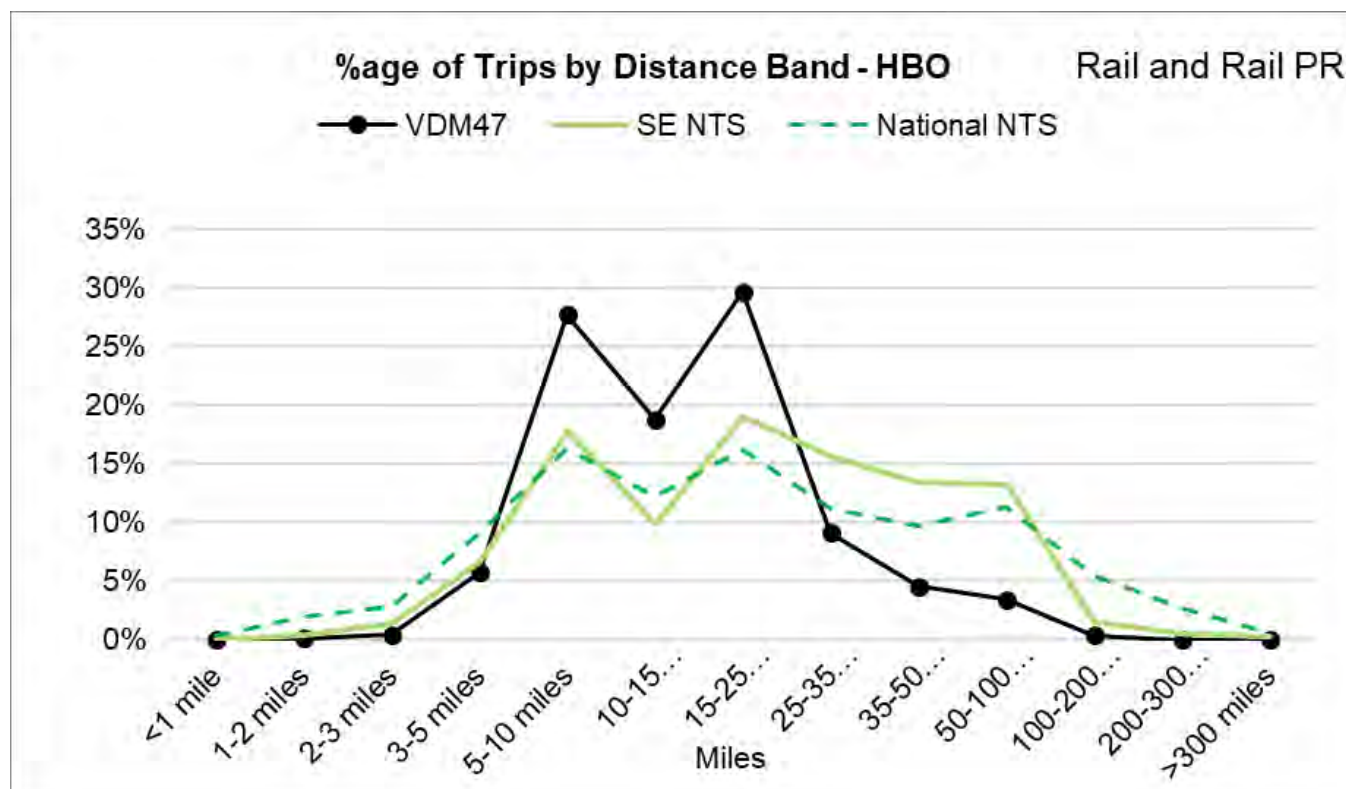


Figure 7-10 – Trip Length Distribution Comparison for HBO (Rail & Rail PR Mode)



7.5 Assignment matrix comparisons

This section presents comparisons of trip totals at overall matrix and sector level between the validated highway base year demand against the synthetic demand produced by the VDM. This comparison is used to inform the user about differences which could potentially impact the pivoting process rather than to judge how “good” the synthetic matrices are. Note the synthetic matrices are not assigned directly. Their sole use is to provide a growth factor to be applied to the validated assignment matrices. The synthetic matrices used for this comparison have been converted to peak hour vehicle trips for highway demand comparisons. The external-external trips are filtered out of the validated base matrices as they are not present in the synthetic demand.

Comparison of the HAM and VDM matrices presented in Table 7-3 and Table 7-4 shows the following:

- Car synthetic demand is generally low compared to the validated base highway demand in all time periods with the highest difference for AM peak. The Table 7-3 compares the absolute differences.
- Given the incremental nature of the model, the variations by sector and trip purpose are equally important. Table 7-4 confirm the overall shape of the matrices are similar in all sectors and user classes. The tables show the percentage of the matrix total for each time period represented by internal districts and user class summing to 100% in each column. The sector-to-sector comparison of HAM and VDM matrix totals are presented in Appendix F.2.

Table 7-3 - Comparison of total matrix sizes for car (VDM vs final HAM, both vehicle trips per hour)

Time Period	HAM Matrix Total	VDM Matrix Total	Difference	% Difference
AM	98,794	62,513	-36,282	-35.94%
IP	62,769	35,579	-27,190	-40.93%
PM	101,863	69,543	-32,320	-29.47%

The differences in user class mix in the AM varies by district. In the inter peak the VDM has a higher proportion of other trips, whereas in the PM peak the VDM has a higher proportion of commuting in all areas. For the internal area the differences are between 5 and 10%.

Table 7-4 - Proportion of car trip origins by District and User Class

District	AUC	AM		IP		PM	
		HAM	VDM	HAM	VDM	HAM	VDM
Aylesbury	CB	9.1%	7.5%	8.8%	7.2%	7.2%	6.6%
	CC	40.4%	45.0%	19.5%	15.1%	34.8%	41.2%
	CO	50.4%	47.6%	71.8%	77.8%	58.0%	52.3%
	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Chiltern	CB	9.0%	6.1%	9.1%	5.6%	7.7%	5.0%
	CC	40.8%	40.4%	18.6%	13.8%	33.0%	39.6%
	CO	50.2%	53.4%	72.3%	80.6%	59.2%	55.3%
	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
South Bucks	CB	9.2%	6.3%	9.7%	6.3%	9.8%	5.3%
	CC	39.9%	37.4%	21.1%	14.8%	37.7%	44.1%
	CO	50.9%	56.3%	69.2%	78.9%	52.5%	50.6%
	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Wycombe	CB	9.0%	6.9%	9.8%	6.6%	8.0%	5.8%
	CC	41.2%	44.0%	22.1%	14.9%	38.6%	42.1%
	CO	49.8%	49.1%	68.1%	78.5%	53.3%	52.1%
	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
External	CB	10.2%	8.5%	12.0%	8.5%	12.1%	5.3%
	CC	46.2%	58.9%	24.2%	24.4%	44.3%	59.5%
	CO	43.6%	32.6%	63.8%	67.0%	43.6%	35.3%
	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total	CB	9.4%	7.2%	9.9%	6.9%	8.9%	5.8%
	CC	42.0%	45.4%	21.3%	16.2%	38.2%	44.8%
	CO	48.7%	47.4%	68.8%	76.9%	52.8%	49.4%
	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

7.6 Summary

Overall, the tables show that demand model is performing well in the aspects of mode shares and trip length distributions at 24-hr P/A. There are differences noted in terms of matrix totals by time period and user class at O-D level. Thus, the real test is the realism testing and application of pivoting process to measure the changes to assignment matrices as discussed in the next chapter.



8. Variable Demand Model Realism Testing

8.1 Introduction

Once a Variable Demand Model has been developed, it is essential to ensure that it behaves in a 'realistic' manner by changing the various components of travel costs and times and checking that the overall demand responses are as would typically be expected. The acceptability of model responses is determined by its demand elasticities to a variety of realism tests. The requirements for realism testing of variable demand models are set out in TAG unit M2.1 section 6.4. In line with these requirements, the three tests undertaken are as follows:

- Car fuel own-cost vehicle-km elasticity, where fuel cost is increased by 10%. Non-fuel vehicle operating costs (for business trips) are not changed.
- Public transport fare own-cost trip elasticity, where fares are increased by 10% (including bus, rail and P&R fares); and
- Car own-travel time trip elasticity, where car in-vehicle time is increased by 10%.

All these tests are performed using the 2019 base year model, which uses the validated 2019 HAM assignment matrices and the associated cost skims. Note the car fuel own-cost test is a fully converged iterative model run, whilst the PT fare test and the car own-travel time test are single pass run of the VDM. PT fare realism is not undertaken as an iterative run as stipulated by the guidance as it was observed from a single pass test that there is only a marginal shift to car. Hence, it is expected to have minimal impacts when run iteratively.

8.2 Car fuel cost responses

The car fuel cost elasticity test required considers the percentage change in car vehicle-kms with respect to the percentage change in fuel cost. For this test, the car fuel cost has been increased by 10% (with non-fuel vehicle operating costs unchanged). TAG unit M2.1 section 6.4.14 suggests the annual average fuel cost elasticity should lie within the range -0.15 to -0.35 across all purposes (based on the outturn HAM response)

8.2.1 Convergence

Before considering the elasticity results from this test, the level of convergence achieved by the iterative VDM process is monitored to demonstrate the stability of the model system. VISUM provides %Gap values separately for individual choice models and hence the convergence is tested by ensuring that the gap values across the choice models is less than 0.2% as per TAG criteria. Table 8-1 shows gap statistics for each of the choice models by purpose.

Table 8-1 - %Gap values for car fuel cost realism

Purpose	Mode & Destination choice
%GAP for HBW	0.22732
%GAP for HBEB	0.23605
%GAP for HBEd	0.14645
%GAP for HBPS	0.06659
%GAP for HBL	0.05965
%GAP for NHBEB	0.11045
%GAP for NHBO	0.08360

The model test converged with a maximum gap value of 0.24% for mode and destination choice and a weighted max gap across all the Main Mode & Destination choices of 0.13% after 2 iterations.

8.2.2 Elasticity responses

The following tables show the response of the VDM to the car fuel cost changes:

- The response by assignment user class and time of day extracted from the assigned network (Table 8-2).
- The overall response of the VDM (Table 8-4).
- The response of the VDM by car ownership (Table 8-5).

