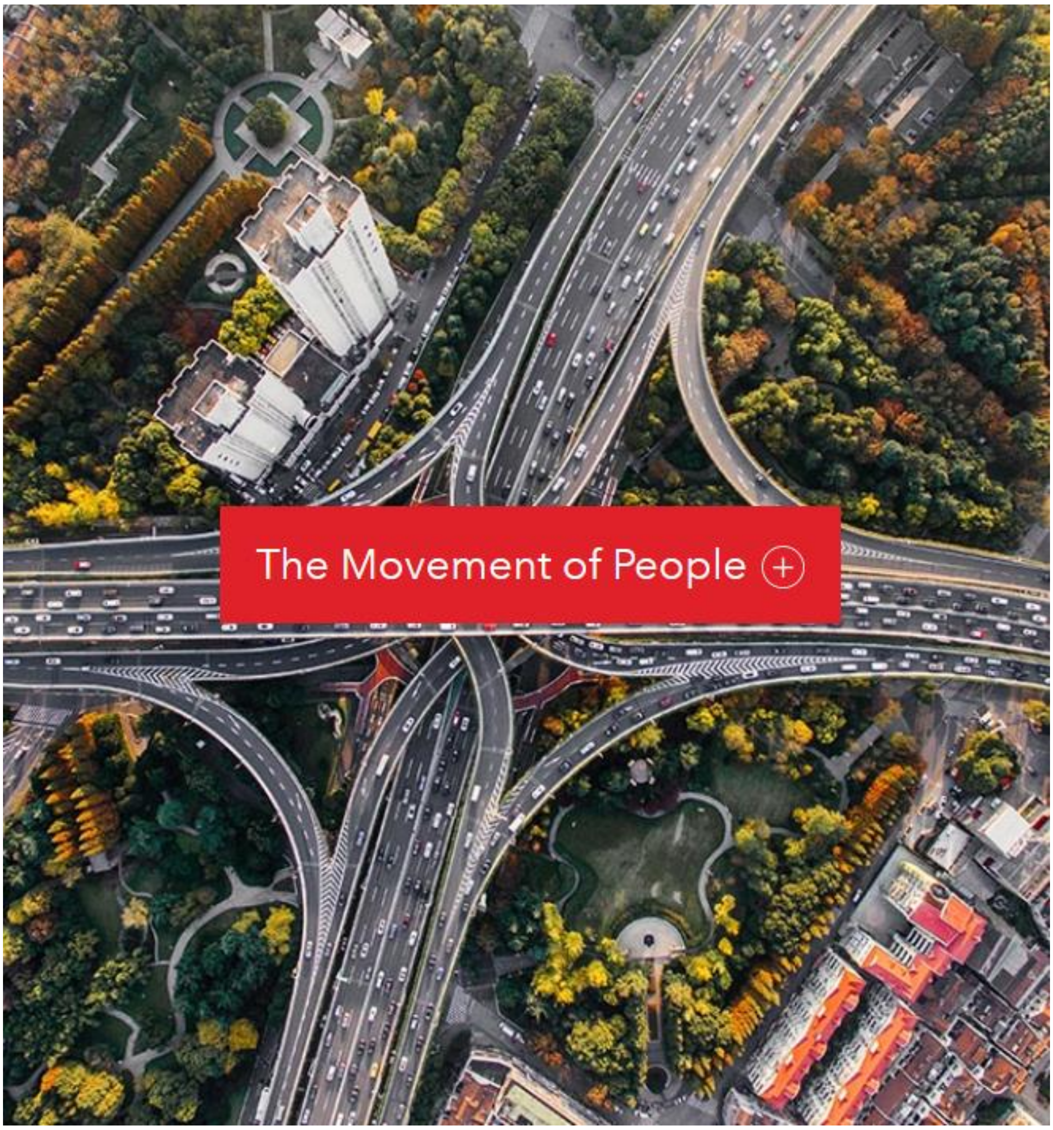
the mind of movement

Charge Project

Transport Model Calibration and Validation Report



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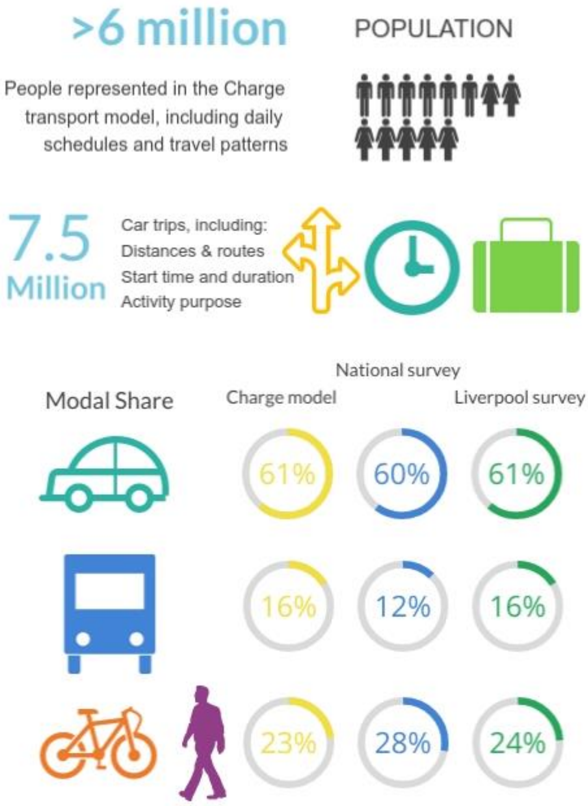
Index

Executive Summary

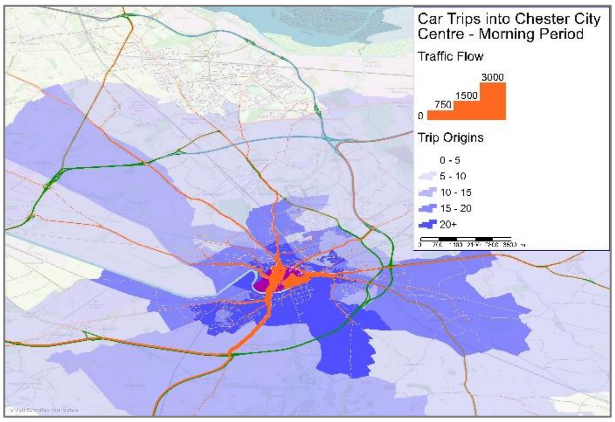
This report has been prepared by PTV for the **Charge project** to summarise the steps taken to build and calibrate a state-of-the-art transport model for the SP Manweb region. It:

- Represents travel patterns of >6 million people across the North West, Cheshire, and North Wales
- Provides detailed schedules for daily activity patterns, including which trips are taken by car, where these trips start and end, and at what time of day
- Compares well to various external sources of data, including the National Travel Survey, the Liverpool Household Survey and Transport Model, and mobile phone data.



Using insight from the transport model, PTV will be able to:

- Provide scenario-based forecasts of EV uptake and usage
- Identify EV trips arriving at an area by time of day (as per image)
- Using trip distances and schedules, calculate demand for EV charging by location and time of day



1. Introduction

1.1. Charge

The Charge project aims to accelerate the connection and planning of public charging infrastructure at the lowest possible costs to GB electricity customers by maximising the use of existing electricity infrastructure assets. This will be achieved by developing and deploying innovative approaches to connecting and managing the uptake of electric vehicles (EVs) across a broad geographical area in combination with learning from other projects and expertise from the world of transport planning. This learning will be coupled with a targeted selection of 'smart' EV charge point connection trials for a range of practical situations.

This approach will form a blueprint for other GB Distributed Network Operators (DNOs) to make best use of their existing assets, plan for future upgrades and signal to the industry where network capacity or other flexible solutions are needed.

It is essential that DNOs help facilitate this transition, becoming the enablers of EV adoption and helping Government to meet climate change targets. For this reason, DNOs need to be at the heart of the discussion, facilitating the timely and optimised connection of future public EV charging infrastructure to avoid delays and developing clear guidance and connection standards to expedite the uptake of EVs.

To achieve this the Charge project will implement three core aspects of work with the following objectives:

- Understand the potential future energy needs from EVs to help anticipate the requirements for future public charging infrastructure. This will be achieved through the development of a transport model in the Manweb region (see Figure 1) which will map out plausible, scenario-based futures of vehicle demand to identify where and when infrastructure may be required.
- Demonstrate smart management of public charging to help optimise the capacity of existing assets. Smart solutions will be implemented at several targeted charging locations across Manweb to help utilise existing capacity and smooth charging loads so that more vehicles can be charged, and network reinforcement can be avoided if possible.
- Develop a web-based tool to identify and visualise where charging points can be installed to help speed up connection requests for third party installers. The tool, called ConnectMore, will provide a visualisation of existing electrical network capacity overlaid with outputs from the transport model to provide a 'treasure map' showing sites where demand for EV charging will potentially be high and capacity exists without the need for reinforcement. This tool will be designed for a range of third-party installers and stakeholders to allow them to identify possible sites for charging deployment and receive indicative costs for connections, depending on their stated preference of charger numbers and type.

The Charge project is being applied in the Manweb region, SP Energy Network's (SPEN's) licence area covering North and Mid Wales, Liverpool and the Wirral, and parts of Cheshire and Shropshire. This extent is shown in Figure 1 below.

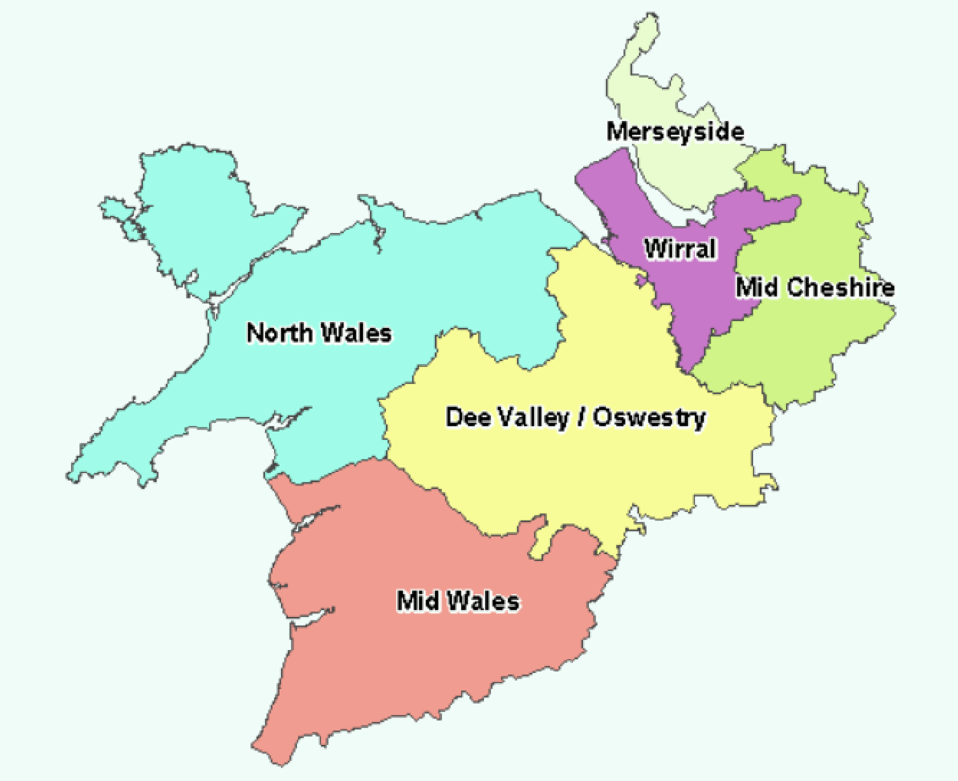


Figure 1: SP Manweb region / Area of Interest for the Charge project

1.2. Purpose of the Transport Model

The Charge transport model has been built to help anticipate future energy needs from electric vehicles (EVs) across the Manweb licence area. The model currently represents travel patterns and car journeys across the region today (2017-19) and will then be used to forecast how EVs might be used in the future. EV uptake and usage assumptions will be informed by a set of detailed scenarios, which are presented in the Scenario Planning Framework report. These inputs will be represented in the transport model with forecasts being distributed at a detailed spatial and temporal level to provide an indication of when trips will take place, how much energy will be required when charging, and which areas of the network are likely to see the highest demand.

1.3. Transport Model Architecture

A transport model consists of various interconnected components, where each component calculates specific aspects of traveller behaviour or network performance. Data is automatically passed between the components in an iterative fashion until the results stabilise. The components included in the Charge Transport Model are as follows:

- **Geospatial Data Model:** this component contains all of the information across the model area related to land use and population which are explained in sections 2, 3 and 4.

- **Network Model**: this component includes a geographical representation of transport infrastructure, algorithms to calculate how it is used, and how it performs. This component is explained in section 5.
- **Demand Model**: this component ties together the geospatial data and transport infrastructure performance to calculate how people choose to travel in terms of how many journeys they undertake in a typical day, which destinations they travel to, which modes they choose for each trip, and what time of day they travel. This component is described in section 6.

The overall architecture is summarised in Figure 2 below.

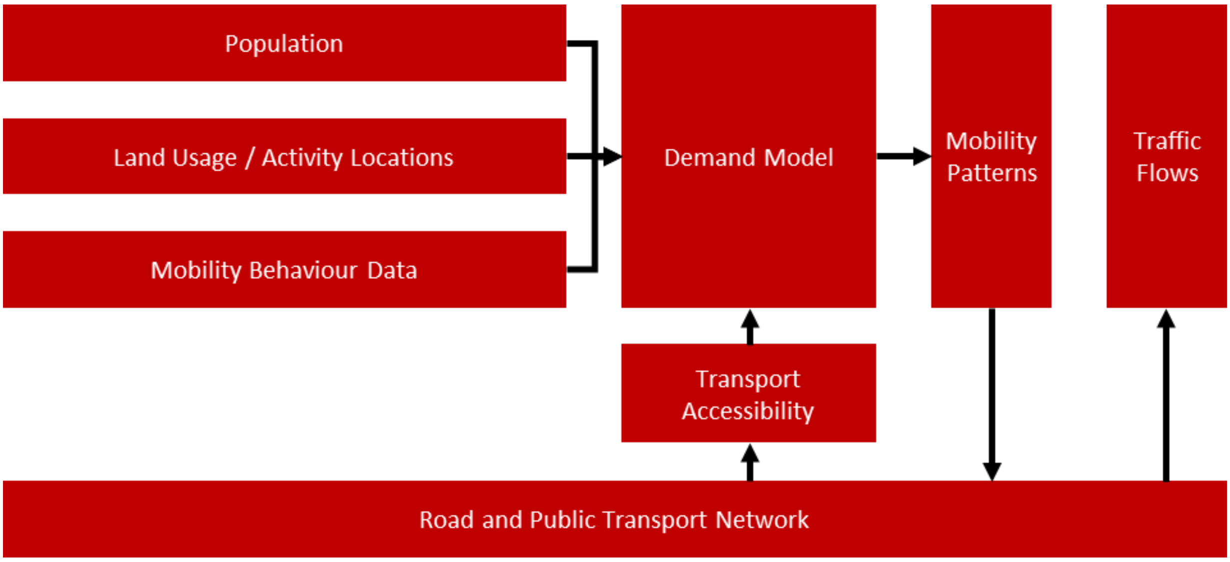


Figure 2: Transport Model Architecture

PTV Visum is a software platform that has existed for more than 30 years and has evolved over that time to be the world leading platform in which transport models are built. All components of the Charge transport model have been implemented as a single ‘version file’ within PTV Visum.

1.4. Purpose of this Report

This report describes how the various components of the Charge transport model have been assembled and then adjusted based on comparisons with empirical data. The following provides a summary of the sections included within this report:

- Section 2: **Spatial Definition**: describing where the model is focused and how the geography has been disaggregated to represent land use and population at various levels of spatial extent.
- Section 3: **The Model Population and Structure**: describing the input data that has been used and processed to represent where people live, what characteristics they have, and how, when they have the propensity to travel.
- Section 4: **Activity Locations**: describing the data that has been used to inform the attractiveness of land use within the model, and how various trip purposes are defined to represent why people travel.

- Section 5: **The Network Model**: describing the road and public transport networks that have been built to provide the means, routes, and costs of travel within the model.
- Section 6: **The Demand Model**: describing how the input datasets are brought together and modelled to represent travel across the region
- Section 7: **Calibration Setup**: detailing how the demand model is initially setup prior to calibration
- Section 8: **Calibration Implementation**: describing the processes that have been applied to adjust the model so that it sufficiently represents observed travel patterns
- Section 9: **Model Validation**: highlighting how well the model produces results that match observed travel patterns
- Section 10: **Summary**: overview of the baseline model build process, calibration, and validation.

2. Spatial Definition

The Charge transport model, as with all Visum models, is underpinned with GIS data and information representing land use and population centres across Manweb. The spatial data in the model dictates where people travel to and from based on where they live, work, and visit for leisure or shopping purposes. These locations are represented by land parcels, or zones, and trips appear on the transport network from the zone via several access nodes and connectors. The Charge model includes a spatial representation of the whole of the UK to some extent, with detail more granular in the study area and more aggregated away from Manweb. Within the main study area trips are fully represented and routed through a detailed congestible network. Outside of this region, trips are modelled if they enter or leave the area with a simplified network used to provide a realistic approximation of journey distance beyond the Manweb border.

2.1. The Model Area

The Charge model is being built to represent travel patterns and demands that will impact SP Energy Network's electricity network in the licence area of Manweb, as shown in Figure 1. Zones have been defined at a detailed spatial level across this area in what is called the **Internal** area. A buffer area has been created, called the **Intermediate** area to provide a transition from the internal region to the external areas, with the **External** area covering the rest of the UK and allowing for the representation of long-distance trips in and out of Manweb. The model zoning system is shown in Figure 3 and Figure 4.