It is to be noted that the VDM does not consider the impact of external-to-external (E-E) trips. Table 8-2 to Table 8-5 do not include external-external movements for this reason.

Network based elasticities

The HAM network elasticities are shown in Table 8-2. The calculation of network elasticities considers links within simulation network (viz., links within Internal Area) and excludes the external-to-external trips to avoid underestimating the fuel cost elasticity as stated by TAG M2.1 section 6.4.18. As per TAG (discussed in detail in section 3.3.1), acceptable range of fuel cost elasticity is within the range of -0.15 to -0.35 (overall, across all purposes). The HAM network assigned car fuel cost elasticity values excluding E-E trips for AM and PM are within the acceptable range suggested by TAG.

Table 8-2 - HAM Network Car Fuel Cost Elasticities Excluding E-E trips (on Links in Internal Area)

Assignment User Class	Car Veh-km Elasticity		
	AM	IP	PM
Car Commute	-0.186	-0.176	-0.181
Car Business	-0.183	-0.172	-0.170
Car Other	-0.504	-0.500	-0.466
Overall	-0.306	-0.374	-0.300

The network elasticity values including E-E trips presented in Table 8-3 shows that car trips are less elastic when compared to the trips excluding E-E trips which is a result of underestimating the fuel cost elasticity.

Table 8-3 - HAM Network Car Fuel Cost Elasticities Including E-E trips (on Links in Internal Area)

Assignment User Class	Car Veh-km Elasticity		
	AM	IP	PM
Car Commute	-0.146	-0.142	-0.151
Car Business	-0.123	-0.122	-0.113
Car Other	-0.290	-0.292	-0.221
Overall	-0.210	-0.244	-0.183

VDM – variations in elasticity by segment

The 24-hour VDM fuel price elasticities are shown in Table 8-4. Results are presented for 'Internal to Internal' (I-I) and 'Internal to External' (I-E) trips (i.e. by residents of the AoDM) and then also including 'External to Internal' (E-I) movements.

Table 8-4 - VDM Car Fuel Cost Elasticities (Uses P/A based Veh-kms)

Purpose	I-I and I-E Elasticity
HBW	-0.249
HBEB	-0.170
HBEd	-0.303
HBL	-0.425
HBPS	-0.414
NHBEB	-0.135
NHBO	-0.266
Total	-0.322

The 24-hour VDM elasticities demonstrate an overall result of -0.32 for movements from or within the Buckinghamshire AoDM. The HBL and HBPS purposes tend to be more elastic compared to other purposes, while business trips are less elastic due to their higher value of time. The elasticities and patterns across purposes are all within the TAG specified range. The elasticity values as per car availability shown in Table 8-5 indicates that with 10% increase in fuel cost there will be an overall fall of 4.2% car trips for household with no-cars, whereas for partial car and full car available households the decrease in car trips will be 3.67% and 3.16% respectively. The reducing elasticity with increasing levels of car availability is appropriate, denoting the greater impact of cost on those without cars.

Table 8-5 - VDM Car Fuel Cost Elasticities by Car Availability (I-I, I-E and E-I)

Purpose	Elasticity (Uses P/A based Veh-kms)		
	Full Car	Part Car	No Car
HBW	-0.219	-0.234	-0.240
HBEB	-0.143	-0.138	-0.126
HBEd	-0.301	-0.313	-0.314
HBL	-0.435	-0.501	-0.548
HBPS	-0.407	-0.463	-0.500
NHBEB	-0.165	-0.225	-0.276
NHBO	-0.340	-0.464	-0.554
Total	-0.316	-0.367	-0.424

8.3 Public transport fare responses

The PT fare elasticity test considers the change in the number of public transport trips (including all PT sub-modes) in response to a 10% increase in bus and rail fares. The fares are increased for each of the demand segments for both bus and rail. TAG unit M2.1 section 6.4.21 states that elasticities of public transport trips with respect to public

transport fares have been found to lie typically in the range –0.2 to -0.9. The elasticities at a main-mode and sub-mode level, for all the purposes are within the TAG specified range with an overall PT fare elasticity of -0.49 as shown in Table 8-6. This means a 10% increase in fares would result in a 5% decrease in ridership.

Table 8-6 - VDM PT Fare Trip Elasticities by purpose (I-I, I-E and E-I)

Purpose	Bus Sub-mode	Rail Sub-mode	PT Main-mode
HBW	-0.417	-0.484	-0.315
HBEB	-0.354	-0.193	-0.223
HBEd	-0.445	-0.483	-0.441
HBL	-0.472	-0.785	-0.674
HBPS	-0.490	-0.724	-0.624
NHBEB	-0.557	-0.326	-0.364
NHBO	-0.557	-0.844	-0.665
Total	-0.464	-0.614	-0.485

8.4 Car journey time responses

The car journey time elasticity test examines the change in car trips with respect to the change in journey time, calculated from a single pass run of the demand model. The results are shown in Table 8-7.

Table 8-7 - VDM Car Own-time Trip Elasticities by purpose (I-I, I-E and E-I)

Purpose	Car Trip Elasticity
HBW	-0.253
HBEB	-0.146
HBEd	-0.346
HBL	-0.210
HBPS	-0.213
NHBEB	-0.181
NHBO	-0.212
Overall	-0.232

The number of car trips decrease with an increase in journey times for all purposes, with an overall 24-hour elasticity of -0.23. This is in line with the TAG recommendation of being negative and smaller in magnitude than - 0.75. The result suggests a low response to journey time changes and congestion in the model, with car trips potentially falling by only 2.32% for every 10% increase in journey time.

9. Model Development Summary

9.1 Overview

This chapter provides a high-level summary of each aspect of the Buckinghamshire Strategic Transport Model's (BSTM2's) demand model development process.

9.2 Demand model build, calibration and validation

The Variable Demand Model operates in Production-Attraction at the daily level and interacts with the period specific highway assignment models. Separate highway assignment model has been developed to represent the AM peak hour, the average inter-peak hour and the PM peak hour conditions for the HAM.

The VDM produced 2019 synthetic matrices based on 24-hr P/A trip ends and modal network skims. The model was calibrated through comparisons of modal shares and trip lengths to Census JTW, NTS and the relevant assignment model matrices. The calibration shows that in general, the demand model matches well with the observed data with some exceptions noted for HBO purposes having longer car trips compared to NTS. However, it is to be noted that the model is representing a wide range of trip patterns well for all the modes of transport (see chapter 7).

The model was validated through several realism tests as defined within TAG unit M2.1. Broadly, the results show a good parity between synthetic and assignment response demonstrating the robustness of the model. The overall fuel cost elasticities are within the recommended TAG values as shown in Table 8-4. Some differences are observed at the individual purpose level and the interpretation of the TAG guidance is discussed in section 8.2.2. The model produced acceptable overall public transport fare and car journey time elasticities in line with TAG guidance. Slightly higher elasticities are observed for fuel cost elasticity values in Inter-peak which is due to the car other trips being more elastic. The PT fare and car own time elasticity values are all within TAG specified acceptable range.

The VDM convergence is measured using nested gap calculation with a stopping criterion of %Gap<0.15% or a maximum of 15 loops. The model presents nested gap for each of the individual choice models, and it is noted that the fuel cost realism test converged with a maximum gap value of 0.24% for HBEB main mode and destination choice and a weighted maximum gap across all the main mode & destination choices of 0.13%.

APPENDICES



Appendix A. Notation

A.1 Notation used in VDM specification equations

Name	Notation	Units	Dimensions	Comment
Assignment User Class (AUC)	auc	n/a	n/a	
Attraction Zone	j	n/a	Zone	
Weight for access time	α	n/a	Mode	
Trip Attraction weight (singly constrained)	$A_{p,j}$	n/a	Zone, purpose, year	Input
Trip Attractions	$A_{ds,j}$	Person trip attractions per 24hr	Zone, demand strata, year	Output
Bus Park & Ride site	b	n/a	n/a	
Balancing Factor	B	n/a	n/a	Doubly constrained choice models only
Bus Park & Ride sub mode	$BusPR$	n/a	n/a	
Weight for waiting time	β	n/a	Mode	
Trip attraction constraint (doubly constrained)	$C_{p,j}$	Person trip attractions per 24hr	Zone, purpose, year	Input target to be met. Total for purpose (activity pair) not specific demand strata
Car main mode	Car	n/a	n/a	
Car sub mode	car	n/a	n/a	
Car business AUC	CB	n/a	n/a	
Car commute AUC	CC	n/a	n/a	



Name	Notation	Units	Dimensions	Comment
Car other AUC	CO	n/a	n/a	
Monetary cost	$cost$	pence (2019)	Mode, TOD, purpose, AUC	Total money cost
Interchange penalty	γ	minutes	Mode	
Destination Zone	d	n/a	Zone	
O-D demand	D	Vehicle trips	Sub-mode, zone pair, AUC	Output
Demand strata	ds	n/a	n/a	
Distance	$dist$	kilometres	Mode, TOD, purpose, AUC	
Weight for ride time	ε	n/a	Mode	
PT fare cost	$fare$	pence (2019)	Mode, TOD, purpose	
From-home (outbound) trips	FH	n/a	TOD	
Generalised Cost	G	minutes	Mode, TOD, purpose, demand strata	All time components of a trip weighted for perception (ie access, wait etc)
Damped Generalised Cost	G'	Minutes	Mode, TOD, purpose, demand strata	
Number of hours in a time period	h	Hours	TOD	
Home-based trip purposes	HB	n/a	n/a	
Production Zone	i	n/a	Zone	
Interchanges between PT modes/stages	$Interchange$	number of interchanges	Mode, TOD, activity pair	
Attraction Zone	j	n/a	Zone	



Name	Notation	Units	Dimensions	Comment
Mode constant (purpose)	$k_{m,p}$	Generalised Cost	Mode, purpose	Calibrated parameter
Mode constant (demand strata)	$k_{m,ds}$	Generalised Cost	Mode, demand strata	Calibrated parameter
Generalised cost damping power	κ	n/a	n/a	
Light Goods Vehicle	LGV	n/a	n/a	
Sensitivity parameter	λ	Utility	Main mode, destination, sub mode	
Main mode	m	n/a	n/a	
Generalised cost damping factor	μ	n/a	n/a	
Number of zones	n	n/a	n/a	
Non-homebased trip purposes	NHB	n/a	n/a	
Origin Zone	o	n/a	Zone	
Occupancy	O	People	Mode, purpose	Observed constant by purpose
Outbound time period	Out	n/a	TOD	
LGV trip proportion	ω	n/a	Purpose, AUC	
Trip Productions	$P_{ds,i}$	Person trip productions per 24hr	Zone, DS, year	Input. Years will be selected for individual runs
Trip purpose	p	n/a	n/a	
Rho (from-home) factors	ρ	n/a	TOD	
Parking cost	$Parking$	pence (2019)	Attraction zone	
PT main mode	PT	n/a	n/a	
PT sub mode	pt	n/a	n/a	
Rail Park & Ride site (station)	r	n/a	n/a	



Name	Notation	Units	Dimensions	Comment
Rail Park & Ride sub mode	$RailPR$	n/a	n/a	
Return time period	$Return$	n/a	TOD	
Ride Time (for PT modes)	IVT	minutes	Mode, TOD, purpose	
Number of Rail Park & Ride sites	s	n/a	n/a	
Sub mode	sm	n/a	n/a	
P/A demand	T	Person P/A trips	Mode, sub-mode, demand strata, P/A pair	Output
To-home (return) trips	TH	n/a	TOD	
Time	$time$	minutes	Mode, TOD, purpose, AUC	
Toll	$toll$	pence (2019)	Mode, TOD, purpose, AUC	
Peak period	TOD	n/a	n/a	
Peak hour	tod	n/a	n/a	
Value of Travel Time	VoT_m	pence (2019)	Mode, purpose	Per person (not vehicle)
Vehicle Operating Cost	VOC	pence (2019)	AUC	
Phi (to-home) factors	ϕ	n/a	TOD	Proportion of return legs starting in time period
Wait Time (for PT modes)	$Wait$	minutes	Mode, TOD, purpose	
Access Time (for PT modes)	$Walk$	minutes	Mode, TOD, purpose	
Zones	$\frac{z}{Z}$	n/a	n/a	
Invehicle time factor	Fac_{IVT}	n/a	n/a	
	Fac_{ACT}	n/a	n/a	



Name	Notation	Units	Dimensions	Comment
Egress time factor	Fac_{EGT}	n/a	n/a	
Transfer walk time factor	Fac_{WKT}	n/a	n/a	
Origin waiting time factor	Fac_{OWT}	n/a	n/a	
Transfer wait time factor	Fac_{TWT}	n/a	n/a	
Number of transfers factor	Fac_{TRN}	n/a	n/a	
Number of operator changes factor	Fac_{OC}	n/a	n/a	



Appendix B. Parking Charges

B.1 Zones with parking charge with short and long stay

Zones	Name	Long Stay 2024 (£)	Short Stay 2024(£)
5	Swan Pool car park (Buckingham)	6.20	1.20
20	Cornwalls Meadow car park (Buckingham)	2.70	0.70
50	Market Square car park (Winslow)	0.00	0.70
134	Waterside car park (Aylesbury)	8.20	2.20
135	Exchange Street car park (Aylesbury)	8.20	2.70
137	Aqua Vale car park (Aylesbury)	10.20	2.20
144	Walton Street car park (Aylesbury)	4.20	2.20
145	Walton Green car park (Aylesbury)	3.20	3.20
150	Friarscroft car park (Aylesbury)	3.20	3.20
151	Waterside North car park (Aylesbury)	8.10	2.60
152	Whitehall Street car park (Aylesbury)	4.20	2.70
154	Cooper's Yard car park (Aylesbury)	8.20	2.20
155	Upper Hundreds car park (Aylesbury)	8.20	2.20
218	Wendover Library car park (Wendover)	4.20	0.70
258	Albany Place car park (Chesham)	4.20	1.60
265	Water Meadow car park (Chesham)	3.80	1.60
267	Star Yard car park (Chesham)	0.00	2.20
271	Link Road car park (Great Missenden)	3.80	1.60
279	Prestwood High Street car park (Prestwood)	3.80	1.60
288	Amersham multi-storey station car park (Amersham)	6.20	1.60
291	Sycamore Road car park (Amersham)	6.20	1.60
306	Amersham Old Town car park (Amersham)	3.80	1.60
318	Snells Wood car park (Little Chalfont)	3.80	1.60
327	Blizzards Yard car park (Chalfont St Giles)	3.80	1.60
336	Church Lane car park (Chalfont St Peter)	3.80	1.60
364	Altons car park (Beaconsfield)	6.20	2.40
373	Warwick Road car park (Beaconsfield)	6.20	2.40
391	Packhorse Road car park (Gerrards Cross)	8.20	2.40



Zones	Name	Long Stay 2024 (£)	Short Stay 2024(£)
392	Station Road car park (Gerrards Cross)	8.20	2.40
407	The Broadway car park (Farnham Common)	2.10	1.60
432	Summers Road car park (Burnham)	2.80	1.50
457	The Mount car park (Princes Risborough)	3.70	1.00
458	Horns Lane car park (Princes Risborough)	10.20	1.70
532	Duke Street car park (High Wycombe)	6.70	2.20
553	Desborough Street car park (High Wycombe)	5.20	2.20
571	Desborough Square car park (High Wycombe)	5.20	2.20
583	Easton Street car park (High Wycombe)	9.20	2.20
585	Wycombe Swan car park	10.20	2.20
586	Handy Cross park and ride (for High Wycombe) car park	3.20	1.40
597	Kingsmead car park (High Wycombe)	2.70	1.20
652	Wakeman Road car park (Bourne End)	4.20	1.20
667	Dean Street car park (Marlow)	6.70	1.80
671	Riley Road car park (Marlow)	6.70	1.80
673	Pound Lane car park (Marlow)	6.20	1.60
674	West Street car park (Marlow)	6.70	1.80
676	Marlow Central car park	10.20	1.80
677	Station Approach car park (Marlow)	0.00	0.00
679	Institute Road car park (Marlow)	6.20	1.60



Appendix C. Segmentation Definition

C.1 Traveller Types to Model Demand Strata correspondence

Population individual Types	Purpose Name	Model Demand Strata
FT_1Adult_0Car	HBW	HBW_HBW_FT_16-74_NC
FT_1Adult_1+Car	HBW	HBW_HBW_FT_16-74_FC
FT_2+Adult_0Car	HBW	HBW_HBW_FT_16-74_NC
FT_2+Adult_1Car	HBW	HBW_HBW_FT_16-74_PC
FT_2+Adult_2+Car	HBW	HBW_HBW_FT_16-74_FC
PT_1Adult_0Car	HBW	HBW_HBW_PT_16-74_NC
PT_1Adult_1+Car	HBW	HBW_HBW_PT_16-74_FC
PT_2+Adult_0Car	HBW	HBW_HBW_PT_16-74_NC
PT_2+Adult_1Car	HBW	HBW_HBW_PT_16-74_PC
PT_2+Adult_2+Car	HBW	HBW_HBW_PT_16-74_FC
FT_1Adult_0Car	HBEB	HBEB_HBEB_FT_16-74_NC
FT_1Adult_1+Car	HBEB	HBEB_HBEB_FT_16-74_FC
FT_2+Adult_0Car	HBEB	HBEB_HBEB_FT_16-74_NC
FT_2+Adult_1Car	HBEB	HBEB_HBEB_FT_16-74_PC
FT_2+Adult_2+Car	HBEB	HBEB_HBEB_FT_16-74_FC
PT_1Adult_0Car	HBEB	HBEB_HBEB_PT_16-74_NC
PT_1Adult_1+Car	HBEB	HBEB_HBEB_PT_16-74_FC
PT_2+Adult_0Car	HBEB	HBEB_HBEB_PT_16-74_NC



Population individual Types	Purpose Name	Model Demand Strata
PT_2+Adult_1Car	HBEB	HBEB_HBEB_PT_16-74_PC
PT_2+Adult_2+Car	HBEB	HBEB_HBEB_PT_16-74_FC
ChildPrimary_1Adult_0Car	HBEd	HBEd_HBEd_Child_PE_5-11_NC
ChildPrimary_1Adult_1+Car	HBEd	HBEd_HBEd_Child_PE_5-11_FC
ChildPrimary_2+Adult_0Car	HBEd	HBEd_HBEd_Child_PE_5-11_NC
ChildPrimary_2+Adult_1Car	HBEd	HBEd_HBEd_Child_PE_5-11_PC
ChildPrimary_2+Adult_2+Car	HBEd	HBEd_HBEd_Child_PE_5-11_FC
ChildSecondary_1Adult_0Car	HBEd	HBEd_HBEd_Child_SE_12-16_NC
ChildSecondary_1Adult_1+Car	HBEd	HBEd_HBEd_Child_SE_12-16_FC
ChildSecondary_2+Adult_0Car	HBEd	HBEd_HBEd_Child_SE_12-16_NC
ChildSecondary_2+Adult_1Car	HBEd	HBEd_HBEd_Child_SE_12-16_PC
ChildSecondary_2+Adult_2+Car	HBEd	HBEd_HBEd_Child_SE_12-16_FC
ChildTertiary_1Adult_0Car	HBEd	HBEd_HBEd_Child_TE_17-18_NC
ChildTertiary_1Adult_1+Car	HBEd	HBEd_HBEd_Child_TE_17-18_FC
ChildTertiary_2+Adult_0Car	HBEd	HBEd_HBEd_Child_TE_17-18_NC
ChildTertiary_2+Adult_1Car	HBEd	HBEd_HBEd_Child_TE_17-18_PC
ChildTertiary_2+Adult_2+Car	HBEd	HBEd_HBEd_Child_TE_17-18_FC
UniStudent_1Adult_0Car	HBEd	HBPS_HBPS_Other_16-74_NC
UniStudent_1Adult_1+Car	HBEd	HBPS_HBPS_Other_16-74_FC
UniStudent_2+Adult_0Car	HBEd	HBPS_HBPS_Other_16-74_NC
UniStudent_2+Adult_1Car	HBEd	HBPS_HBPS_Other_16-74_PC
UniStudent_2+Adult_2+Car	HBEd	HBPS_HBPS_Other_16-74_FC