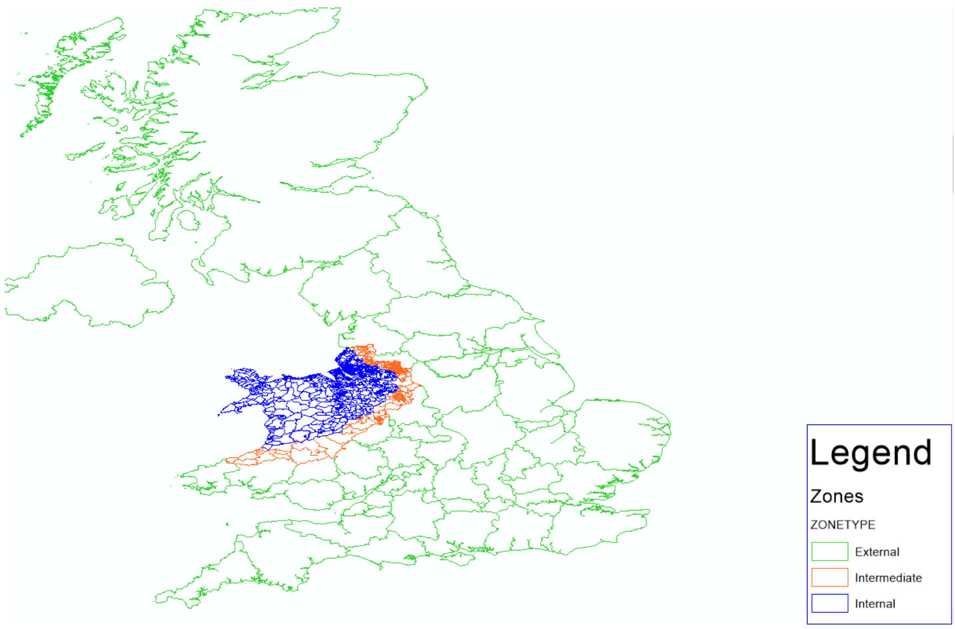


Figure 3: The Charge zoning system

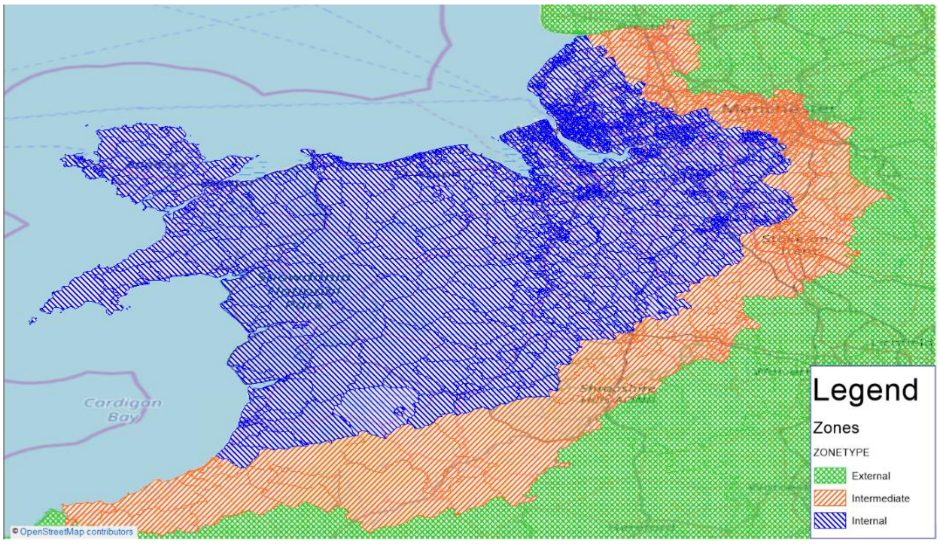


Figure 4: Internal and Intermediate zone regions

2.2. Model Regions

The Internal area covers the Manweb region, based on a boundary shapefile provided by SPEN. It has the following characteristics and purposes:

- Represent and provide outputs for the core region in the project;
- 2,128 zones based on Lower Super Output Areas (LSOAs) to cover the Manweb licence area, with attributes to correspond to the population, workday population, and land attractiveness. A description of LSOAs is provided in Table 1.
- A detailed road and public transport network;
- Trip patterns and daily schedules modelled in detail for various person group segments.

Table 1: LSOA and MSOA definitions

Population and household minimum and maximum thresholds for SOAs in England and Wales

Geography	Minimum population	Maximum population	Minimum number of houseolds	Maximum number of households
LSOA	1,000	3,000	400	1,200
MSOA	5,000	15,000	2,000	6,000

The total of 2011 LSOAs and MSOAs for England and Wales

Geography	England	Wales
LSOA	32,844	1,909
MSOA	6,791	410

[1]

[1] https://www.ons.gov.uk/methodology/geography/ukgeographies/censusgeography

The Intermediate area has the following characteristics:

- 372 zones based on a combination of Middle Super Output Areas (MSOAs) and LSOAs covering the periphery of the Manweb region, with attributes similar to the Internal zones;
- The area where the detailed internal road network is joined with the more skeletal external network. A public transport network with services connected to Manweb;
- Trip patterns and daily schedules modelled in detail for various person group segments.

The external region in Charge covers the rest of the UK and has the following characteristics:

- 55 large, aggregated zones based on Local Authority boundaries;
- A skeletal representation of the road and public transport network, sufficient to provide approximate trip distances and times to and from Manweb;
- Trips are only modelled in the external region if they are generated in the Internal or Intermediate region

For the purposes of providing simplified analysis, the model region has also been split into sectors, with 8 sectors in the Internal and Intermediate region, and 6 in the external. Figure 5 shows the extent of these sectors.

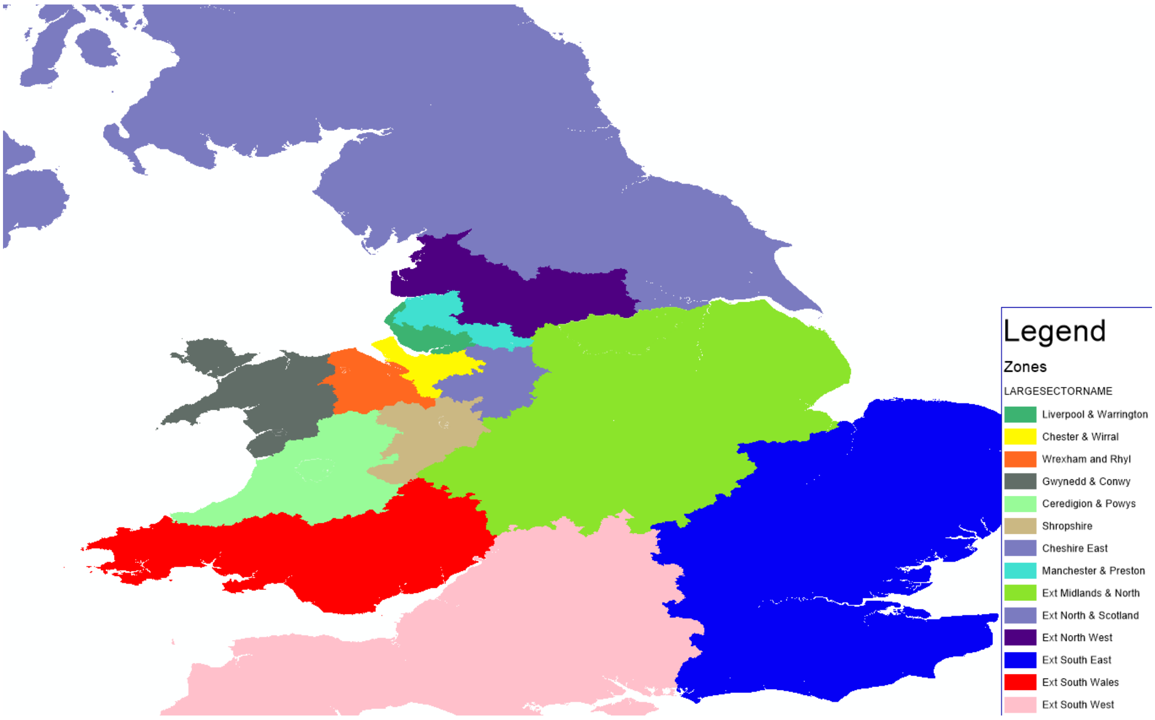


Figure 5: The Charge Sector System

3. The Model Population and Structure

The population in a transport model defines where travel demand originates and is mapped to the zoning system in the Internal and Intermediate regions. For each zone the population is split into **person groups** and **activities**, which are each defined by a tour rate (or trip frequency), modal shares, trip lengths, and time of day distribution.

3.1. Population Data

The population in the Charge model is based on the ONS 2017 mid-year estimate[2] and is attributed at a zonal level within the Internal and Intermediate regions. The population in the Internal area is ~3.4 million and 2.8 million in the Intermediate region. A breakdown of population at the sector level is provided in Table 2 (note that some sectors encompass Internal and Intermediate zones), and Figure 6 shows the population density within each zone in the Internal region.

Table 2: Population at Sector Level

Sector Name	Population
Liverpool & Warrington	1,431,328
Chester & Wirral	660,782
Wrexham and Rhyl	385,885
Gwynedd & Conwy	310,399
Ceredigion & Powys	165,580
Shropshire	409,399
Cheshire East	873,190
Manchester & Preston	1,988,074
Total	**6,224,637**

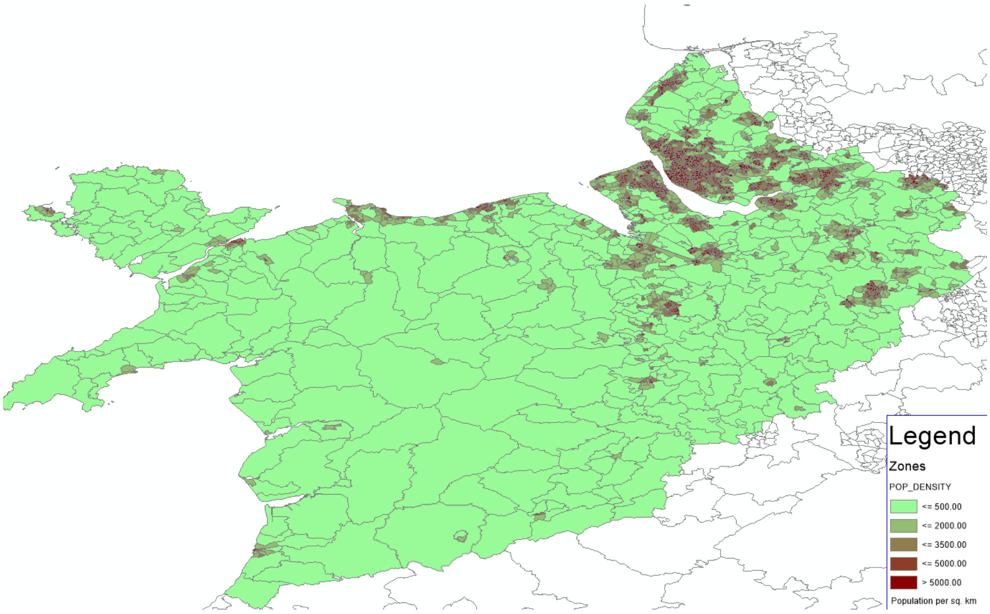


Figure 6: Population density at zonal level

[2]https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/annualmidyearpopulationestimates/mid2017

3.2. Person Groups

The population is sub-divided into various **person groups** to represent differences in likely travel behaviours. For the purpose of the transport model, person groups correspond to homogenous segments of the population whose travel patterns are defined by fixed parameters and distributions. Within the Charge model, person groups are characterised by four attributes and are based on a combination of data from the National Trip End Model (NTEM)[3], survey results from the National Travel Survey[4] (composite of 2015 – 2017 surveys inclusive and based on weekday data only), and income data from the Office for National Statistics[5]. The classifications include the area type of the home zone, a person's economic status, their car availability, and their income level. For instance, a person segment is defined for Urban people who are employed, have a car, and have a medium income. The segments for each attribute and the percentage represented within the population is shown in Table 3. In total, 54 distinct person groups are defined within the model with the population divided into these groups based on the surveyed proportions. Car driving under 16-year olds has been excluded as a possible group.

Table 3: Person groups within Charge model

Area Type	% Trip rate split between area type
Rural	14.8%
Urban	85.2%
Grand Total	**100.0%**

Economic classification	% Trip rate split between economic activity
Economically inactive: Permanent (retired, sick, disabled)	25.9%
Employed	47.5%
Student	4.1%
Under 16	18.5%
Unemployed and Economically inactive: Other	4.0%
Grand Total	**100.0%**

Car availability	% Trip rate split between car availability
Car	64.5%
No car	35.5%
Grand Total	**100.0%**

Income level*	% Trip rate split between income type
High	17.7%
Low	20.9%
Medium	61.5%
Grand Total	**100.0%**

[3] https://data.gov.uk/dataset/11bc7aaf-ddf6-4133-a91d-84e6f20a663e/national-trip-end-model-ntem
[4] https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=5340
[5] https://www.ons.gov.uk/datasets/ashe-table-8-earnings/editions/time-series/versions/1

**Income bands defined from NTS, where medium income covers the middle 3 quintiles at a national level. Percentages shown here represent the proportion of people within each income band in the study area.*

3.3. Activities

Activities within the model correspond to the purpose of travel and the activity that is being undertaken at the destination. The **activities** defined in the Charge model are aggregated from those used in the National Travel Survey[4] *(table TripPurpose_B04ID)* and are shown in Table 4.

Table 4: The Charge Activity types

NTS Trip purpose	Charge Activity type
Trip of any purpose where the destination is home	Home (H)
Commuting to work	Work (W)
Business	Employer's Business (B)
Education/escort education	Education (E)
Shopping	Shopping (S)
Other escort	Other (O)
Personal business	Other (O)
Leisure	Other (O)
Other	Other (O)

The proportion of trips, based on NTS data, going to each activity location is presented in Table 5.

Table 5: Proportion of trips by activity type

Activity type	Proportion of trips by purpose (% if home is excluded)
Home	42.5% (0%)
Other	25.4% (43.5%)
Work	11.2% (19.9%)
Shopping	9.5% (16.8)
Education	9.1% (16.2%)
Business	2.3% (3.5%)
Grand Total	**100.0%**

Source: derived from NTS data https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=5340

3.4. Tour Types

Travel choices in the Charge model are defined by the sequence of activities that are undertaken by each person group throughout a day. Each activity set, or **tour type**, has been specified using data from the National Travel Survey[4] (NTS) with the most popular tours being used in this model. Since trip generation is linked to the underlying population, all tours are defined as starting and ending at home; for instance, the tour HWH represents the daily schedule of trips from Home to Work and back to Home. To help simplify the trip distribution and reduce the number of tours that are applied in the model, tours are limited to a maximum of 5 activities (4 legs) and are only used if the chain represents more than 1% of trips for any person group. These criteria mean that **30 distinct tours** have been applied in the model. The full set of these tours is shown in section 13.1 (Appendix C). Overall, these represent ~95% of all tours and more than 90% of all trips from NTS. The trips from the excluded tours (10%) have been proportionally redistributed based on equivalent activities into the chosen tours so that 100% of trips are represented.

3.5. Tour Rates

NTS provides the number of tours undertaken by each person group. This is based on data from weekdays and is averaged to define the frequency of tour type per person group. In combination, these parameters make up what is called the **Demand Strata**. For instance, there is a distinct demand stratum for those in the person group: Urban, Employed, Car driver, Medium income who have the tour type HWH. Based on NTS data, this demand stratum represents 7.21% of all tours undertaken (this is also the highest tour rate of any demand stratum in the model). At the aggregated tour rate, the top 5 most popular tours, as represented in the model, are shown in Table 6 (shown in full in section 13.1 (Appendix C)). In total, 408 distinct demand strata have been applied in the Charge model.

Table 6: The top 5 most popular tours represented in the model

Tour type	Proportion of trips
HOH	32.57%
HWH	19.83%
HEH	16.86%
HSH	13.24%
HOOH	4.87%

3.6. Mode Shares

The modes represented in the Charge demand model are as follows:

- Car driver
- Car passenger
- Bike

- Walk
- Public transport (combined as one mode)
- Light goods vehicles and heavy goods vehicles (Represented in the network model only)

The main purpose of the Charge model is to accurately represent private car trips, with information from these later being used to inform charging requirements for future EVs. As such, it is important that the modal share for car drivers is representative of observed patterns. To help judge this, other modes are also included to help provide representative balance in the model. As an output from the model, modal shares can be calculated at the study area level or at an individual OD (origin to destination) level. Shares can also be calculated at a trip purpose level.

For the Charge project, two sources of data on modal share splits will be used to calibrate and compare the model results against: NTS and the Liverpool City Region Transport Model and associated household survey.

3.7. Trip Lengths

Trip lengths (for car) refer to the distance travelled on road for a particular origin to destination trip. Cumulatively across the model, these trip lengths can be visualised in a trip length distribution. For Charge, trip length information will be used to calculate the amount of energy that is consumed per EV trip. Calibration sources for trip length include: NTS, the Liverpool City Region Transport Model and associated household survey. Trip lengths will be compared at a modal level, with a particular focus on car, and at a purpose level as described in sections 9.1 and 9.3.