Population individual Types	Purpose Name	Model Demand Strata
Other_1Adult_0Car	HBEd	HBPS_HBPS_Other_16-74_NC
Other_1Adult_1+Car	HBEd	HBPS_HBPS_Other_16-74_FC
Other_2+Adult_0Car	HBEd	HBPS_HBPS_Other_16-74_NC
Other_2+Adult_1Car	HBEd	HBPS_HBPS_Other_16-74_PC
Other_2+Adult_2+Car	HBEd	HBPS_HBPS_Other_16-74_FC
FT_1Adult_0Car	HBPS	HBPS_HBPS_FT_16-74_NC
FT_1Adult_1+Car	HBPS	HBPS_HBPS_FT_16-74_FC
FT_2+Adult_0Car	HBPS	HBPS_HBPS_FT_16-74_NC
FT_2+Adult_1Car	HBPS	HBPS_HBPS_FT_16-74_PC
FT_2+Adult_2+Car	HBPS	HBPS_HBPS_FT_16-74_FC
PT_1Adult_0Car	HBPS	HBPS_HBPS_PT_16-74_NC
PT_1Adult_1+Car	HBPS	HBPS_HBPS_PT_16-74_FC
PT_2+Adult_0Car	HBPS	HBPS_HBPS_PT_16-74_NC
PT_2+Adult_1Car	HBPS	HBPS_HBPS_PT_16-74_PC
PT_2+Adult_2+Car	HBPS	HBPS_HBPS_PT_16-74_FC
75+_1Adult_0Car	HBPS	HBPS_HBPS_75_NC
75+_1Adult_1+Car	HBPS	HBPS_HBPS_75_FC
75+_2+Adult_0Car	HBPS	HBPS_HBPS_75_NC
75+_2+Adult_1Car	HBPS	HBPS_HBPS_75_PC
75+_2+Adult_2+Car	HBPS	HBPS_HBPS_75_FC
Child_1Adult_0Car	HBPS	HBPS_HBPS_Child_NC
Child_1Adult_1+Car	HBPS	HBPS_HBPS_Child_FC



Population individual Types	Purpose Name	Model Demand Strata
Child_2+Adult_0Car	HBPS	HBPS_HBPS_Child_NC
Child_2+Adult_1Car	HBPS	HBPS_HBPS_Child_PC
Child_2+Adult_2+Car	HBPS	HBPS_HBPS_Child_FC
Student_1Adult_0Car	HBPS	HBPS_HBPS_Student_16-74_NC
Student_1Adult_1+Car	HBPS	HBPS_HBPS_Student_16-74_FC
Student_2+Adult_0Car	HBPS	HBPS_HBPS_Student_16-74_NC
Student_2+Adult_1Car	HBPS	HBPS_HBPS_Student_16-74_PC
Student_2+Adult_2+Car	HBPS	HBPS_HBPS_Student_16-74_FC
Other_1Adult_0Car	HBPS	HBPS_HBPS_Other_16-74_NC
Other_1Adult_1+Car	HBPS	HBPS_HBPS_Other_16-74_FC
Other_2+Adult_0Car	HBPS	HBPS_HBPS_Other_16-74_NC
Other_2+Adult_1Car	HBPS	HBPS_HBPS_Other_16-74_PC
Other_2+Adult_2+Car	HBPS	HBPS_HBPS_Other_16-74_FC
FT_1Adult_0Car	HBL	HBL_HBL_FT_16-74_NC
FT_1Adult_1+Car	HBL	HBL_HBL_FT_16-74_FC
FT_2+Adult_0Car	HBL	HBL_HBL_FT_16-74_NC
FT_2+Adult_1Car	HBL	HBL_HBL_FT_16-74_PC
FT_2+Adult_2+Car	HBL	HBL_HBL_FT_16-74_FC
PT_1Adult_0Car	HBL	HBL_HBL_PT_16-74_NC
PT_1Adult_1+Car	HBL	HBL_HBL_PT_16-74_FC
PT_2+Adult_0Car	HBL	HBL_HBL_PT_16-74_NC
PT_2+Adult_1Car	HBL	HBL_HBL_PT_16-74_PC



Population individual Types	Purpose Name	Model Demand Strata
PT_2+Adult_2+Car	HL	HL_HL_PT_16-74_FC
75+_1Adult_0Car	HL	HL_HL_75_NC
75+_1Adult_1+Car	HL	HL_HL_75_FC
75+_2+Adult_0Car	HL	HL_HL_75_NC
75+_2+Adult_1Car	HL	HL_HL_75_PC
75+_2+Adult_2+Car	HL	HL_HL_75_FC
Child_1Adult_0Car	HL	HL_HL_Child_NC
Child_1Adult_1+Car	HL	HL_HL_Child_FC
Child_2+Adult_0Car	HL	HL_HL_Child_NC
Child_2+Adult_1Car	HL	HL_HL_Child_PC
Child_2+Adult_2+Car	HL	HL_HL_Child_FC
Student_1Adult_0Car	HL	HL_HL_Student_16-74_NC
Student_1Adult_1+Car	HL	HL_HL_Student_16-74_FC
Student_2+Adult_0Car	HL	HL_HL_Student_16-74_NC
Student_2+Adult_1Car	HL	HL_HL_Student_16-74_PC
Student_2+Adult_2+Car	HL	HL_HL_Student_16-74_FC
Other_1Adult_0Car	HL	HL_HL_Other_16-74_NC
Other_1Adult_1+Car	HL	HL_HL_Other_16-74_FC
Other_2+Adult_0Car	HL	HL_HL_Other_16-74_NC
Other_2+Adult_1Car	HL	HL_HL_Other_16-74_PC
Other_2+Adult_2+Car	HL	HL_HL_Other_16-74_FC
ChildNursery_1Adult_0Car	HBEd	HBEd_HBEd_Child_NE_0-4_NC



Population individual Types	Purpose Name	Model Demand Strata
ChildNursery_1Adult_1+Car	HBEd	HBEd_HBEd_Child_NE_0-4_FC
ChildNursery_2+Adult_0Car	HBEd	HBEd_HBEd_Child_NE_0-4_NC
ChildNursery_2+Adult_1Car	HBEd	HBEd_HBEd_Child_NE_0-4_PC
ChildNursery_2+Adult_2+Car	HBEd	HBEd_HBEd_Child_NE_0-4_FC



Appendix D. Demand Inputs to VDM

D.1 Trip Productions

Sectors	HBW	HBEB	HBEd	HBL	HBPS	Total
101	22,958	3,859	22,543	20,720	26,788	96,868
102	21,405	2,435	17,064	15,873	22,613	79,390
103	15,398	2,334	13,177	13,037	17,481	61,428
104	13,025	1,987	12,858	12,562	16,826	57,257
105	25,722	3,038	24,521	21,852	30,384	105,517
106	10,635	1,413	9,712	10,044	13,780	45,583
107	17,054	2,295	19,426	17,515	24,195	80,486
108	7,266	944	8,525	8,053	10,978	35,765
109	6,918	941	8,056	7,397	10,186	33,498
110	10,658	1,433	11,603	11,659	15,936	51,289
111	2,169	253	-	1,723	2,420	6,566
113	3,741	418	-	3,059	4,320	11,538
114	1,661	245	-	1,508	2,044	5,459
201	3,500	414	-	2,071	3,520	9,506
302	2,374	332	-	1,924	2,718	7,348
303	885	123	-	668	981	2,657
305	2,962	396	-	2,633	3,633	9,624
306	940	143	-	907	1,243	3,232



Sectors	HBW	HBEB	HBEd	HBL	HBPS	Total
307	1,389	183	-	1,122	1,538	4,232
308	1,075	157	-	968	1,303	3,502
401	631	79	-	586	849	2,145
403	503	72	-	446	616	1,637
407	932	117	-	781	1,093	2,924
409	1,012	133	-	792	1,157	3,094
412	557	56	-	435	629	1,676
414	482	61	-	298	462	1,303
501	474	60	-	442	654	1,630
502	2,297	290	-	1,933	2,640	7,160
503	497	65	-	483	706	1,751
504	1,644	198	-	1,006	1,675	4,524
505	2,462	315	-	1,686	2,638	7,101
506	2,450	304	-	2,057	2,897	7,708
901	749	98	-	715	1,042	2,602
902	751	90	-	696	1,047	2,584
903	634	82	-	602	881	2,199
904	371	42	-	325	502	1,240
905	238	27	-	214	331	810
906	118	13	-	107	169	408
907	160	20	-	159	238	578
Total	188,696	25,464	147,485	169,061	233,115	763,820



D.2 Trip Attractions

Sectors	HBW	HBEB	HBEd	HBL	HBPS	NHBEB	NHBO
101	35,863	35,863	12,911	20,013	13,378	35,863	14,907
102	39,620	39,620	13,697	12,801	26,385	39,620	17,796
103	26,345	26,345	6,901	10,342	17,154	26,345	9,778
104	21,243	21,243	5,757	11,475	9,712	21,243	9,309
105	54,009	54,009	14,637	23,766	35,859	54,009	25,326
106	27,088	27,088	7,005	10,733	12,898	27,088	9,602
107	29,867	29,867	11,613	15,657	20,563	29,867	14,790
108	11,385	11,385	5,403	6,129	6,394	11,385	4,829
109	17,117	17,117	5,157	7,789	12,334	17,117	8,204
110	27,428	27,428	3,655	14,056	10,063	27,428	10,641
111	6,914	51,949	-	24,523	37,912	51,949	1,019
113	8,884	26,849	-	7,113	14,084	26,849	878
114	3,971	5,757	-	3,428	2,734	5,757	517
201	26,423	949,342	-	284,088	277,379	949,342	2,705
302	5,342	22,526	-	10,274	14,889	22,526	838
303	2,098	11,990	-	5,998	6,037	11,990	259
305	7,191	27,588	-	16,091	13,694	27,588	990
306	1,710	16,145	-	7,472	9,163	16,145	228
307	3,211	25,816	-	9,476	18,759	25,816	480
308	1,562	53,232	-	27,864	33,272	53,232	323



Sectors	HBW	HBEB	HBEd	HBL	HBPS	NHBEB	NHBO
401	1,023	319,510	-	156,472	198,972	319,510	143
403	1,142	38,959	-	19,012	21,207	38,959	150
407	2,774	126,746	-	52,197	91,770	126,746	373
409	3,190	193,975	-	85,295	114,413	193,975	410
412	2,709	35,054	-	10,057	20,615	35,054	359
414	1,691	18,215	-	6,312	11,584	18,215	216
501	615	517,362	-	246,104	400,394	517,362	90
502	4,896	110,490	-	42,669	60,983	110,490	620
503	825	629,729	-	314,952	458,948	629,729	119
504	5,616	583,661	-	219,589	310,417	583,661	564
505	10,802	58,834	-	17,295	25,773	58,834	992
506	3,516	90,653	-	40,779	64,731	90,653	516
901	740	878,196	-	425,951	565,695	878,196	104
902	875	837,084	-	434,369	598,939	837,084	131
903	599	708,049	-	357,477	483,016	708,049	87
904	336	1,058,675	-	532,105	742,058	1,058,675	49
905	275	747,368	-	373,893	521,747	747,368	40
906	69	362,794	-	192,791	274,313	362,794	10
907	140	438,268	-	238,109	321,331	438,268	22
908	-	-	-	-	-	-	-
Total	399,101	9,234,780	86,736	4,294,516	5,879,567	9,234,780	138,413



Appendix E. Production and Attraction

E.1 HBW Mode Shares by Production/Home District (24-hour P/A)

Production Sector	Car		PT		Cycle		Walk	
	BSTM2	Census	BSTM2	Census	BSTM2	Census	BSTM2	Census
101 Aylesbury North	82%	84%	10%	8%	4%	1%	5%	7%
102 Aylesbury Central	64%	72%	12%	8%	10%	3%	15%	17%
103 Aylesbury South	74%	77%	12%	11%	6%	3%	8%	9%
104 Wycombe North-West	78%	79%	11%	10%	6%	2%	6%	8%
105 Wycombe Central and East	67%	74%	12%	12%	9%	1%	12%	12%
106 Wycombe South	76%	81%	9%	9%	7%	2%	9%	8%
107 Chiltern North	74%	72%	14%	18%	5%	1%	7%	8%
108 Chiltern South	77%	74%	13%	18%	5%	1%	5%	6%
109 South Bucks West	74%	75%	14%	15%	6%	2%	6%	8%
110 South Bucks East	74%	81%	12%	13%	8%	1%	5%	5%
111 Milton Keynes	94%	91%	3%	5%	3%	1%	0%	2%
113 Slough	78%	80%	7%	11%	10%	3%	5%	6%
114 Bicester	87%	96%	7%	2%	5%	1%	2%	1%
201 Central and Northwest London	81%	70%	19%	28%	1%	0%	0%	1%
302 Dacorum	93%	95%	3%	3%	3%	1%	0%	1%
303 Three Rivers	90%	93%	6%	5%	4%	1%	0%	1%
305 Windsor and Maidenhead	88%	93%	5%	4%	6%	1%	1%	2%
306 South Oxfordshire	88%	97%	10%	2%	1%	1%	0%	1%
307 Cherwell	82%	90%	17%	4%	1%	2%	0%	4%



Production Sector	Car		PT		Cycle		Walk	
	BSTM2	Census	BSTM2	Census	BSTM2	Census	BSTM2	Census
308 Northamptonshire	96%	96%	3%	2%	1%	0%	0%	2%
401 Hampshire	16%	91%	84%	3%	0%	1%	0%	6%
403 Oxfordshire	90%	96%	10%	1%	0%	1%	0%	2%
407 Hertfordshire	96%	94%	4%	4%	0%	0%	0%	2%
409 Surrey	95%	96%	4%	2%	0%	0%	0%	1%
412 Oxford	76%	90%	24%	6%	0%	1%	0%	3%
414 Watford	91%	91%	7%	6%	2%	1%	0%	1%
501 West Sussex and Kent	38%	84%	62%	8%	0%	1%	0%	7%
502 Berkshire	87%	95%	12%	4%	0%	0%	0%	1%
503 Cambridgeshire, Essex and East of England	70%	86%	30%	6%	0%	1%	0%	7%
504 East and South-West London	88%	72%	12%	26%	1%	0%	0%	2%
505 Hillingdon South and Uxbridge	84%	85%	9%	12%	6%	1%	1%	2%
506 Bedfordshire and Bedford	92%	95%	5%	3%	3%	1%	0%	2%
901 South West	16%	86%	84%	3%	0%	2%	0%	9%
902 West Midlands	18%	83%	82%	8%	0%	1%	0%	8%
903 East Midlands	100%	86%	0%	3%	0%	3%	0%	9%
904 North West	97%	81%	3%	7%	0%	2%	0%	10%
905 Yorkshire and The Humber	100%	78%	0%	8%	0%	2%	0%	12%
906 North East	100%	76%	0%	6%	0%	2%	0%	16%
907 Wales	26%	83%	74%	5%	0%	1%	0%	11%



E.2 HBW Mode Shares by Attraction/Work District (24-hour P/A)

Production Sector	Car		PT		Cycle		Walk	
	BSTM2	Census	BSTM2	Census	BSTM2	Census	BSTM2	Census
101 Aylesbury North	87%	84%	2%	3%	5%	2%	6%	11%
102 Aylesbury Central	65%	73%	5%	6%	12%	3%	18%	18%
103 Aylesbury South	82%	80%	3%	5%	6%	3%	8%	11%
104 Wycombe North-West	85%	80%	5%	5%	5%	4%	6%	11%
105 Wycombe Central and East	69%	78%	8%	8%	10%	1%	13%	13%
106 Wycombe South	79%	85%	7%	5%	6%	2%	7%	8%
107 Chiltern North	80%	81%	5%	6%	6%	1%	8%	12%
108 Chiltern South	84%	84%	5%	7%	5%	1%	6%	8%
109 South Bucks West	76%	81%	12%	7%	6%	2%	5%	10%
110 South Bucks East	80%	84%	10%	10%	5%	2%	4%	5%
111 Milton Keynes	96%	95%	1%	3%	2%	0%	0%	1%
113 Slough	86%	92%	4%	4%	7%	1%	3%	2%
114 Bicester	87%	94%	8%	4%	4%	1%	1%	1%
201 Central and Northwest London	31%	36%	69%	62%	0%	0%	0%	1%
302 Dacorum	95%	95%	2%	3%	3%	1%	0%	1%
303 Three Rivers	91%	94%	6%	5%	3%	1%	0%	1%
305 Windsor and Maidenhead	92%	93%	3%	4%	4%	2%	1%	1%
306 South Oxfordshire	89%	95%	9%	3%	1%	0%	0%	1%
307 Cherwell	87%	93%	12%	5%	1%	1%	0%	2%
308 Northamptonshire	96%	95%	3%	3%	1%	0%	0%	1%



Production Sector	Car		PT		Cycle		Walk	
	BSTM2	Census	BSTM2	Census	BSTM2	Census	BSTM2	Census
401 Hampshire	2%	93%	98%	3%	0%	1%	0%	3%
403 Oxfordshire	87%	95%	13%	2%	0%	0%	0%	3%
407 Hertfordshire	96%	97%	4%	2%	0%	0%	0%	1%
409 Surrey	94%	95%	6%	3%	0%	1%	0%	1%
412 Oxford	83%	92%	17%	6%	0%	1%	0%	1%
414 Watford	94%	93%	5%	5%	1%	0%	0%	1%
501 West Sussex and Kent	10%	89%	90%	6%	0%	0%	0%	4%
502 Berkshire	87%	93%	13%	6%	0%	0%	0%	1%
503 Cambridgeshire, Essex and East of England	42%	87%	58%	6%	0%	1%	0%	6%
504 East and South-West London	62%	64%	38%	34%	0%	0%	0%	1%
505 Hillingdon South and Uxbridge	66%	94%	21%	4%	10%	1%	3%	1%
506 Bedfordshire and Bedford	96%	95%	2%	3%	2%	1%	0%	1%
901 South West	17%	79%	83%	10%	0%	1%	0%	10%
902 West Midlands	15%	86%	85%	10%	0%	1%	0%	3%
903 East Midlands	99%	87%	1%	4%	0%	1%	0%	7%
904 North West	0%	76%	100%	14%	0%	1%	0%	9%
905 Yorkshire and The Humber	100%	72%	0%	8%	0%	3%	0%	18%
906 North East	100%	66%	0%	24%	0%	3%	0%	7%
907 Wales	14%	80%	86%	3%	0%	4%	0%	12%



Appendix F. VDM Calibration Analysis

F.1 VDM Calibration Plots

Figure F-1 – Trip Length Distribution Comparison for HBEB (Car)

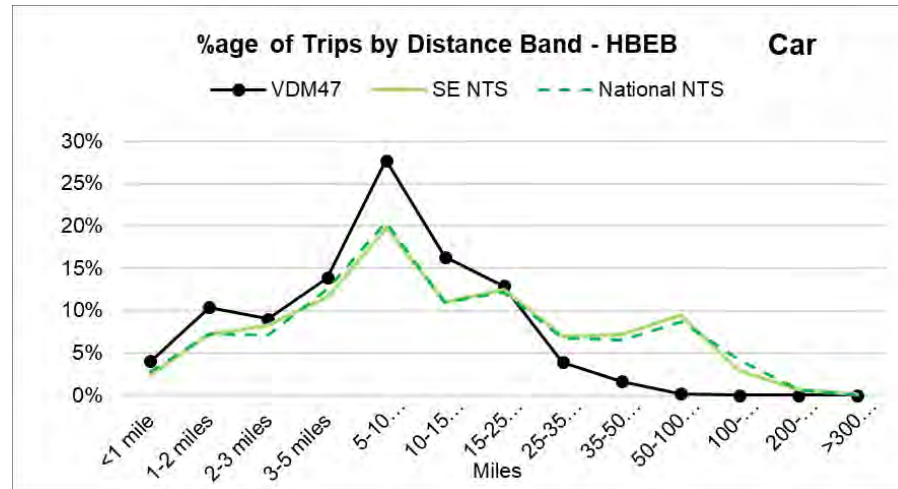


Figure F-2 – Trip Length Distribution Comparison for HBEB (PT)