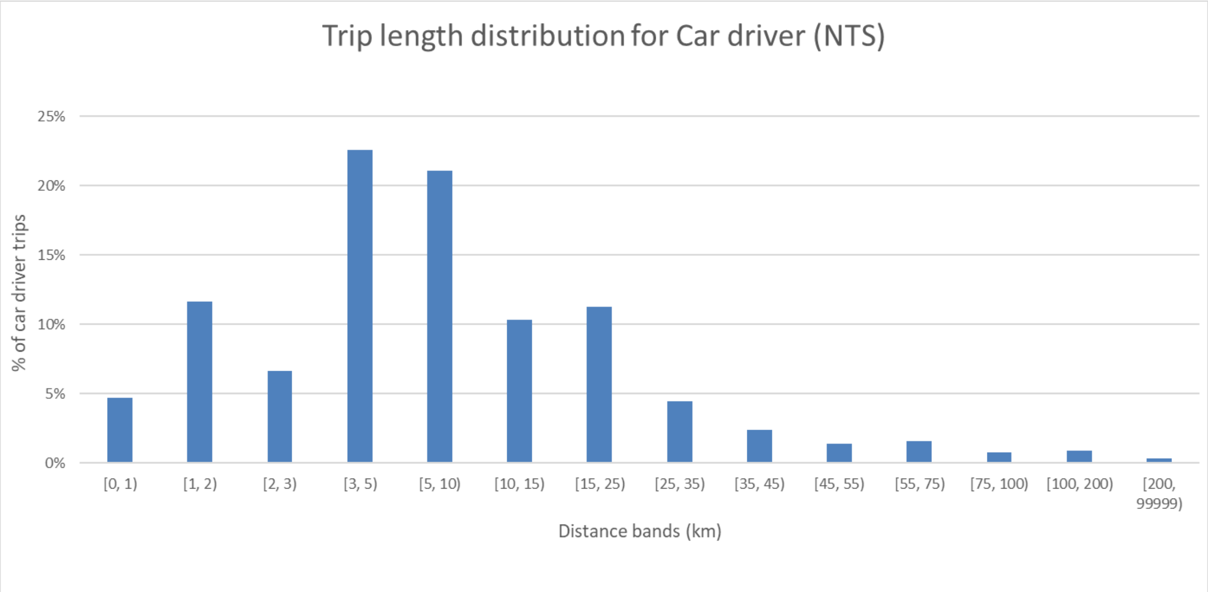


Figure 7 shows the trip length distribution for car drivers based on NTS data[4].

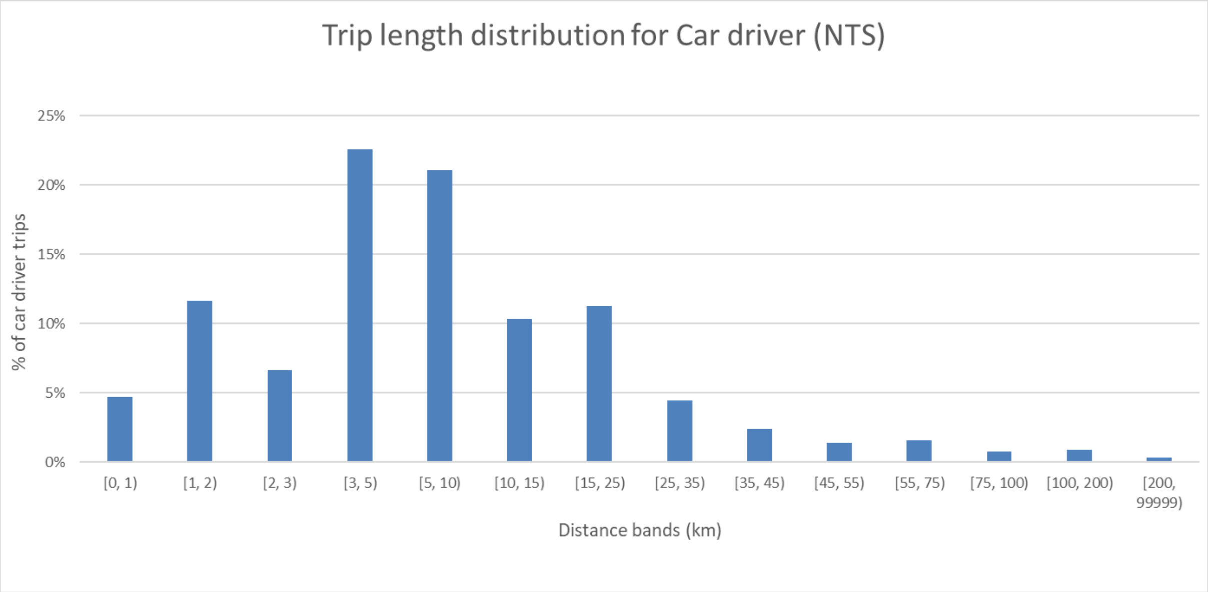


Figure 7: Trip length distribution for Car driver (NTS)

Source: derived from NTS data https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=5340

3.8. Time of Day

The Charge model is built to represent 24 hours of a typical weekday. Within the day, demand is distributed at an hourly level based on travel time profiles from NTS. The time profile covering all car (driver) trips, taken from NTS, is shown in Figure 8. Separate time profiles have also been defined for each demand stratum as described in section 3.5. An example of a time profile for a particular demand stratum is shown in Figure 9. This shows the distribution of home to work trips for the person group: urban, car available, medium income; highlighting that most trips of this type take place in the morning peak. Time profile data in the Charge project will be used to define when trips take place for various activities. For instance, we will know that if 1000 home to work trips arrive in a particular zone in a day, and 25% of these trips take place between 8am – 9am, 250 trips will arrive in this period. This information will be used to determine when and where charging is likely to take place. Combined with the known trip distances from these journeys (and with knowledge of previous and subsequent trips) we can calculate how much energy might be required for charging at that location and that time.

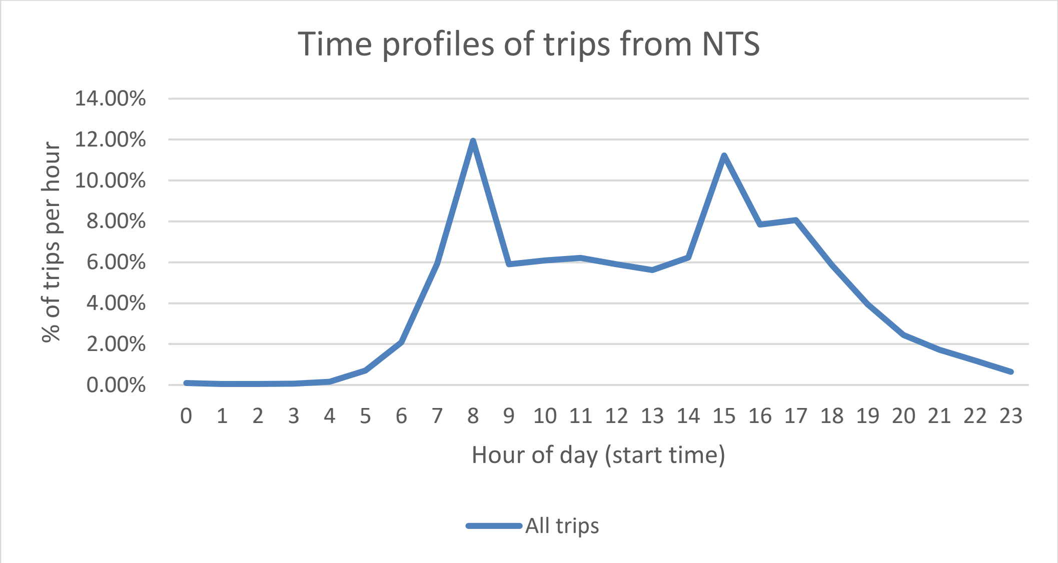


Figure 8: Time profile for all trips, NTS

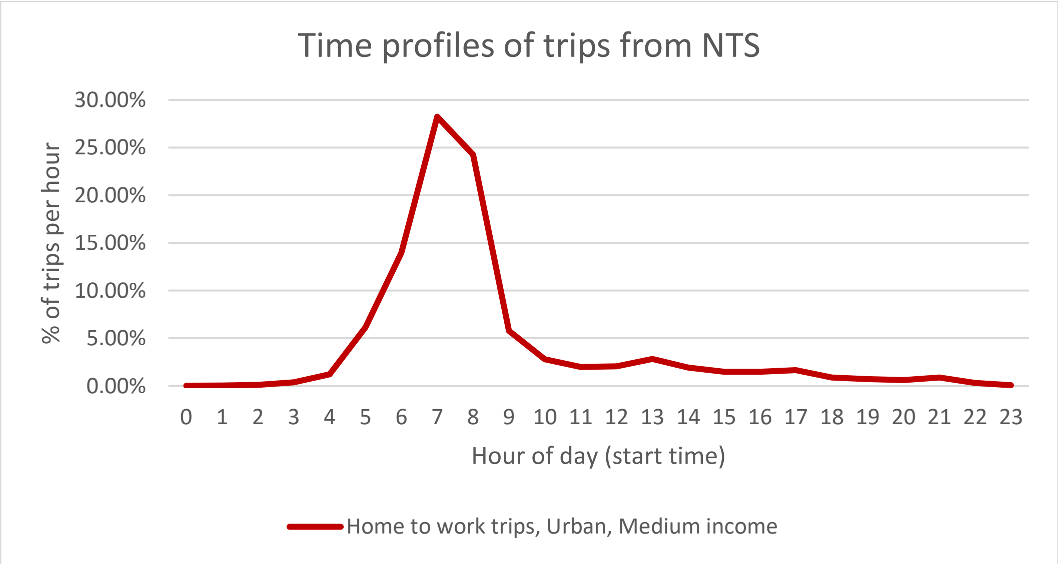


Figure 9: Time profile for Home to Work, Urban, Medium income trips

Time of day travel will also be validated against observed traffic counts, mobile phone data, and the Liverpool City Region Transport Model. Traffic count data will help determine how many trips are in progress at a specific location and time. Where appropriate counts are available, for instance around Liverpool City Centre, the data can inform how many trips are arriving into a large area at a particular time. The results from this comparison are provided in section 9.5. Mobile phone data, available for most of Wales, is aggregated to time periods throughout the day (AM, interpeak / IP, and PM). This data is used to validate the scale of trips between areas at times of day as described in section 9.4. Similar comparisons have also been made with the Liverpool City Region Transport Model, which has available data for the AM, IP, and PM periods.

4. Activity Locations

Activity locations represent the places people travel to for work, shopping, education, or any other means and are referred to as the **Structural Properties** of the model. As with population, activity locations are defined by the model zones and populated with attribute information relating to the attractiveness of that location. For each zone, a relative structural property weight is applied for each activity purpose.

4.1. Workplaces and Education

The number of workplaces is used to inform the attractiveness of the Work and Business activities. This data has been extracted from the 2011 Census[6] – using the workday population – and attributed to each zone (including the external zones). The Internal area has a workday population of ~2.4 million, the Intermediate ~2 million, and the external/rest of the UK ~39.8 million.

The distribution of the work Structural Properties across Manweb is shown in Figure 11.

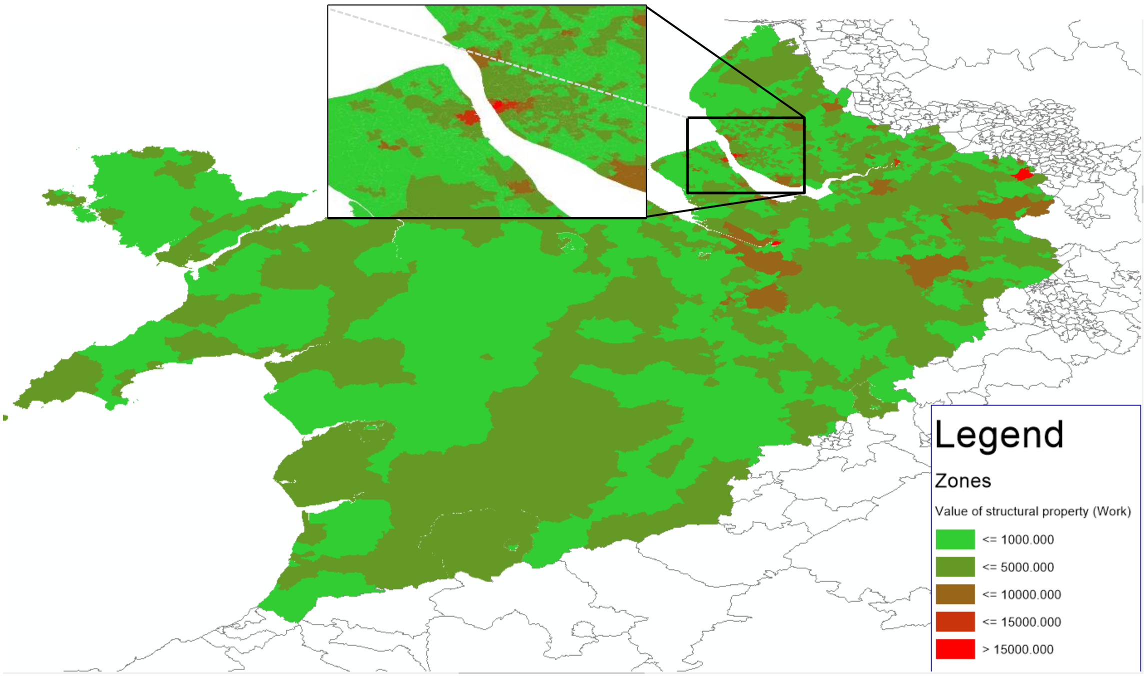


Figure 10: Workday population across Manweb

Education data has been sourced from the annual school census data available for all nursery, primary, secondary and special schools, academies, and colleges in England[7] and Wales[8]. This includes exact numbers of pupil enrolments per school, which have been mapped and matched to the Charge model zones.

[6] https://www.nomisweb.co.uk/query/construct/submit.asp?menuopt=201&subcomp=
[7] https://www.gov.uk/government/collections/statistics-school-and-pupil-numbers
[8] https://statswales.gov.wales/Catalogue/Education-and-Skills/Schools-and-Teachers/Schools-Census/Pupil-Level-Annual-School-Census/Pupils

4.2. Other and Shopping

As shown in Table 5, ~44% and 17% of all trips are for other and shopping purposes (if home is excluded as an activity). Unlike workplace statistics, which are collected at a detailed and nationwide scale, the destinations of other activities are not definitively collected in a single source of data. As such, we have used Open Street Map[9] (OSM) land use and buildings data as a proxy to estimate trip attractiveness. OSM contains publicly generated mapping layers with a range of identifying tags to designate the built environment, such as 'office', 'retail', 'hotel' etc. Where data is available as buildings polygons, the area of the building and the tag has been used to contribute to the underlying zone's attractiveness. For instance, buildings tagged as 'retail' have been assigned a high weight to help designate the attractiveness of the shopping purpose within each zone.

The weighted scores for each activity have been applied at a zonal level throughout the model. Although the attributes are unitless, they provide relative levels of attractiveness that the model uses to calculate the likely scale of trip making to any area. These numbers have been adjusted to reflect the number of trips that are likely to be met by the population in the core model area. A plot showing the attractiveness levels for shopping activities across Manweb is shown in Figure 12. The OSM derived structural properties have been compared in relation to the underlying population and jobs, with correlations highlighting a link between shopping locations and workplaces, and education and population (i.e. residential areas).

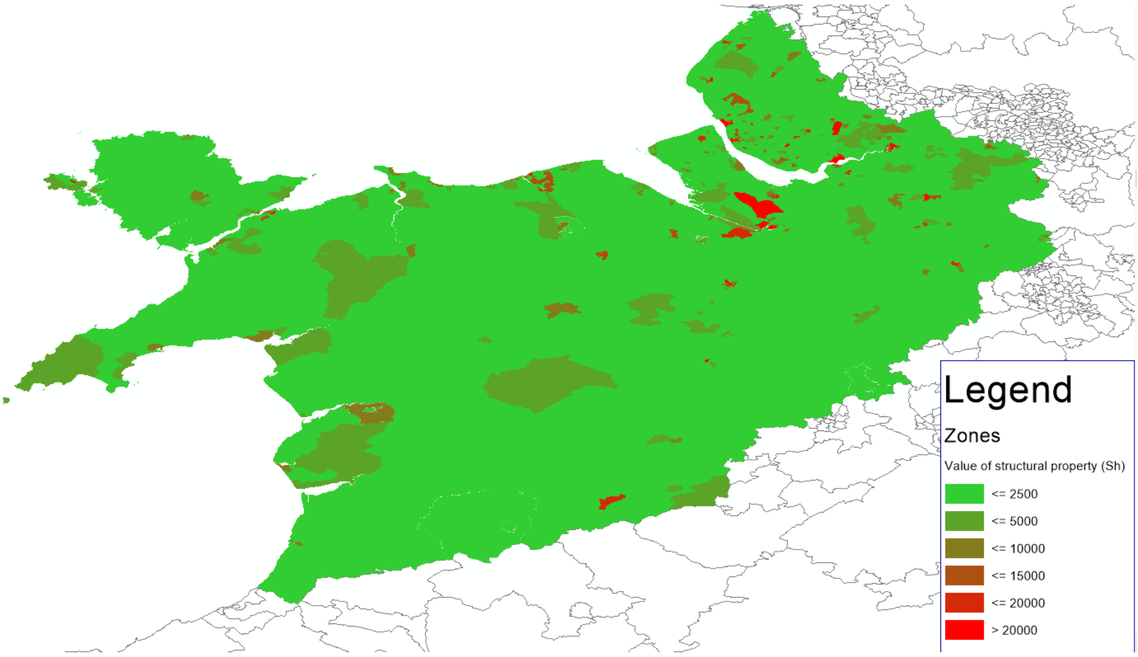


Figure 12: Shopping attractiveness per zone across Manweb

9 https://www.geofabrik.de/geofabrik/openstreetmap.html

5. Network Model

The network model provides a representation of the physical transport system, including the road network and public transport routes. The network model in Charge consists of:

- Connected geographical data layers which define the physical infrastructure of the transport network
- Information about these layers which describe the infrastructure and how it operates or responds to usage

The following sections describe how these layers have been developed and the rules that define how they respond to traffic.