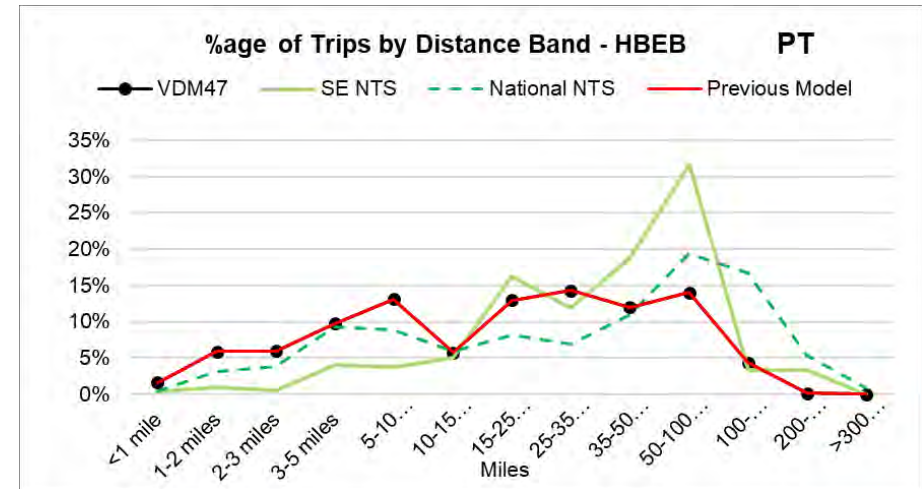


Figure F-3 – Trip Length Distribution Comparison for HBEB (Walk)

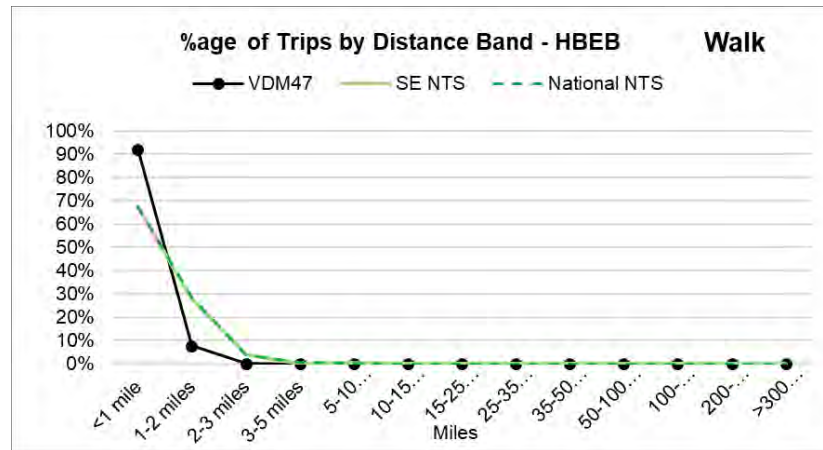


Figure F-4 – Trip Length Distribution Comparison for HBEB (Cycle)

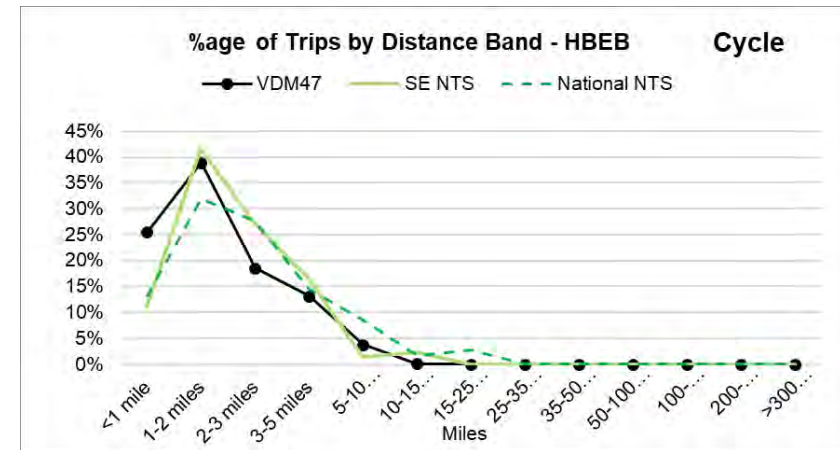


Figure F-5 – Trip Length Distribution Comparison for HBPS (Car)

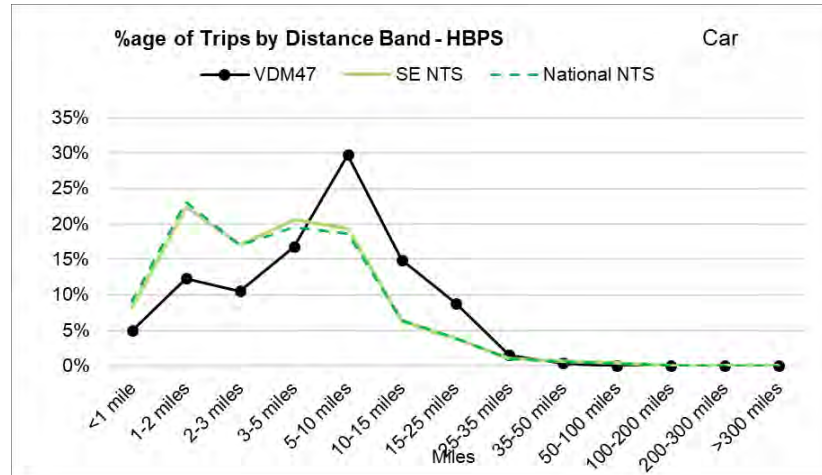


Figure F-6 – Trip Length Distribution Comparison for HBPS (PT)

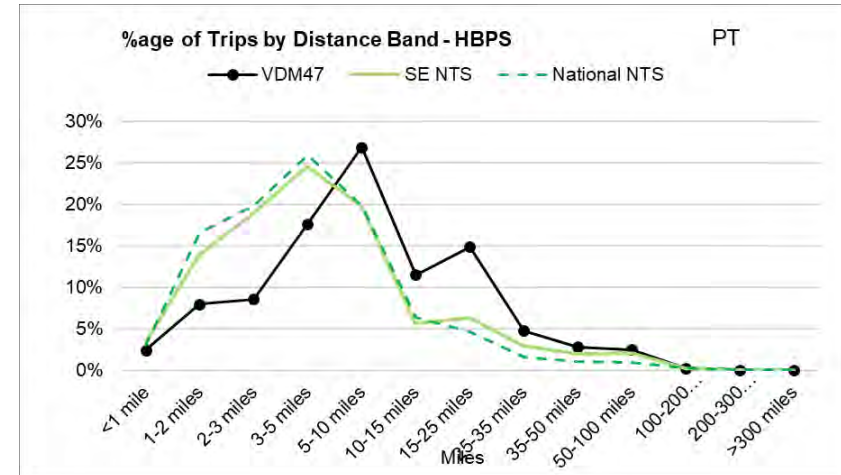


Figure F-7 – Trip Length Distribution Comparison for HBPS (Walk)

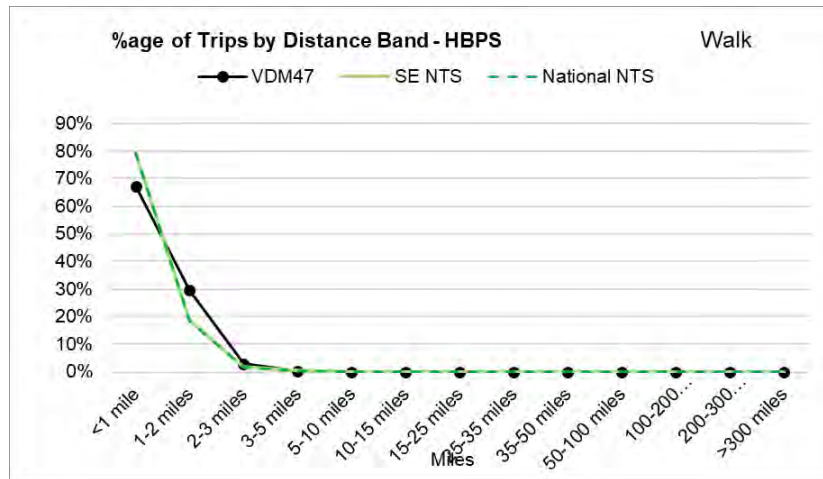


Figure F-8 – Trip Length Distribution Comparison for HBPS (Cycle)

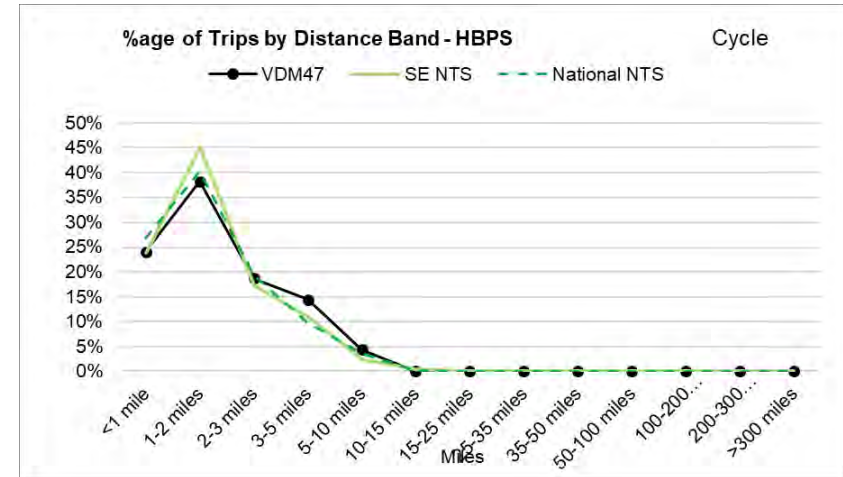


Figure F-9 – Trip Length Distribution Comparison for HBL (Car)