5.1. Network Building

The fundamental structure of a network that is used for a transport model is as follows:

- **Links** represent the physical roads, paths or rails traversed by a transport system or pedestrian. Links must start and end at a point object called a **node**, which can simply represent where a link changes (for example a road going from 2 lanes to 3 lanes) or an intersection, such as a signalised junction or a give-way junction.
- **Turns** represent the allowable movements through a node from one link to another
- **Line routes** define the course through the link/node/turn network on which public transport services run. Associated with line routes is a **timetable** that defines all of the **vehicle journeys** that run on the line routes.
- **Stop points** are the places where passengers board and alight public transport services, and these can be grouped in to **stop areas** and **stops**.
- **Zones**, which are described in section 2, represent land parcels and the origin or destination of trips.
- **Connectors** are the abstract linkages between a zone and the node at which people or vehicles enter and exit the transport network.

The Road Network

The underlying transport network covering the Internal and Intermediate areas of the model, as shown by the links in grey in Figure 13, is based on a commercial TomTom network layer. This source was chosen because TomTom delivers the most current digital map of the transport system, stemming from GPS measurements from users and is combined with traditional sources including paper maps, field surveys, aerial and satellite imagery and mobile mapping vans. The TomTom database was converted and imported in to Visum. This includes the links, nodes and turns, as well as detailed information such as road type, turning prohibitions, speed limits, and number of lanes.

For the external area, which covers the rest of the UK, the network data was taken from the Validate UK model which is a legacy model owned by PTV. The form of this network is less detailed than in the Internal and Intermediate area and is used to provide an approximation of journey times into and out of the Internal area.

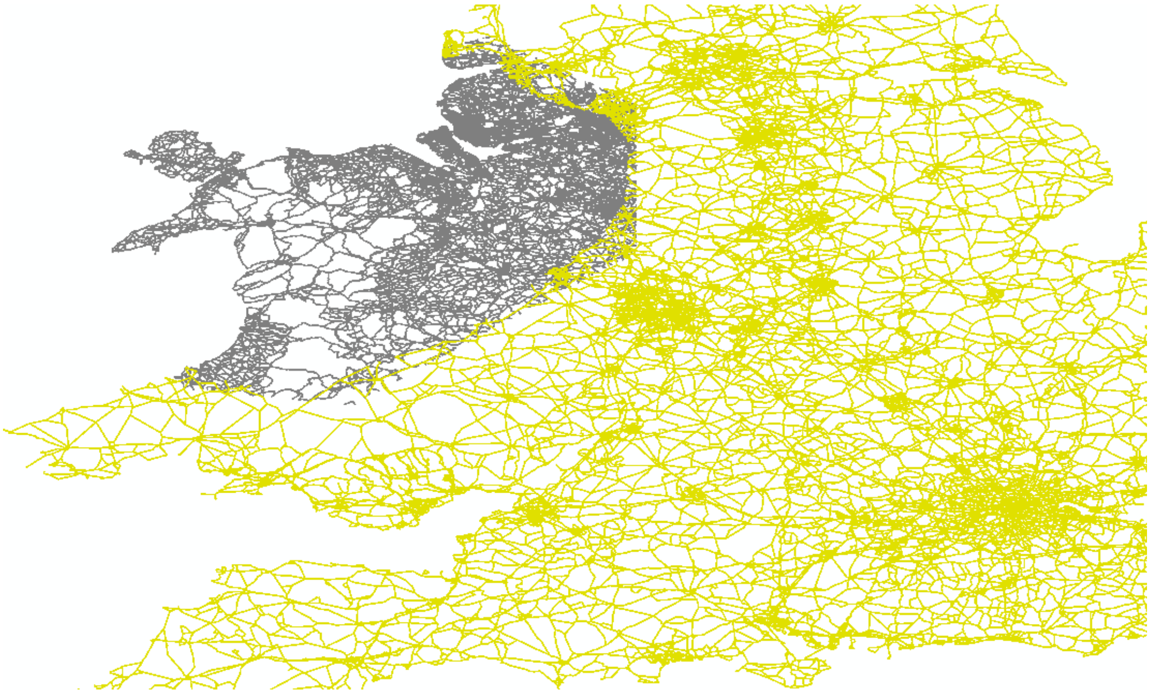


Figure 13: The Charge network model with detail in the Internal area (grey) and less detail in the External area (yellow)

The road network model allows travel to be represented as trips from a zone, along the network, and then to another zone symbolising both the connectivity and quality (which can include journey time and cost) of journeys. For private transport users, in our case car drivers, the quality of the connection depends on how much traffic is using the network. As the traffic flow increases, congestion will increase, and speeds will reduce. This has been defined in the network model as follows:

- Every link has been assigned a detailed road **link type** based on the initial classification from TomTom and comparisons with online mapping services.
- Every link has been assigned a **capacity** based on its link type and the number of lanes available, which defines how many vehicles can use the link at a given time and speed. Where demand exceeds capacity, the volume delay function adjusts the achievable speed and travel time that is realistic given the amount of demand.
- Every link has been assigned a permissible **transport system**, such as car, bus, or bike, which has been taken from the TomTom network.
- Every link type has been assigned a proportion of LGV and HGV traffic based on vehicle type splits from observed counts. This volume of **pre-loaded traffic** has the effect of reducing the available capacity for car drivers.
- Every link has an associated **length** and a **free-flow speed** (the achievable speed in an uncongested system, usually equivalent to the posted speed limit).
- Every link also has a **volume delay function (VDF)** which defines the relationship between flow and speed

- An algorithm called the **assignment** calculates routes between every pair of zones and determines the proportion of demand that uses each route. It does this in consideration of the volume delay functions and attempts to reach an equilibrium in the transport system.
- After the assignment, the performance of the network can be assessed in terms of journey times and the relative cost of getting between two zones for any given route.

The classifications for link types that have been defined for this model are shown in Figure 14. These link types classifications are also shown in the Figure 15 for an area of the Internal network.

No	GType	Name	Strict	Rank	NumLanes	CapPrT	V0PrT	VMinPrT	VdfNo	RTF_TYPE
0	0	Inactive	☐	1	1	99999	50km/h	0km/h	7	Minor Roads
1	0	Motorways - Dual Lane - fast	☐	2	2	3400	112km/h	0km/h	1	Motorway
2	0	Motorways - Dual Lane - medium	☐	2	2	3400	96km/h	0km/h	1	Motorway
3	0	Motorways - Dual Lane - slow	☐	2	2	3400	80km/h	0km/h	1	Motorway
4	0	Motorways - Dual Lane - roundabouts	☐	2	2	3400	80km/h	0km/h	1	Motorway
5	0	Motorways - Dual Lane - interchanges	☐	2	2	3400	80km/h	0km/h	1	Motorway
6	1	A-Road - Dual Lane - slow	☐	3	2	3200	80km/h	0km/h	3	Principal A
7	1	A-Road - Dual Lane - medium	☐	3	2	3200	96km/h	0km/h	3	Principal A
8	1	A-Road - Dual Lane - fast	☐	3	2	3200	112km/h	0km/h	1	Trunk A
9	1	A-Road - Single Lane - fast	☐	3	1	1100	96km/h	0km/h	2	Trunk A
10	1	A-Road - Single Lane - medium	☐	3	1	1100	64km/h	0km/h	2	Principal A
11	1	A-Road - Single Lane - slow	☐	3	1	1100	48km/h	0km/h	4	Principal A
12	2	B-Road - Dual Lane - medium	☐	4	2	2800	80km/h	0km/h	4	Minor Roads
13	2	B-Road - Dual Lane - fast	☐	4	2	2800	96km/h	0km/h	1	Minor Roads
14	2	B-Road - Single Lane - slow	☐	4	1	950	48km/h	0km/h	4	Minor Roads
15	2	B-Road - Single Lane - fast	☐	4	1	950	96km/h	0km/h	2	Minor Roads
16	2	B-Road - Single Lane - medium	☐	4	1	950	64km/h	0km/h	4	Minor Roads
17	2	B-Road - Single Lane Urban - fast	☐	4	1	950	80km/h	0km/h	2	Minor Roads
18	3	Secondary Road - Dual Lane - fast	☐	5	2	2800	96km/h	0km/h	3	Minor Roads
19	3	Secondary Road - Dual Lane Urban - fast	☐	5	2	2400	80km/h	0km/h	5	Minor Roads
20	3	Secondary Road - Single Lane - fast	☐	5	1	850	80km/h	0km/h	4	Minor Roads
21	3	Secondary Road - Single Lane Urban - fast	☐	5	1	1000	64km/h	0km/h	6	Minor Roads
22	4	Local Connecting Roads - Dual Lane - medium	☐	6	2	2000	48km/h	0km/h	5	Minor Roads
23	4	Local Connecting Roads - Dual Lane - slow	☐	6	2	2000	48km/h	0km/h	5	Minor Roads
24	4	Local Connecting Roads - Dual Lane Urban - medium	☐	6	2	2000	64km/h	0km/h	5	Minor Roads
25	4	Local Connecting Roads - Single Lane - medium	☐	6	1	850	64km/h	0km/h	6	Minor Roads
26	4	Local Connecting Roads - Single Lane - slow	☐	6	1	850	48km/h	0km/h	6	Minor Roads
27	4	Local Connecting Roads - Single Lane Urban - medium	☐	6	1	850	48km/h	0km/h	6	Minor Roads
28	5	Local Roads - Dual Lane - slow	☐	7	2	2000	48km/h	0km/h	5	Minor Roads
29	5	Local Roads - Dual Lane Urban - medium	☐	7	2	2000	48km/h	0km/h	5	Minor Roads
30	5	Local Roads - Dual Lane Urban - slow	☐	7	2	2000	64km/h	0km/h	5	Minor Roads
31	5	Local Roads - Single Lane - slow	☐	7	1	850	30km/h	0km/h	6	Minor Roads
32	5	Local Roads - Single Lane Urban - medium	☐	7	1	850	48km/h	0km/h	6	Minor Roads
33	5	Local Roads - Single Lane Urban - slow	☐	7	1	850	30km/h	0km/h	6	Minor Roads
34	6	Local Roads - unsuitable for driving	☐	8	1	800	20km/h	0km/h	7	Minor Roads
35	0	Ferry Crossings	☐	10	1	100	10km/h	0km/h	7	Minor Roads
36	3	Roundabout - Single Lane	☐	4	1	99999	48km/h	0km/h	6	Minor Roads
37	3	Roundabout - Dual Lane	☐	4	2	99999	48km/h	0km/h	5	Minor Roads
38	3	Ramp - Single Lane	☐	4	1	99999	48km/h	0km/h	6	Minor Roads
39	3	Ramp - Dual Lane	☐	4	2	99999	48km/h	0km/h	5	Minor Roads
40	4	Unknown	☐	9	1	99999	48km/h	0km/h	7	Minor Roads

Figure 14: Link types in the model

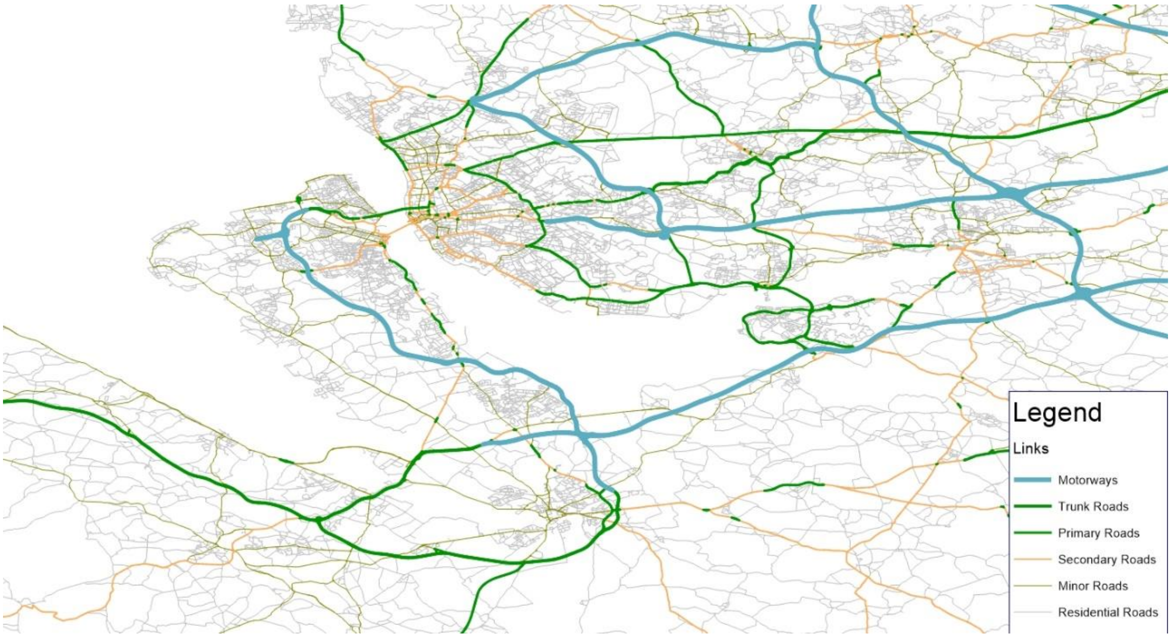


Figure 15: The Charge network model in the Internal area with link types shown

Every link has a volume delay function (VDF) based on its link type which defines the relationship between flow and speed. Each VDF has the following functional form:

$$t = t_0 * (1 + a * \left(\frac{q}{q_{max} * c}\right)^b$$

where t is the travel time of the link, t_0 is the free-flow time on the link derived from the length and free flow speed, q is the traffic flow, and q_{max} is the capacity. The parameters a, b and c are dependent on the link type as seen in the BPR function above.

VD functions

Number: 7	No	Name	Description
1	1	Multi High Speed	BPR (0.42 1.40 1.00)
2	2	Single High Speed	BPR (0.60 1.18 1.00)
3	3	Multi Main road	BPR (0.42 1.50 1.00)
4	4	Single Main road	BPR (0.70 2.20 1.00)
5	5	Multi Residential road	BPR (0.60 2.53 1.00)
6	6	Single Residential road	BPR (0.80 1.80 1.00)
7	7	Other road	BPR (1.40 1.50 1.00)

Figure 16: Initial Volume Delay Functions used for Charge

The resulting relationship between the speed on links and the traffic flow is visualised in Figure 17, where the VDF numbers listed in Figure 16 correspond to those in Figure 14This graph shows the relationships between speed (in the Y axis) and the saturation level (in the X axis). The saturation level describes the amount of traffic that wants to travel on a link versus the carrying capacity of that link. As can be seen, as saturation increases (i.e. congestion), the speed on the link decreases. The volume delay functions used in the initial build of the Charge network model are based on analysis of automatic traffic counts for another project in the UK and may be further adjusted during the calibration and validation phase.

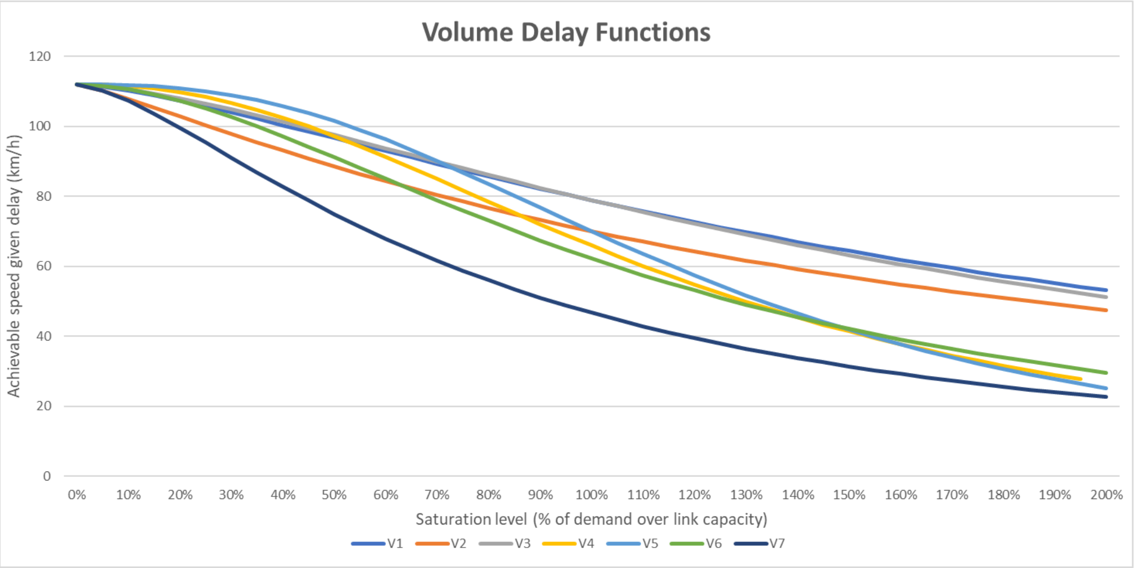


Figure 17: Plot of Volume Delay Functions

Public Transport

Public transport information has been sourced from an open data portal[10]. The data downloaded for buses is originally sourced and licenced by Traveline[11] and converted to a format called the General Transit Feed Specification (GTFS) by an organisation called Planar[12]. It is this organisation that maintains the transitfeed bus data which has been used for this transport model[13]. The same portal has been used to source rail data[14], this time with the original data provided and licenced by the Rail Delivery Group[15].