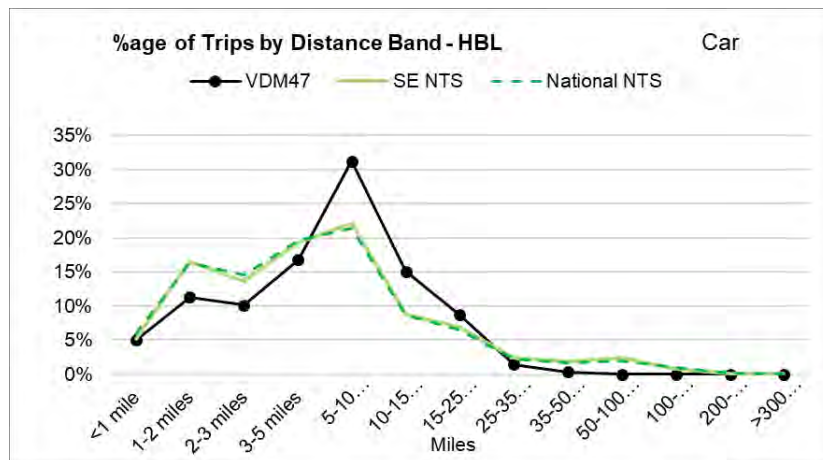


Figure F-10 – Trip Length Distribution Comparison for HBL (PT)

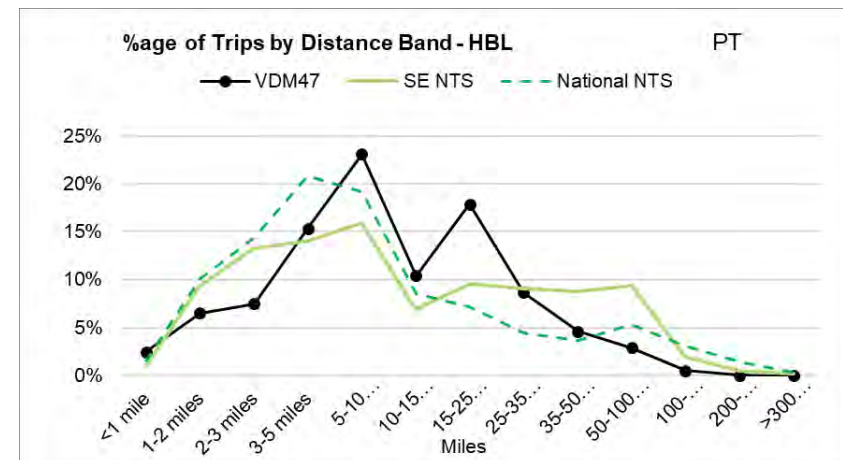


Figure F-11 – Trip Length Distribution Comparison for HBL (Walk)

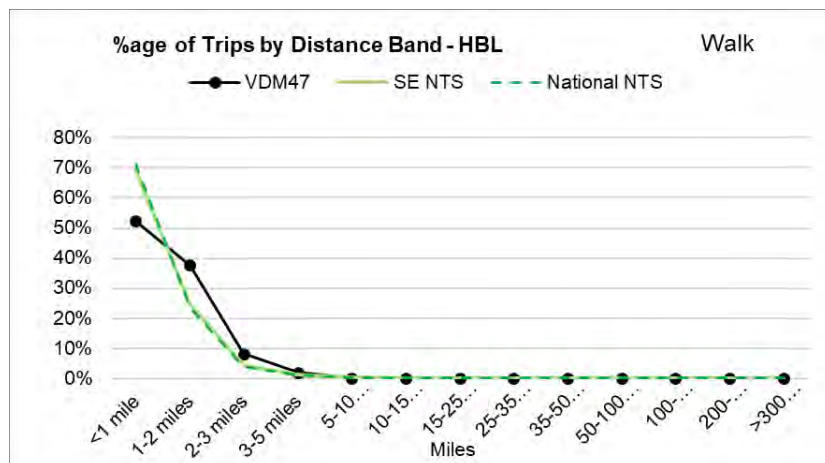


Figure F-12 – Trip Length Distribution Comparison for HBL (Cycle)

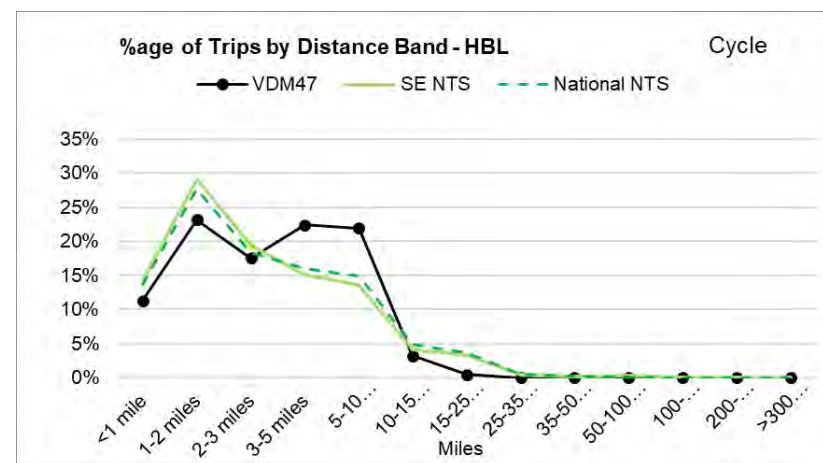


Figure F-13 – Trip Length Distribution Comparison for HBEd (Car)

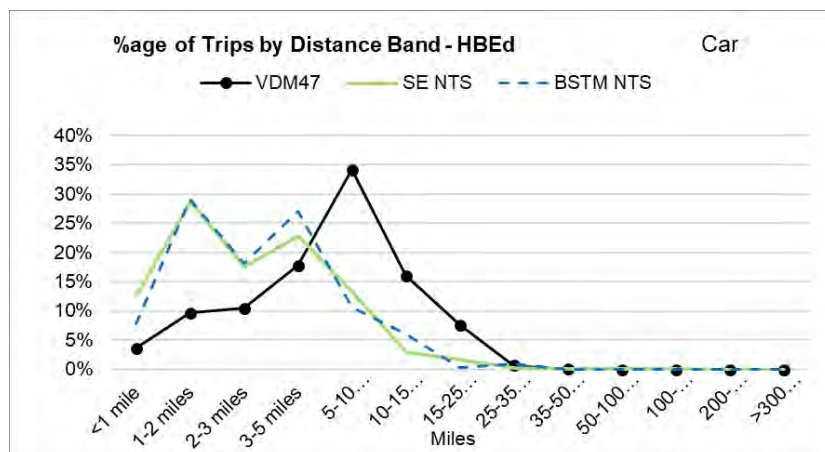


Figure F-14 – Trip Length Distribution Comparison for HBEd (PT)

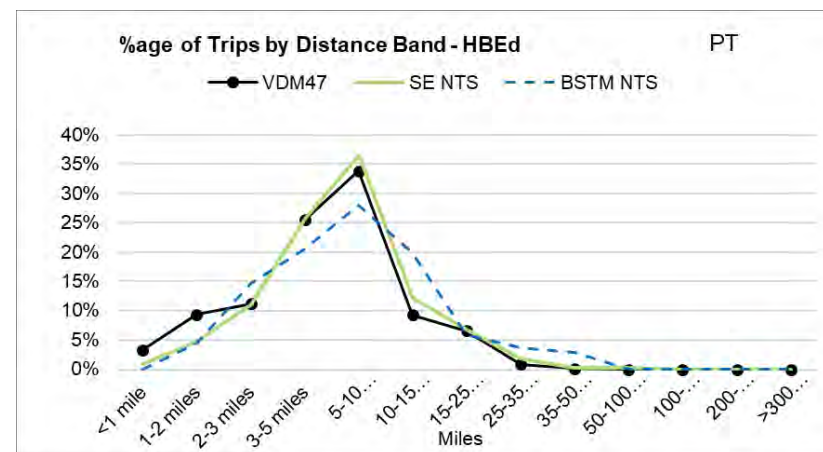


Figure F-15 – Trip Length Distribution Comparison for HBEd (Walk)

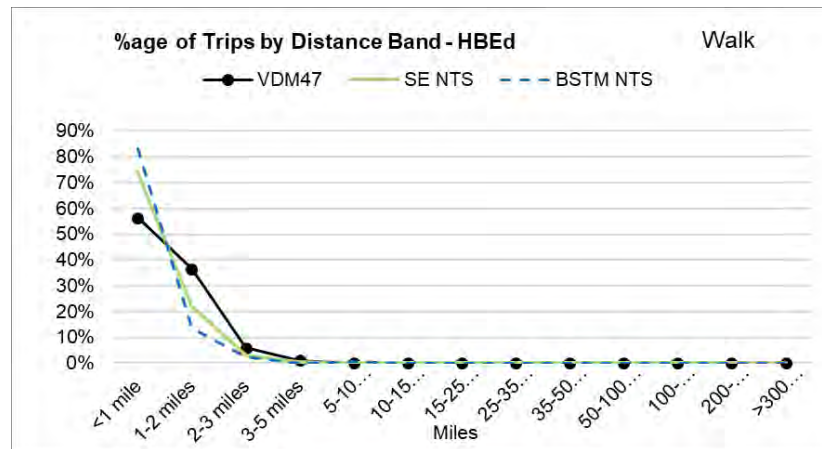
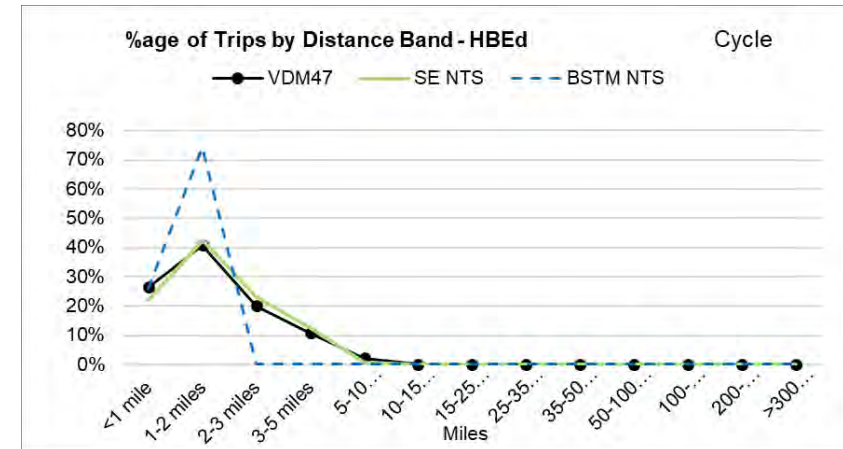