The advantage of the GTFS format is that it is now widely used and PTV have developed an interface and process for importing and fusing this data with the rest of the transport model. This process was used to import both the bus and rail datasets covering the internal and intermediate areas but also long-distance services reaching other stations in the country.

The result of the import is that the Visum data layers have been populated with the timetable and public transport route information from the GTFS source. Figure 18 shows one of the bus lines in Visum after the import; the number 19 in Liverpool.

10 https://transitfeeds.com/
11 https://www.travelinedata.org.uk/
12 https://planar.network/projects/feeds
13 https://transitfeeds.com/p/traveline/1033
14 https://transitfeeds.com/p/association-of-train-operating-companies/284
15 https://www.raildeliverygroup.com/

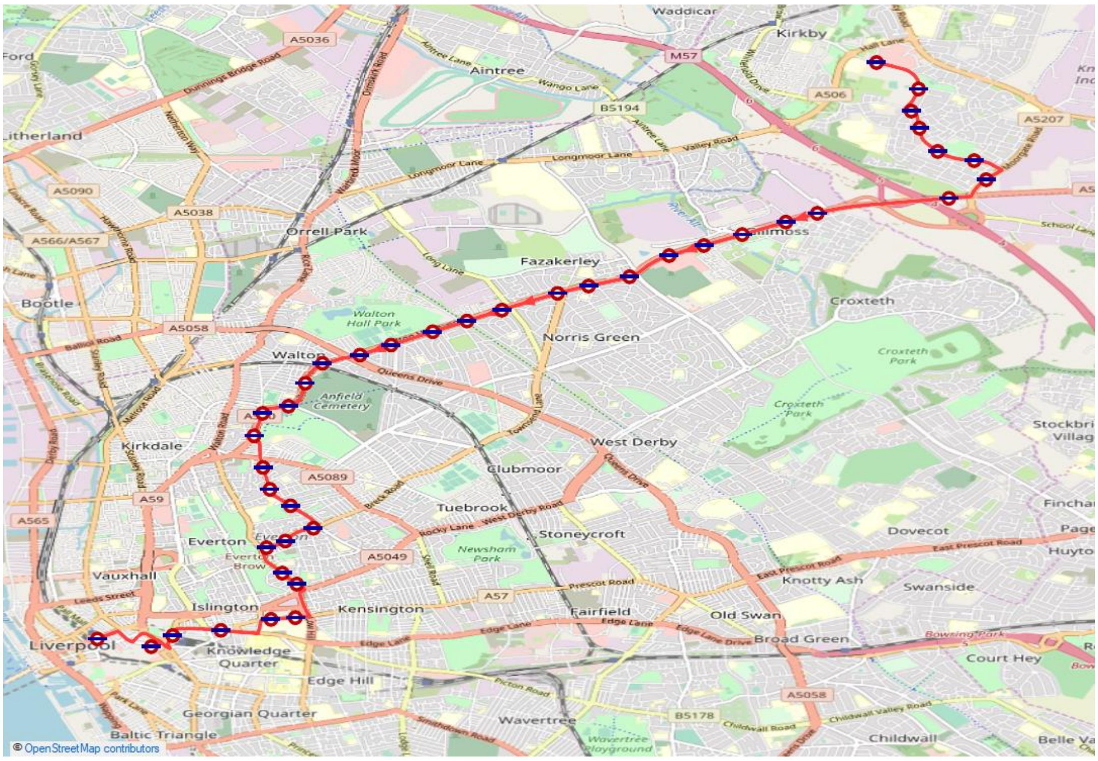


Figure 18: Bus 19 Mann Island - Kirkby Civic Centre

In Figure 18 the **Line Route** can be seen as the red lines, with related **Stop Points** which are the dots with stop signs. The GTFS files also contain the timetables, i.e. the departure and arrival times of every vehicle journey operating on a line route, such that representative journeys can be produced by the model to include multiple legs and sensible overall journey times.

The public transport model is supplemented by walking links which allow for connection between stops so that interchanges between services can be made. In addition, walk link connectors are generated so that trips can originate from a zone and enter the public transport network, as described in the next section.

Connectivity

Connectors are abstract modelling objects which connect people, who are assumed to undertake activities at any location within a zone, with the transport network. Each zone has a single point called a **centroid** which represents the middle point of that zone, and each zone can have one or more connectors which connect the centroid to a transport network node. Figure 19 shows connectors for an Internal zone in the Charge model near Prenton. The light blue connectors are for public transport and represent people walking to board or alight at a stop point. The orange connectors are for road users, including cars, goods vehicles, and pedal bikes.

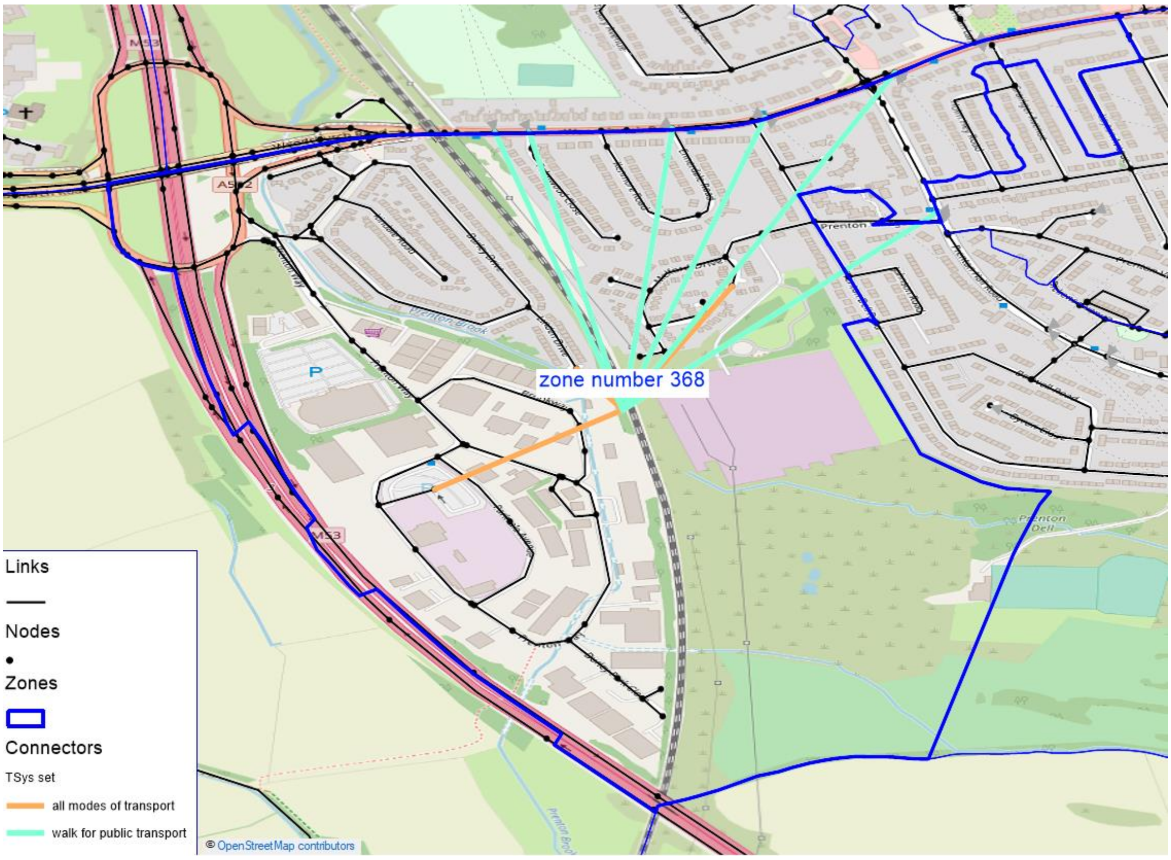


Figure 19: A sample of network elements (links, nodes, a zone and connectors)

Public transport connectors link the zone directly to public transport access points (which correspond to bus stops or train stations). The connector is assigned a slow walking speed to reflect the time that it would take someone to walk from their actual location in the zone and their chosen public transport stop. In addition, the road network has been opened to walking to allow for transfers between stops (i.e. from a train station to a bus stop).

For road transport, a bespoke script was developed that links up the zone centre with relevant nodes on the road network. The locations of these connections were chosen to correspond to areas where people live and work, thus providing more realistic access points for where traffic is likely to originate.

Walking

Walking-only trips are not explicitly represented in the network model but walking as a way to access public transport *is*. It is assumed that people walk to/from their zone to/from a public transport stop to board or alight services. They may also walk within stops in order to interchange.

5.2. Integration with the Demand Model

A measure of accessibility between all pairs of zones is required to model people's travel choices in the Demand Model. These measures are required for various different aspects of travel, such as travel time and distance, and they are required for all of the modes that are considered in the Demand Model. Table 7 summarises the different measures for each mode.

Transport Mode	Measures	Method
Bike	• Journey Time	Free-flow time for bike from the network model
Car Driver / Passenger	• Journey Time • Journey Distance	Congested time and distance for car from the network model
Public Transport	• Access Time (the time needed to reach a service from the origin) • Egress Time (the time needed to reach a destination from the service) • Walk Time • Transfer Wait Time • In-Vehicle Time • In-Vehicle Distance • Number of Transfers	Extracted from routes calculated in the network model
Walk	• Journey Time	Direct 'crow flies' distance from the network model, multiplied by 1.4 as a detour factor, and then by 12 to convert from kilometres to minutes assuming a walk speed of 5 km/h

Table 7: Accessibility Information Extracted from the Network Model for Input to the Demand Model

The above measures are calculated within Visum using mathematical algorithms and elements from advanced graph theory. Even without consideration of how much traffic is using the network, a 'shortest path search' between an origin zone and destination zone (referred to as **OD** for short) can provide information about the level of accessibility of the network in uncongested conditions.

Indeed, this 'initial' cost information is used in the first stages of model calibration since we do not know how much traffic will use the network until the demand model is calibrated, which in turn first needs an estimate of travel costs.

When there is information about the amount of traffic that wants to use the network, which we refer to as the **demand**, then routing calculations are carried out at scale across all OD pairs and in an iterative fashion, distributing traffic across different routes until a state of equilibrium is achieved. This process is called **assignment, or network**

modelling, and is one of the key aspects of a transport modelling platform. Further information on the fundamentals of assignments in Visum can be found in the software manual[16].

[16] https://cgi.ptvgroup.com/vision-help/Visum_2020_ENG/#1_Benutzermodell_Multimodal/1_8_Multimodale_umlegung.htm#kanchor3409

6. The Demand Model

6.1. Principles of Tour-Based Demand Modelling

The demand model is the component of the transport model where the following choices are modelled for each person:

- How many tours do I perform on a typical day and of which type/purpose?
- What locations do I travel to, to undertake the activities on a tour?
- Which modes of transport do I use to undertake the trips on a tour?
- What time of day do I travel for each trip?

There are different types of demand model in transport modelling practice. The type of model that has been chosen for Charge is called a tour-based demand model. The advantage of this is that it explicitly considers the impact of undertaking more than one activity on a tour. This is important for Charge because we will need to understand when people are at different locations to assess the impact of trip-end EV charging, and we want to know tour-lengths so we can assess battery states more precisely.

A **tour** is a sequence of activities that are undertaken where the sequence of activities must start and end at home. The activities being modelled for Charge are Home (H), Business (B), Education (E), Shopping (S), Work (W), and Other (O). The **tour types** that are considered in the model are therefore a sequence of these activities, starting or ending in H, such as HEWH. Section 3.4 explains how the National Travel Survey (NTS) has been analysed to identify the most relevant subset of all tour types that capture the vast majority of travel demand.

People are represented in the Charge demand model as relatively homogenous segments of the population, known as **person groups**. Section 3.2 explains which person groups are used for the Charge model.

The workflow for the tour-based demand model, that is applied for each person group, is shown in Figure 20.

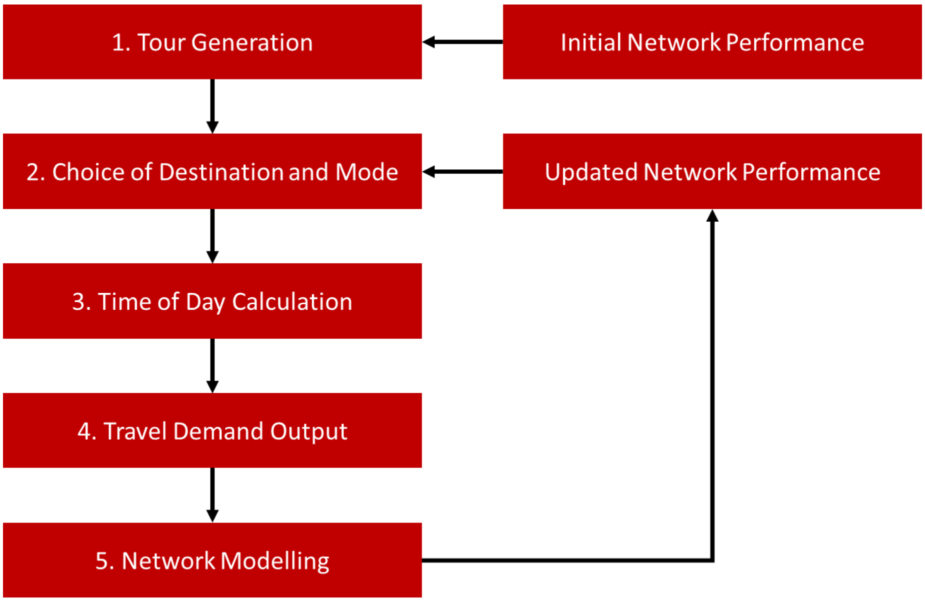


Figure 20: A workflow representation of the tour-based demand model

6.2. Tour Generation

Section 3.5 describes how **tour rates** have been derived for each person group. The first step of the demand model is to apply these tour rates to the number of people of each person group in each zone, or demand stratum. For this there is a built-in procedure inside the software which automatically picks up the person group data and tour rates. The output is a set of data for each zone which contains the number of **home trips** for each tour type and person group, for example as shown in Figure 21 below, which shows the number of trips generated for the Home to Education to Home segment with characteristics: urban, employed, car available, and medium income. The urban/rural segmentation has been applied in a binary fashion at a zonal level, i.e. rural zones produce no trips of the type urban and vice-versa.

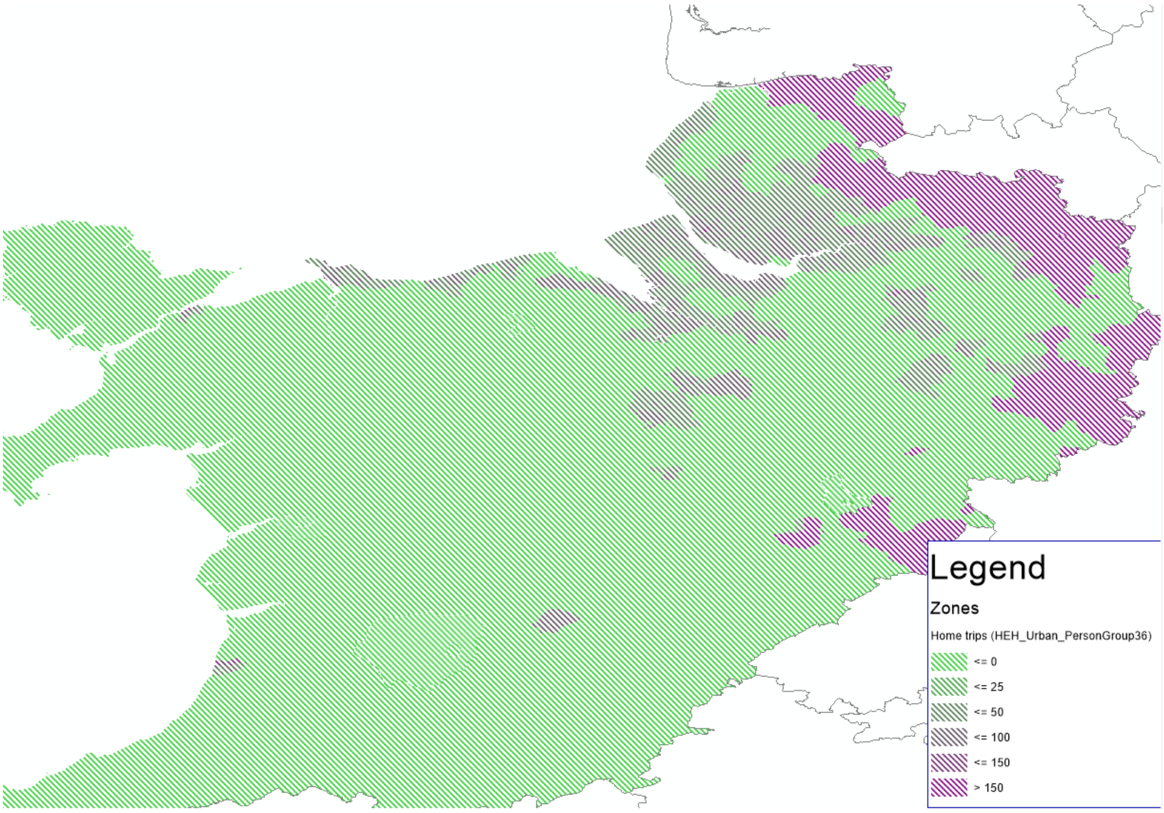


Figure 21: Home trips assigned to the people who are Urban, Employed, have a Car Available, a medium income, and are travelling for the purpose of Education

6.3. Combined Destination and Mode Choice

Once we know how many tours begin in each zone for each person group, we can perform the largest calculation which is to determine the destination of each activity in the tour, and the modes that are chosen for each trip in the tour.