Figure F-16 – Trip Length Distribution Comparison for HBEd (Cycle)



F.2 Sector-to-Sector Comparisons

Table F-1 - Sector-to-Sector Car Commute Trips Comparison- AM

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	5,151	551	162	660	2,562
Chiltern	278	1,168	515	666	1,134
South Bucks	31	218	636	393	1,370
Wycombe	431	654	653	3,733	1,781
External	1,845	824	1,572	1,770	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	5,319	370	71	939	4,515
Chiltern	273	1,399	723	1,220	2,084



South Bucks	19	366	563	604	2,162
Wycombe	634	847	772	5,274	2,745
External	3,687	1,528	2,448	2,901	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-168	182	91	-279	-1953
Chiltern	5	-231	-209	-554	-950
South Bucks	13	-148	72	-211	-792
Wycombe	-203	-193	-119	-1541	-964
External	-1842	-704	-875	-1132	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-3%	49%	128%	-30%	-43%
Chiltern	2%	-17%	-29%	-45%	-46%
South Bucks	68%	-40%	13%	-35%	-37%
Wycombe	-32%	-23%	-15%	-29%	-35%
External	-50%	-46%	-36%	-39%	-



Table F-2 - Sector-to-Sector Car Commute Trips Comparison- IP

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	1,077	81	18	110	447
Chiltern	92	244	71	138	199
South Bucks	23	82	133	115	312
Wycombe	119	138	104	780	371
External	475	211	304	371	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	1,728	93	8	211	1,249
Chiltern	100	444	140	283	558
South Bucks	8	134	205	196	802
Wycombe	231	364	222	1,942	966
External	1,225	546	792	933	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-651	-12	9	-102	-803
Chiltern	-8	-200	-70	-145	-360
South Bucks	14	-52	-72	-82	-490
Wycombe	-113	-226	-117	-1161	-595
External	-750	-335	-488	-561	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-38%	-13%	110%	-48%	-64%
Chiltern	-8%	-45%	-50%	-51%	-64%
South Bucks	176%	-39%	-35%	-42%	-61%
Wycombe	-49%	-62%	-53%	-60%	-62%
External	-61%	-61%	-62%	-60%	-



Table F-3 - Sector-to-Sector Car Commute Trips Comparison- PM

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	5,770	327	42	496	2,108
Chiltern	602	1,309	261	733	941
South Bucks	174	559	712	717	1,750
Wycombe	726	745	456	4,181	1,983
External	2,829	1,253	1,547	1,994	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	4,695	304	23	507	3,854
Chiltern	312	1,245	370	710	1,664
South Bucks	47	420	486	638	2,029
Wycombe	1,294	1,006	582	4,905	2,738
External	4,513	1,692	2,268	2,615	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	1075	23	19	-11	-1747
Chiltern	290	64	-109	23	-723
South Bucks	126	139	227	79	-279
Wycombe	-568	-260	-127	-723	-755
External	-1684	-439	-722	-621	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	23%	8%	82%	-2%	-45%
Chiltern	93%	5%	-29%	3%	-43%
South Bucks	267%	33%	47%	12%	-14%
Wycombe	-44%	-26%	-22%	-15%	-28%
External	-37%	-26%	-32%	-24%	-



Table F-4 - Sector-to-Sector Car Business Trips Comparison- AM

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	1,110	66	14	96	226
Chiltern	61	206	77	126	100
South Bucks	7	49	145	98	148
Wycombe	91	106	96	722	124
External	281	115	232	241	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	1,084	143	29	290	989
Chiltern	46	327	138	186	560
South Bucks	9	72	65	191	519
Wycombe	90	151	159	1,025	824
External	745	335	605	657	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	26	-76	-15	-193	-762
Chiltern	15	-120	-61	-59	-460
South Bucks	-1	-23	79	-93	-370
Wycombe	1	-45	-63	-304	-700
External	-465	-220	-374	-416	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	2%	-54%	-52%	-67%	-77%
Chiltern	32%	-37%	-44%	-32%	-82%
South Bucks	-16%	-32%	121%	-49%	-71%
Wycombe	2%	-30%	-40%	-30%	-85%
External	-62%	-66%	-62%	-63%	-



Table F-5 - Sector-to-Sector Car Business Trips Comparison- IP

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	618	35	6	53	111
Chiltern	35	116	37	68	46
South Bucks	6	38	92	62	84
Wycombe	50	63	56	420	79
External	152	70	135	119	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	873	53	7	93	459
Chiltern	56	262	58	106	268
South Bucks	6	67	48	135	362
Wycombe	89	117	87	895	468
External	528	281	415	499	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-255	-18	0	-39	-348
Chiltern	-21	-145	-21	-38	-222
South Bucks	0	-30	44	-73	-278
Wycombe	-39	-55	-31	-474	-389
External	-376	-211	-280	-380	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-29%	-34%	-7%	-42%	-76%
Chiltern	-38%	-56%	-36%	-36%	-83%
South Bucks	-7%	-44%	92%	-54%	-77%
Wycombe	-44%	-47%	-36%	-53%	-83%
External	-71%	-75%	-68%	-76%	-



Table F-6 - Sector-to-Sector Car Business Trips Comparison- PM

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	1,012	56	8	86	229
Chiltern	60	188	48	102	90
South Bucks	12	67	128	90	170
Wycombe	85	109	84	652	182
External	240	107	174	152	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	1,036	62	10	98	732
Chiltern	126	311	68	146	357
South Bucks	20	111	62	225	529
Wycombe	275	175	97	1,068	570
External	1,084	534	579	841	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-23	-5	-3	-11	-503
Chiltern	-66	-123	-20	-43	-267
South Bucks	-8	-44	66	-135	-358
Wycombe	-190	-66	-13	-416	-388
External	-844	-427	-405	-690	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-2%	-9%	-28%	-12%	-69%
Chiltern	-53%	-40%	-30%	-30%	-75%
South Bucks	-40%	-40%	106%	-60%	-68%
Wycombe	-69%	-38%	-14%	-39%	-68%
External	-78%	-80%	-70%	-82%	-



Table F-7 - Sector-to-Sector Car Other Trips Comparison- AM

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	8,004	394	51	493	669
Chiltern	667	2,382	562	1,075	283
South Bucks	98	775	1,585	1,032	491
Wycombe	709	927	615	5,504	344
External	1,094	470	893	869	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	9,676	135	13	524	3,632
Chiltern	187	4,119	481	875	1,346
South Bucks	13	565	1,130	445	2,581
Wycombe	639	816	450	9,117	1,382
External	3,768	1,367	2,813	2,018	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-1672	259	38	-31	-2964
Chiltern	480	-1737	81	200	-1063
South Bucks	85	210	455	587	-2090
Wycombe	71	111	165	-3613	-1038
External	-2674	-897	-1920	-1148	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-17%	191%	300%	-6%	-82%
Chiltern	256%	-42%	17%	23%	-79%
South Bucks	649%	37%	40%	132%	-81%
Wycombe	11%	14%	37%	-40%	-75%
External	-71%	-66%	-68%	-57%	-



Table F-8 - Sector-to-Sector Car Other Trips Comparison- IP

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	6,721	464	69	576	1,114
Chiltern	381	2,004	609	892	469
South Bucks	52	528	1,400	701	849
Wycombe	476	866	769	5,093	745
External	1,273	551	1,012	900	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	8,146	172	9	445	3,362
Chiltern	206	3,150	471	746	1,364
South Bucks	14	457	880	535	2,531
Wycombe	483	846	469	8,027	1,649
External	3,366	1,329	2,758	1,744	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-1425	292	59	131	-2248
Chiltern	176	-1146	138	147	-895
South Bucks	38	72	519	166	-1681
Wycombe	-7	20	300	-2935	-904
External	-2093	-778	-1746	-844	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-17%	170%	632%	29%	-67%
Chiltern	85%	-36%	29%	20%	-66%
South Bucks	271%	16%	59%	31%	-66%
Wycombe	-1%	2%	64%	-37%	-55%
External	-62%	-59%	-63%	-48%	-



Table F-9 - Sector-to-Sector Car Other Trips Comparison- PM

VDM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	8,200	547	77	674	1,596
Chiltern	474	2,453	713	1,058	672
South Bucks	65	664	1,671	855	1,228
Wycombe	602	1,085	939	6,279	1,125
External	1,572	682	1,205	1,062	-
HAM	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	10,417	209	12	557	4,447
Chiltern	186	4,402	631	875	1,618
South Bucks	16	506	1,215	496	2,811
Wycombe	735	1,010	532	10,344	1,908
External	4,381	1,551	3,159	1,813	-
Abs. Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-2217	338	65	117	-2851
Chiltern	288	-1949	82	183	-946
South Bucks	49	157	457	359	-1584
Wycombe	-133	75	407	-4065	-782
External	-2809	-868	-1954	-751	0
% Diff.	Aylesbury	Chiltern	South Bucks	Wycombe	External
Aylesbury	-21%	162%	552%	21%	-64%
Chiltern	154%	-44%	13%	21%	-58%
South Bucks	312%	31%	38%	72%	-56%
Wycombe	-18%	7%	76%	-39%	-41%
External	-64%	-56%	-62%	-41%	-



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