The basis of this calculation is a choice model where the probability of an option (a destination and mode) is calculated by choosing each option from a set of alternatives. The probability is calculated as follows:

$$P_{ij} = \frac{Z_j \cdot f(u_{ij})}{\sum_{k=1}^{B} Z_k \cdot f(u_{ik})} \qquad (1)$$

where P_{ij} is the probability of destination j for origin zone i, Z_j is the **structural property** of zone j as described in section 4, f(uij) is the **utility function** which is closer to zero for locations that have a greater travel cost, and B is the number of zones.

Utility Functions

In the tour-based demand model the choice of destination and mode is done simultaneously to represent the fact that the attractiveness of a destination depends on the accessibility to that destination across all modes of transport. Therefore, the utility for a particular destination includes a measure of accessibility across all **modes** of transport.

A contribution towards utility needs to be calculated for each mode and each pair of zones, where the following modes are considered in the Charge model:

- Car driver
- Car passenger
- Public transport
- Walk
- (Pedal) Bike

Mode utilities can be different depending on the destination activity and the person group. Table 8 shows the general form of utility function for the car driver. The full set of calibrated mode utilities will be presented in the Calibration and Validation report. Note that the outcome of the function is always a number between 1 (good accessibility) and 0 (poor accessibility).

Table 8: Mode utility function

Mode	**General Form of Mode Utility Function**
Car Driver	e ^ {- λ* α * [((access time) + (egress time)) * β_1 + (travel time) + (travel distance) * (β_2 / (β_3* β_4)) + (parking cost) / (β_3* β_4)] + constant} where: β_1 = walk time weight β_2 = vehicle operating cost in £ per km β_3 = average number of people per car β_4 = value of time in £ / minute β_5 = cost damping cut-off β_6 = cost damping parameter A β_7 = cost damping parameter B λ = sensitivity parameter α = cost damping factor, which is 1 if the travel distance is less than β_5, otherwise equals [(distance) / β_6] $^{-\beta_7}$

The coloured parameters in the functions in Table 8 are different depending on the destination activity and the person group (those in red are dependent on the activity, and those in blue are dependent on the person group). Some of these parameters have been given a fixed input such as the value of time and vehicle operating cost. They have been derived using UK best practice such as TAG[17],[18] or our own judgement. Others are adjusted during the calibration process as described in section 7.4.

Some of the costs in Table 8 are based on the destination zone, such as the parking cost, and some are based on the level of accessibility between a pair of zones, such as the travel time. The zone-to-zone costs are derived from the network model as described in 5.2. Once these functions have been applied, we then know the utility (between 0 and 1) for each mode between each pair of zones and for each person group and destination activity. We are then ready to calculate the destination probabilities using formula (1), where the general form of f(uij) within formula (1) is as follows:

$$\exp[\, \partial * \; ln \sum_{j=1}^{M} \exp\,(U_j)] \qquad (2)$$

δ is a calibration parameter used to scale the sensitivity in the model between mode and destination choice, M is the number of modes, and U is the mode utility. The term $ln \sum_{j=1}^{M} \exp\,(U_j)$ is called the logsum and acts as a kind of average of the utilities across the various the modes. The parameter δ will be adjusted during calibration and reported as such.

Main Activities and Rubberbanding

Each tour (or activity chain) represents the sequence and purpose of trips that a particular person group will make throughout a day. Ordinarily, the choice of mode and destination would be made equally across all destinations throughout the day. However, in reality, a specific activity is often more important than others and defines where and how the supplementary activities are chosen. For instance, for the tour HWSH, it is likely that the Work activity is more important than the Shopping trip – i.e. someone's choice of shopping destination is influenced by where they work, rather than the other way around. In this case the **main activity** of the tour would be Work and we denote this as H[W]SH.

We represent this phenomenon by first doing the calculation of destination and mode for the main activity in a tour. The main activity of each tour is determined by its rank, with the lowest number meaning an activity has a higher rank. Table 9 below contains the ranking for the Charge model which represents a hierarchy of which activity locations would be chosen.

Table 9: Ranking of activities in Charge model

Activity	Rank (1 = high)
Business	6
Education	4
Home	1

17 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/805252/tag-unit-m2-variable-demand-modelling.pdf

18 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816195/tag-data-book.xlsm

Other	2
Shopping	5
Work	3

Once the choice of location and mode for the main activity is made, the locations and modes of other activities and trips in the tour can be determined. The choice of location is made depending on the amount of **rubberbanding** that has been allowed for each person group and tour type combination. The parameter that controls rubberbanding will be adjusted during the calibration process and reported there. It is enough to know here that its effect is like tying a rubber band first between the Home and Main Activity, and then choosing intermediate activities in such a way as to minimise the strain on the rubber band when it is stretched to incorporate them.

Figure 22 is an illustration of this where the work location has been chosen first, and then either Shop 1 or Shop 2 is to be chosen as an intermediate stop. The choice will depend on minimising the length of the imaginary 'rubber band'.

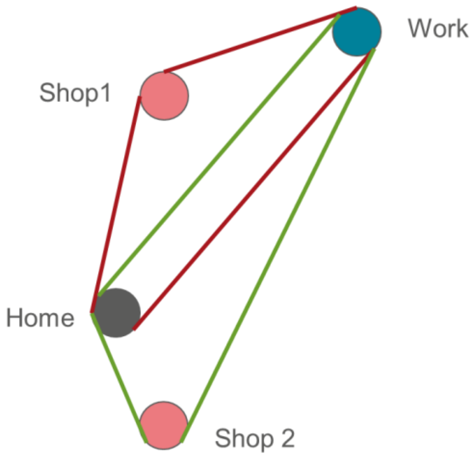


Figure 22: Illustration of rubber-banding in the tour-based demand model

In most cases the choice of mode for the main activity then determines the mode for the rest of the tour. For example, if you decide to drive by car to work, you will also drive to a shop on the way home rather than get the bus. Some modes are allowed to be interchangeable. For example, if walk or bike is chosen as the mode for the main activity, then it is realistic that public transport is also allowed for other trips in the tour. The interchangeable modes defined for Charge are as follows:

- Car passenger
- Public transport
- Walk
- Bike

After the destination and mode choice calculations, the output is a set of **matrices** of travel demand, which tell us how many people want to go between every pair of zones in the model. These travel demand matrices can be outputted for every pair of activities, every mode, and every person group. Typically, we only output the ones that are of most interest.

7. Calibration Setup

The previous sections of this report describe the components that have been used to build a variable demand transport model for the Manweb region. This section describes how this data has been combined with various starting parameters to provide an initial estimation of travel patterns, and then tweaked to incrementally improve the model results when compared to observed data sources. This process is referred to as **calibration** and a high-level workflow is provided in Figure 23 below.

7.1. Workflow

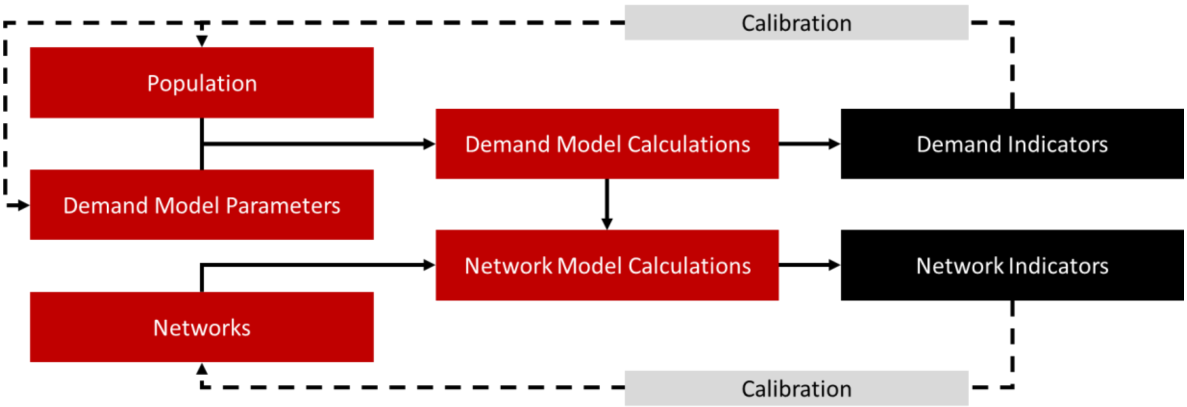


Figure 23: The Calibration workflow

We use indicators which are derived from empirical data to assess how well the model is reproducing real-world phenomena. For the demand model, we look at the following indicators:

- Mode shares (e.g. the proportions of people travelling to work by car, or public transport etc.)
- Trip lengths
- Total amount of travel generated and attracted, by area
- Total amount of travel moving between sectors

In the road network model, we look at the following indicators:

- Modelled traffic flows versus observed traffic counts

We monitor the results against these indicators as we make adjustments to the various components of the model until we are satisfied that the model is sufficiently accurate, or in other words, that the model is valid. This process, known as calibration and validation, is described in more detail in the following sections.

7.2. Sources of Calibration and Validation Data

We have gathered several sources of empirical and observed data that we are using to calibrate and validate the model. These include:

- The **National Travel Survey**: which provides detailed surveyed statistics, representative of England and Wales. As described in section 3 we will compare the model results against trip lengths and mode shares.
- **Mobile phone data** for Wales and Cheshire: which was originally commissioned for use in the North Wales transport model and provides aggregated matrices of trips across the region by time of day and mode. We will use this data to control how many trips move between various areas of the model.
- The **Liverpool City Region Transport Model** (LCRTM): which has been built to represent travel in the Merseyside area. An output from this model is OD matrices for various modes and time periods, that we will use to compare against the scale and distribution of trips in the Charge model.
- The **Liverpool Household Survey**: which was commissioned as an input into the LCRTM and provides similar data as the NTS but bespoke to the Liverpool region. We will use this data to calibrate mode shares and trip lengths throughout Liverpool.
- **Traffic counts**: which have been sourced from several places, including Webtris the Highways England databased of traffic data on the strategic road network (motorways); the LCRTM, where bespoke traffic surveys were commissioned to help calibrate that model; DfT road traffic statistics which provide high level traffic volumes across the whole study area; and bespoke traffic counts in Denbighshire that were provided by the local authority. The traffic counts will be compared to the modelled traffic flow where counts are available, with various elements of the network and demand model being adjusted to help approximate to these observed values.

7.3. Initial Model Setup

The initial demand model was prepared with a set of inputs as described in the earlier sections of this report and represented in Figure 23. This includes:

- The population, split into person groups, assigned to various activity chains (resulting in discrete demand strata), and distributed into each of the model zones
- Mobility generation rates for each demand stratum
- Structural Properties data, indicating the attractiveness of each zone for various trip purposes
- An initial highway (skim) assignment taken from the network model to derive the uncongested times and distances for trips from and to each zone, for car and bike
- An initial public transport (skim) assignment to derive the journey times, distances, number of transfers, and walking legs for each zone to zone pair via public transport
- A first instance of the demand model with starting utility functions and parameters

7.4. Initial Demand Model Parameters

The initial demand model setup comprised a set of **distribution utility functions**, **mode choice utility functions**, and a set of **parameters** that influenced these functions. These initial parameters were estimated following **TAG guidance.** TAG (Transport Analysis Guidance)[19] is the UK Government's documentation material that supports and guides transport assessments and model development throughout the country. We have therefore used TAG as supporting best practice to help build and compare to the Charge model.

Some of the starting parameters within the model have been taken from TAG and not adjusted as part of the calibration process, while others have been amended to help bring the model results in line with observed data.

The full set of initial parameters used have been provided for reference in section 11 (Appendix A).

[19] https://www.gov.uk/guidance/transport-analysis-guidance-webtag

8. Calibration Implementation

8.1. Demand Model Parameter Adjustment

The initial parameter values set out in section 11 (Appendix A) were input to the model and the results were analysed against a number of data sources to assess performance. Based on this, incremental adjustments were made in order to improve the results. The final parameter values are provided here for reference and as a guide to help inform similar transport model builds like the Charge model.

The principles for making adjustments and the final parameters are discussed below. The final validation results, and therefore the outcome of making the adjustments described in this chapter are found in later sections as follows:

- Mode share results: section 9.2
- Trip length results: section 9.3
- Amount of travel generated and attracted to each zone (trip ends): section 9.4
- Evidence for a realistic response to changes in costs (realism testing): section 14.1

Public Transport Cost Weights

Public transport cost weights define the relative (dis)attractiveness of the various elements of a public transport trip. These include:

- Walking (access/egress) time
- Wait time
- Interchanges
- In-vehicle time

In combination, these weights imply that a direct service is more attractive than a circuitous trip which includes several legs. The initial weights were adjusted following a review of the generalised costs between car and public transport modes based on their competitiveness along known routes such as Liverpool to Manchester. This initial process revealed that the public transport generalised costs were significantly higher than the equivalent car costs (making public transport less attractive) and hence the weights were reduced to the lower values in the recommended value ranges in order to make public transport more attractive. These values are presented in Table 10.

Table 10: Public transport cost weights

Component	Weight value
Walk time	1.5 (factor)
Wait time	1.5 (factor)

Interchange penalty	5 minutes
In-vehicle time	1 (factor)

Mode Sensitivity

The mode sensitivity parameters (known as λ values) are the main parameters that require careful calibration as they have a significant impact on mode shares, trip lengths and the responses of the model to input changes. TAG sets out a series of realism tests that should be carried out to assess how the model responds to defined input changes, the results of which are discussed in section 14.1. A heuristic approach has been taken, as suggested by TAG, to make changes to these parameter values, benchmarking the results against observed data and then making improvements as necessary. The λ parameters were the first parameters to be refined as they have the widest impact on the model.

Table 11: Post-calibration mode sensitivity parameters

Activity	Final λ values	Initial λ values
B	0.12	0.15
E	0.40	0.50
H	0.20	0.25
O	0.12	0.45
S	0.12	0.45
W	0.15	0.25

Destination Sensitivity

Destination sensitivity parameters, or θ values, define the attractiveness of different trip purpose types. These can be applied at the person group level such that different person groups might be represented to value certain types of trips more strongly. During calibration, the performance of these values is assessed using trip length distributions, trip end data and realism test results. After changing other parameter values and since a good overall level of validation was achieved, we found that the initial starting values of $\theta = 1$ were sufficient and so were not changed.

Cost Damping

Following the calibration of the sensitivity parameters, the trip length distributions of each activity by mode were reviewed. This highlighted that there was an underrepresentation of long-distance trips and so cost damping was introduced to help increase the attractiveness of these trips. Cost damping is a mechanism used to decrease the sensitivity to cost changes with increasing trip length, in other words an additional 10 minutes of journey time is set to have a smaller impact on a journey of 2 hours versus a journey of 15 minutes. Suggested values in TAG are for $\alpha = 0.5, D = k = 30$, however it was determined that only a small amount of damping was required and hence a smaller value of α has been used. The calibrated cost damping parameters are shown in Table 12, where $IF\left(D > 30, \left(\frac{Distance}{k}\right)^{-\alpha}, 1\right)$ is the formula used.

Table 12: Cost damping parameters

Activity	α	D	k
B	0.25	30	30
O	0.25	20	20
S	0.08	20	20
E, H, W	0.00	N/A	N/A

Mode Specific Constants

The final set of parameters to be calibrated are the mode specific constants as they have the most targeted impact, solely on mode share, rather than affecting all aspects of the model. The mode specific constants thus can be used to make certain modes more or less attractive, with these values calibrated to approximate to the targets presented in section 9.2. The mode constants are additive with a positive constant resulting in making that mode less attractive (and vice-versa for a negative constant).

The resultant parameter values are shown in Table 13 and Table 14.

Table 13: Mode specific constants

Mode	Overall
Car	0
Car Passenger	-1
Public Transport	-6
Bike	-6
Walk	-7

Table 14: Activity mode specific constants

Activity	Car	Car Passenger	Public Transport	Bike	Walk
B	2	6	-15	0	4
E	0	0	-5	5	-3
H	0	3	-20	0	0
O	2	-2	-25	3	1
S	5	0	-35	3	5
W	4	9	-20	-5	2

9. Model Validation

9.1. Overview

This section describes how the Charge model compares to various comparison datasets and statistical indicators. In particular:

- Demonstrating that the overall mode choice and reasons for travelling are consistent with the National Travel Survey and the Liverpool household survey (section 9.2)
- Showing that modelled car trip distances are consistent with national and local survey data (section 9.3)
- Demonstrating that the overall amount of travel and the pattern of movements is representative when compared to data collected from mobile phones and an existing regional model (section 9.4)
- Highlighting that modelled car traffic flows are consistent in scale and geography with observed traffic counts across the model area (section 9.5)
- Discussing findings from three ‘realism tests’ which help to show the model produces sensible results when various parameters are changed (section 14.1 / Appendix D). This comparison is based on recommended thresholds from TAG, the UK government’s guidance documentation for transport model assessment.

9.2. Mode and Purpose Shares

The modal and purpose shares describe the proportion of trips made by each mode of transport and, separately or in combination, the proportion of trips made for different purposes. For calibration and comparison, we have used two sources of data: NTS, and the Liverpool Household Survey. As described in earlier sections, the NTS data used in this project is composited from 2015-2017 data and the Liverpool Household Survey was conducted in 2017. Table 15 shows how mode shares from the model, split by purpose, compare to these two sources. Car driver is the principal mode that will inform future EV usage patterns and the model share typically falls between the values for NTS and the Liverpool survey, demonstrating a good level of validation.

Table 15: Mode Share Validation split by Purpose

Charge Model Shares vs. Surveys		Car Driver	Car Passenger	Public Transport	Bike	Walk
Business	Charge	**75%**	**7%**	**12%**	**0%**	**6%**
	NTS	70%	5%	14%	1%	9%
	L'Pool	72%	6%	5%	0%	17%
Education	Charge	**23%**	**24%**	**10%**	**1%**	**41%**
	NTS	23%	24%	11%	1%	41%
	L'Pool	24%	22%	15%	2%	36%
Home	Charge	**44%**	**18%**	**15%**	**2%**	**20%**

	NTS	41%	19%	12%	2%	26%
	L'Pool	44%	17%	15%	2%	22%
Other	Charge	**42%**	**23%**	**7%**	**1%**	**27%**
	NTS	39%	25%	8%	1%	27%
	L'Pool	45%	19%	11%	2%	24%
Shopping	Charge	**45%**	**17%**	**11%**	**2%**	**26%**
	NTS	46%	17%	10%	1%	27%
	L'Pool	39%	16%	22%	1%	21%
Work	Charge	**62%**	**8%**	**17%**	**2%**	**12%**
	NTS	57%	7%	18%	4%	14%
	L'Pool	68%	8%	13%	3%	8%
All Purposes	Charge	**44%**	**19%**	**12%**	**2%**	**23%**
	NTS	42%	19%	11%	2%	26%
	L'Pool	44%	17%	15%	2%	22%

Table 16 shows the proportion of trips made for each purpose compared to the validation sources. This shows that trips back to home are the most common, followed by other trips and then work trips. The Charge model purpose shares are consistent with the survey data suggesting the model sufficiently represents different types of trip.

Table 16: Purpose Split Validation

Overall Trip Purpose Splits	Charge	NTS	Liverpool
Business	2%	2%	0%
Education	8%	9%	11%
Home	46%	43%	45%
Other	25%	25%	18%
Shopping	9%	9%	13%
Work	10%	11%	13%

9.3. Trip Length Comparisons

Trip lengths in the Charge model have been validated against the same survey sources as the mode shares: NTS and the Liverpool Household survey with example distributions presented in section 3.7. Accurate trip length distributions across purposes suggest the model is sufficiently representing the range of trips that take place, which will be a key input in the energy consumption from EVs calculation. Figure 24 shows the trip length distribution for all car trips in the model against car journey distances recorded in NTS and the Liverpool survey. As can be seen, the model distribution follows the survey distributions closely, especially for trips over 25km. Figure 25 below shows an equivalent trip length comparison but for all trips going to work.

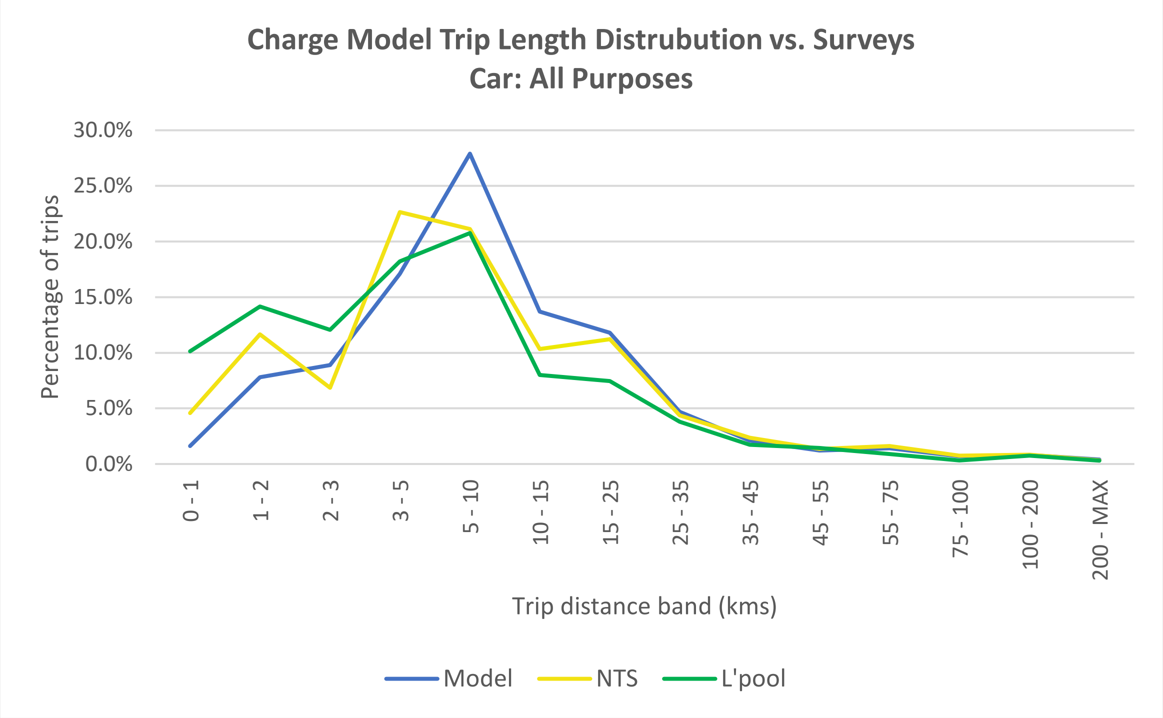


Figure 24: Trip Length Distribution for Car All Purposes

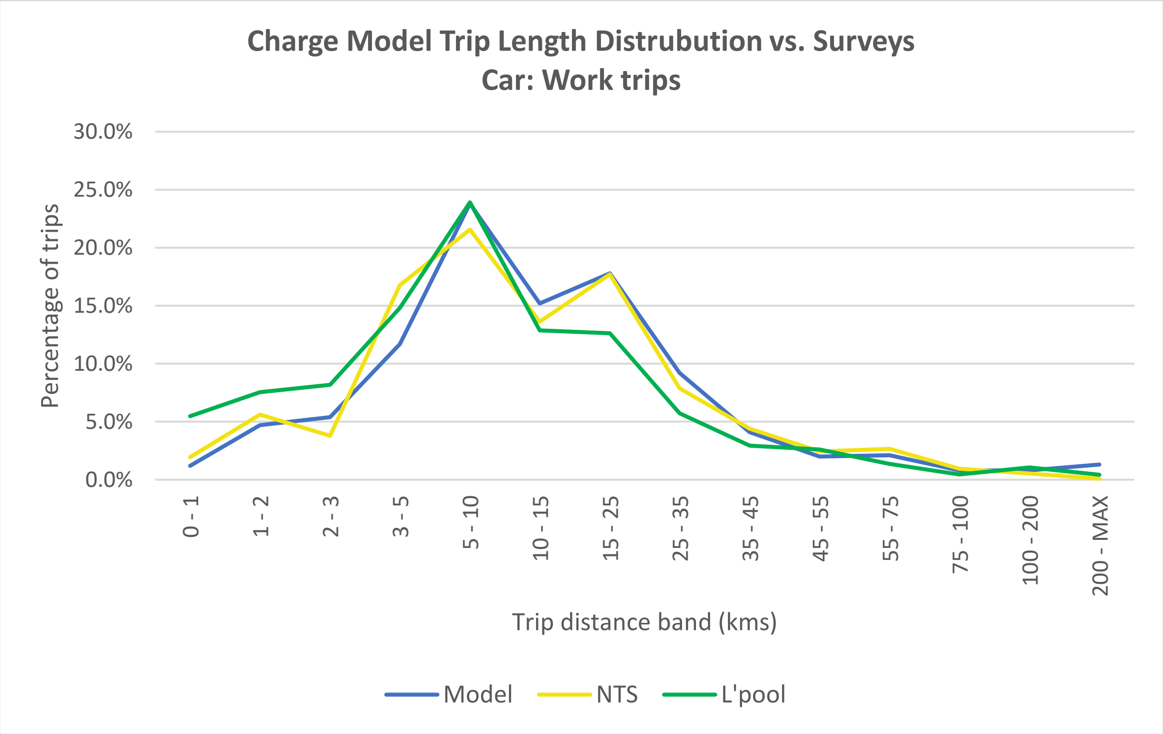


Figure 25: Trip Length Distribution for Car Work trips

9.4. Distribution of Trips

A primary output from the demand model is a set of Origin-Destination (OD) matrices which quantify the distribution of trips across the model. A good comparison with comparable movement matrices suggests that the model is accurately reflecting where trips originate and to which destinations they end up. For the validation of this model, we have compared against two independent sets of OD matrices – mobile phone data from Telefonica, and calibrated outputs from the Liverpool City Region Transport Model.

Mobile Phone Data

For use in this project, PTV purchased a set of observed matrices from Telefonica, who own the O2 network in the UK. The dataset is built through the analysis of mobile network events, created by a sample of 25 million handsets on the O2 mobile network which are then extrapolated to be representative of the UK population. Observed mobile phone movements are aggregated by O2/Telefonica and assigned to a specified zoning system, creating OD matrices[20]. The data used in this project was initially specified by Transport for Wales (TfW) in 2019 to inform various transport model builds throughout the country. It contains the following attributes:

- Based on an MSOA zoning system for the whole of Wales and including some peripheral zones in England (including Cheshire). Outside of this area, external zones were specified corresponding to Local Authority districts. Because this data was specified by TfW, certain areas in the Charge model are not covered by internal mobile phone zones, including Liverpool.
- Averaged and aggregated records from 4th March 2019 to 12th April based on Monday-Thursday records to define a typical weekday.
- Mode of travel: including a) Car (all motorised road-based trips except HGVs), b) Heavy Goods Vehicles, c) Rail, d) Walk trips
- Purpose*: Trips split by inferred purpose from home and/or work
- Time of day: including AM (07:00 – 10:00), IP (10:00 – 16:00), PM (16:00 – 19:00), and OP (19:00 – 07:00)

*For direct comparison with the Charge model, and due to inconsistencies identified in the purpose splits in the mobile phone data, all purposes were combined for the sake of comparison.

To help validate the distribution of movements in the Charge model, patterns are compared with comparable observed mobile phone data. To help visualise this comparison, a set of sectors has been defined in areas where mobile phone data was available and are inside the Charge core area. A plot of these sectors is shown in Figure 26.

[20] https://www.gov.uk/government/publications/mobile-phone-data-in-transport-modelling

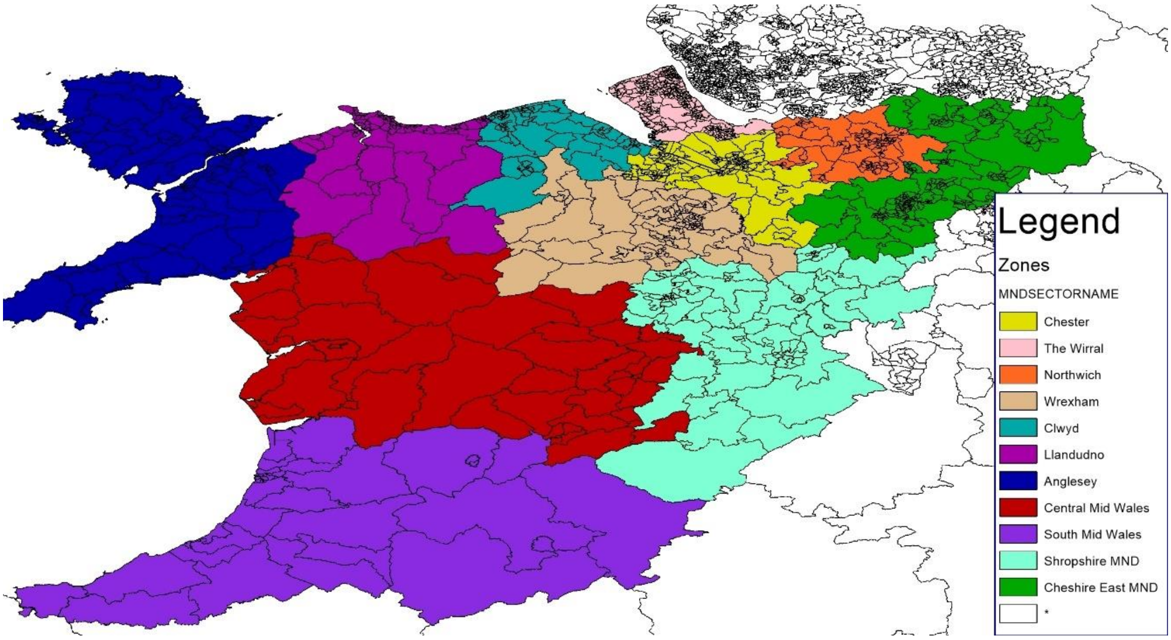


Figure 26: Mobile Phone Coverage and Sector System

Table 17 and Table 18 show the number of trips for the AM period (7am – 10am) between sectors, where the cell in the top left-hand corner represents the number of trips starting and finishing within the Chester area. Table 17 shows the number of trips recorded by Telefonica for a typical weekday morning (after factoring up to represent the whole population), and Table 18 shows the number of trips produced by the Charge model for a typical weekday morning. Trips shorter than 4km are removed from the model figures to make a like-for-like comparison, since these are typically missed from mobile phone data.

The patterns of movements shown in Table 17 and Table 18 suggest that the Charge model is sufficiently representing where trips take place in reality. This can be seen visually by comparing the cell colouring of where values are smaller (green) or larger (red through yellow/orange). The rows are the 'from' sectors and the columns are the 'to' sectors. For example, the mobile phone data estimates 5,605 trips from Chester to The Wirral, and the Charge model estimates 6,860 trips. This data is also represented as a scatter plot in Figure 27 which shows the correlation between the observed mobile phone data and the Charge model estimations.

Additional analyses for the other periods in the day, shown in section 12.1 (Appendix B), show that the distribution of trips throughout the day is also representative of reality.

MOBILE PHONE DATA

Table 17: 7AM - 10AM Mobile Phone trips by road

MOBILE PHONE DATA												
Total	295,417	Sector Number										
Sector Name	Sector Number	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**5.1**	**5.2**	**6.1**	**7.1**
Chester	**2.1**	20,079	5,605	1,816	6,421	2,823	399	231	98	26	734	1,306
The Wirral	**2.2**	8,964	30,790	861	839	1,427	195	101	42	5	141	502
Northwich	**2.3**	3,132	1,054	8,716	335	99	46	35	20	5	140	5,897
Wrexham	**3.1**	7,478	789	328	16,578	1,669	383	137	419	39	2,701	493
Clwyd	**3.2**	4,049	1,334	93	1,762	7,210	3,497	463	85	10	101	104
Llandudno	**4.1**	572	136	34	427	3,569	9,557	3,040	302	33	74	48
Anglesey	**4.2**	204	105	21	141	490	2,731	22,341	1,249	49	61	50
Central Mid Wales	**5.1**	141	25	15	716	108	335	1,402	6,316	1,395	2,914	43
South Mid Wales	**5.2**	12	8	4	26	7	12	42	1,367	8,072	235	6
Shropshire MND	**6.1**	1,109	152	186	3,083	105	81	61	2,015	166	22,091	1,674
Cheshire East MND	**7.1**	1,683	383	5,481	453	87	66	87	31	9	1,081	34,292

Table 18: 7AM - 10AM Charge Model trips by car

CHARGE MODEL (Trips >4km)												
Total	318,855	Sector Number										
Sector Name	Sector Number	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**5.1**	**5.2**	**6.1**	**7.1**
Chester	**2.1**	17,805	6,860	2,118	5,803	2,606	156	17	72	4	941	1,091
The Wirral	**2.2**	8,087	36,320	867	761	514	48	11	15	1	117	288
Northwich	**2.3**	2,763	1,094	10,103	341	67	10	2	6	0	198	5,887
Wrexham	**3.1**	7,446	767	304	19,062	1,508	246	20	684	28	3,557	437
Clwyd	**3.2**	3,594	732	97	1,613	10,571	2,111	89	68	2	68	51
Llandudno	**4.1**	346	106	19	482	3,824	12,053	2,018	419	6	27	14
Anglesey	**4.2**	43	24	4	36	140	1,990	29,624	757	8	8	4
Central Mid Wales	**5.1**	176	48	15	1,063	138	368	545	13,551	1,811	2,662	31
South Mid Wales	**5.2**	21	6	2	83	6	5	4	2,036	15,862	332	4
Shropshire MND	**6.1**	1,078	130	140	3,235	43	13	4	2,087	403	23,911	971
Cheshire East MND	**7.1**	997	235	5,689	330	26	6	1	10	1	1,133	29,666

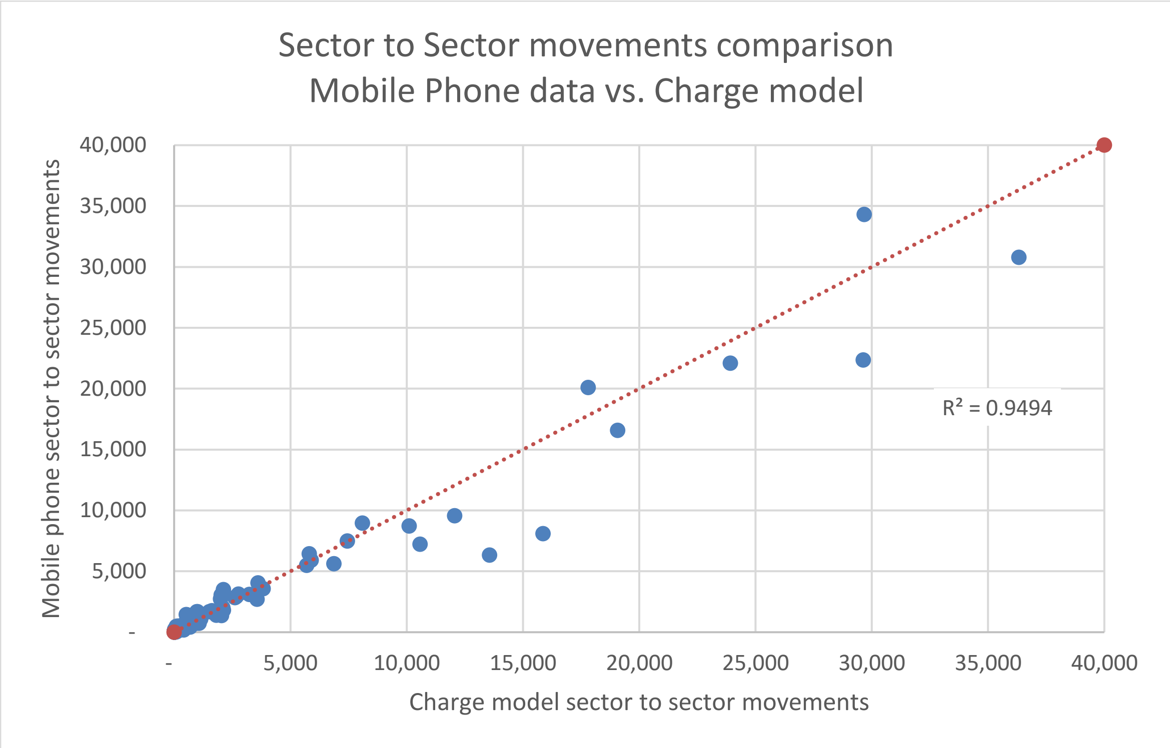


Figure 27: Sector to sector movements comparison – Mobile Phone Data vs Model

Liverpool City Region Transport Model Outputs

The Liverpool City Region Transport Model (or LCRTM) is a strategic transport model developed and maintained by Mott MacDonald on behalf of the Liverpool City Region Authority. It is used for numerous transport assessment schemes across the region and was last refreshed with 2017 population and traffic data. As a stakeholder to the Charge project, Liverpool City Region Authority agreed to provide the outputs from the model so they could be used as a comparison source. Here, we compare to the calibrated LCRTM matrices which have been adjusted using observed traffic count data (matrix estimation). As with the mobile phone data, a specific sector system has been defined so that results can be compared like-for-like. Figure 28 shows the sectors that have been defined for comparison purposes.

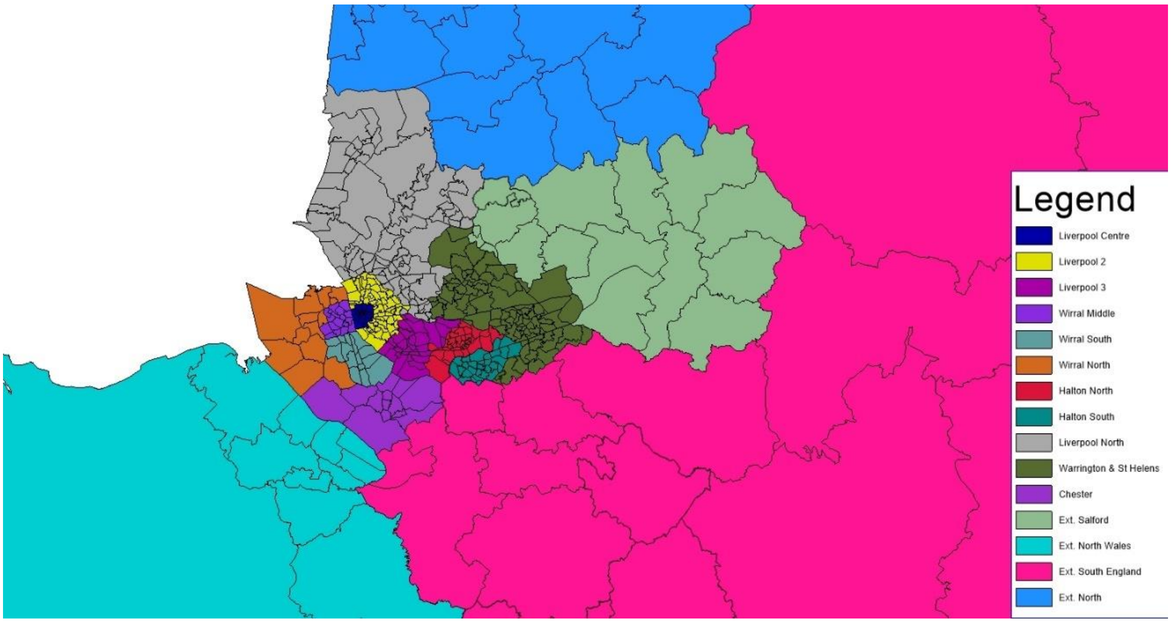


Figure 28: Sector System for LCRTM Comparison

Table 19 and Table 20 below show the sector to sector matrix for car trips in an average AM hour for LCRTM and the Charge model. This is also represented in a scatter plot in Figure 29. As can be seen, the patterns between the two models are broadly similar, suggesting the scale of trips generated by the Charge model and the distribution is in line with the TAG compliant LCRTM. Additional analyses comparing different times of day and also splits by purpose are presented in section 12.2 (Appendix B).

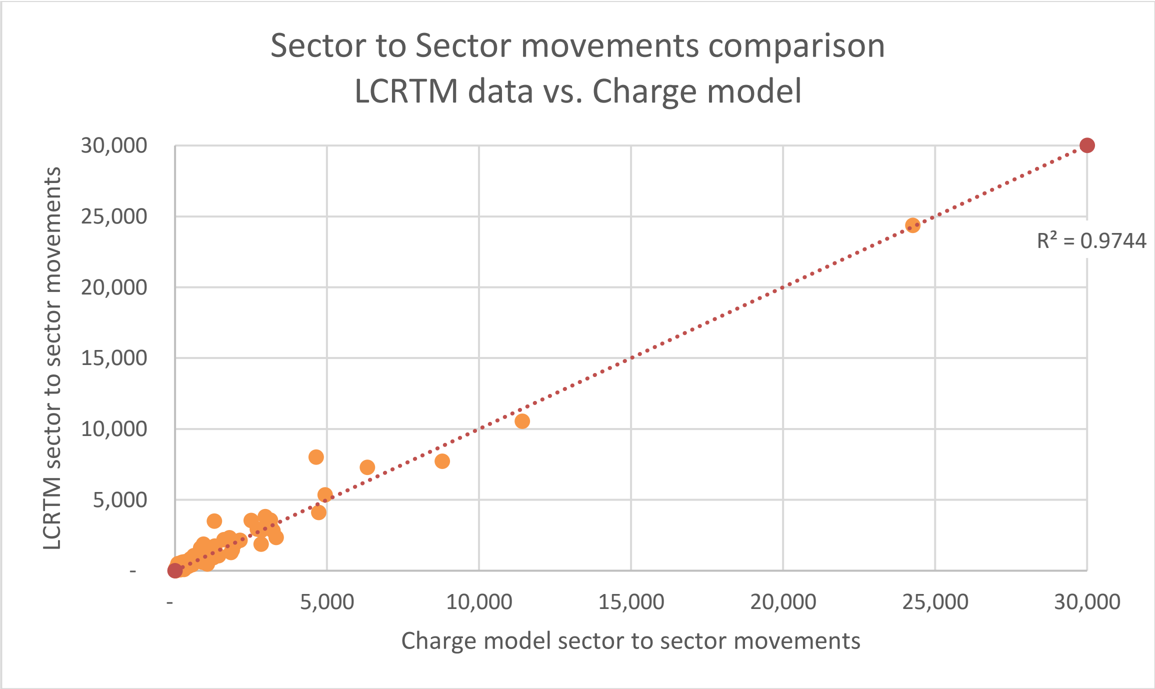


Figure 29: Sector to sector movements comparison - LCRTM vs Charge model

Table 19: LCRTM sector matrix for Car AM (1 hour)

LCRTM_Car_AM				LCRTM														
No.31		156,687	20,189	Core											External			
		20,379	197,255	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Sum		90%											10%			
				11,127	22,545	11,069	8,700	5,454	12,718	6,138	5,853	40,591	39,761	13,110	8,396	2,101	6,858	2,833
Liverpool_Centre	1	90%	5,745	2,002	1,326	299	194	117	223	48	11	876	270	67	92	27	159	35
Liverpool_2	2		22,389	3,455	7,893	2,925	410	100	233	307	81	4,889	1,219	183	268	59	219	147
Liverpool_3	3		11,627	856	3,706	3,836	58	21	44	463	150	1,239	773	65	160	28	161	65
Wirral_Middle	4		7,594	344	302	88	2,451	897	2,148	6	23	311	90	500	79	156	169	32
Wirral_South	5		6,225	118	199	116	1,392	2,349	864	14	59	42	96	619	67	104	178	9
Wirral_North	6		14,744	999	306	169	2,703	1,126	7,141	10	39	229	125	1,186	111	340	239	20
Halton_North	7		6,244	79	423	576	5	8	9	2,323	376	506	1,178	122	212	46	359	20
Halton_South	8		5,695	14	56	82	30	34	3	506	1,725	164	1,421	131	435	65	933	96
Liverpool_North	9		43,599	2,165	6,065	1,677	294	85	130	382	209	26,209	3,029	61	1,128	46	427	1,692
Warrington_St.Helens	10		39,362	394	1,311	564	91	42	69	1,157	1,651	2,742	22,863	201	5,574	153	1,870	680
Chester	11		13,651	75	150	90	518	320	1,225	148	169	133	311	6,985	269	1,077	2,144	37
Salford	12	10%	9,105	222	355	244	136	34	93	151	442	1,515	5,636	278	303,219	349	16,268	10,426
North Wales	13		1,564	55	58	28	63	99	176	45	48	39	133	821	221	32,815	6,067	44
South England	14		7,414	271	320	331	320	217	338	552	804	434	1,960	1,864	15,308	4,789	90,083	1,091
Others	15		2,297	78	75	44	34	5	22	26	68	1,262	656	26	11,829	38	1,298	89,403

Table 20: Charge model sector matrix for Car AM (1 hour)

Car_AM _Avg1hr				CHARGE MODEL														
10		152,365	17,375	Core											External			
		18,712	188,453	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Sum		91%											9%			
				8,302	23,390	10,596	7,275	6,910	12,566	6,397	5,983	42,974	37,744	8,942	7,735	1,959	5,490	2,190
Liverpool_Centre	1	90%	3,815	1,142	1,398	169	282	88	183	23	9	398	70	10	23	5	11	4
Liverpool_2	2		20,312	2,877	9,621	1,955	301	109	194	257	102	3,697	805	26	224	20	86	37
Liverpool_3	3		11,031	609	2,899	4,148	42	20	24	666	227	1,064	943	26	193	27	128	15
Wirral_Middle	4		6,052	460	417	42	2,300	767	1,514	8	11	154	32	170	16	77	82	3
Wirral_South	5		7,759	330	252	34	1,191	2,996	1,177	17	42	85	58	906	38	306	323	2
Wirral_North	6		14,486	527	509	52	2,434	1,192	8,095	16	37	211	68	722	47	288	282	5
Halton_North	7		6,977	124	455	1,037	9	11	9	2,056	476	550	1,692	41	261	37	197	21
Halton_South	8		6,103	48	157	323	13	33	23	558	2,556	192	1,028	148	246	95	672	13
Liverpool_North	9		45,826	1,568	5,696	1,138	161	58	106	458	187	29,804	2,902	33	1,701	37	296	1,682
Warrington_St.Helens	10		37,899	336	1,304	1,179	35	39	36	1,711	1,075	3,173	21,561	142	4,875	116	1,918	400
Chester	11		9,480	73	65	44	262	1,018	740	55	152	44	172	4,290	111	952	1,495	7
Salford	12	10%	9,309	83	359	225	15	25	23	269	250	1,874	6,095	90	108,613	164	6,865	2,697
North Wales	13		2,142	41	50	47	120	291	245	52	115	58	182	940	415	82,639	7,200	38
South England	14		5,387	62	149	188	105	262	193	236	733	257	1,812	1,392	5,423	4,645	136,644	162
Others	15		1,874	22	58	17	4	2	4	16	10	1,413	322	6	2,789	19	298	20,383

9.5. Network Model Validation

As shown in Figure 20 in section 6.1, the demand model is run in a loop with the network model so that updated costs of travel (congestion effects) can be fed back into the demand calculations. After a final output of the demand model, the latest patterns are reassigned onto the network and are presented in this section.

For TAG compliant transport assessment models, typically the model calibration and validation efforts are focussed on closely reproducing traffic flows on individual roads. This is because the most frequent use of transport models is to assess the potential impacts of road schemes.

However, the focus of the Charge model is on overall travel demand patterns, tour patterns, and scenario-based forecasts. Traffic counts therefore have *not* been used as a calibration source. Instead, we use this information to check that the general volume and movements of demand are correct.

For this purpose, we have compared a single time period, the AM average hour network model (the 1-hour average in the period 7AM – 10AM) to equivalent counts. These counts have been collated across the region, including:

- LCRTM bespoke traffic survey counts: in addition to the model output matrices which are used for comparison in section 9.4, the Liverpool City Region Authority provided us with traffic counts that had been collected to inform the LCRTM. This data was collected in 2017 and covers 993 sites (where separate sides of the same road are classified as unique counts).
- WebTRIS[21] strategic road network counts: permanent traffic count sites maintained and collected by Highways England which cover traffic flows on most major motorways and some trunk roads. We have used data collected in 2017 and 2018 at 101 sites.
- DfT Road Traffic statistics[22]: A mixture of observed and estimated counts for various road types across the country. These counts are provided as annual traffic counts, averaged to represent a typical day. We have used data from 721 sites across the model based on 2018 data.
- Denbighshire Local Authority local traffic counts: As a stakeholder to the Charge project, Denbighshire Local Authority provided traffic counts covering their region. The data was collected between 2014 and 2018 across 565 sites.

Figure 30 shows the locations of all the counts across the region that have been used in the comparison with the model results for the AM period.

[21] http://webtris.highwaysengland.co.uk/
[22] https://roadtraffic.dft.gov.uk/downloads

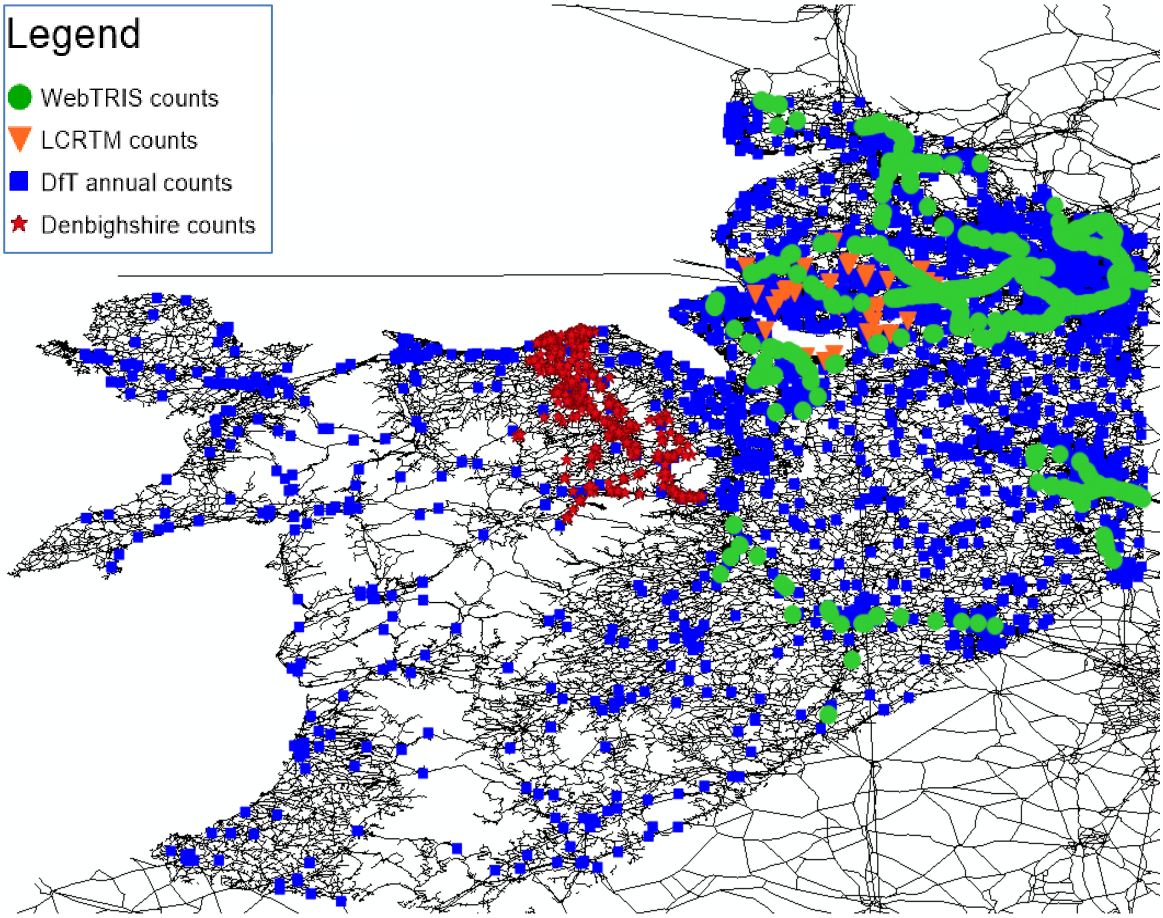


Figure 30: Count locations across model area

Sector Level Aggregated Count Comparison

At an overall level, we have aggregated traffic counts by Local Authority region and compared the observed totals against the model totals in that area. Figure 31 shows this comparison for all counts and all road types by region. This analysis is heavily skewed by the number and type of roads included, and as can be seen, Warrington has the highest observed traffic flow due to the number of motorways that pass through the area. Figure 32 therefore shows the comparison if motorways are excluded.

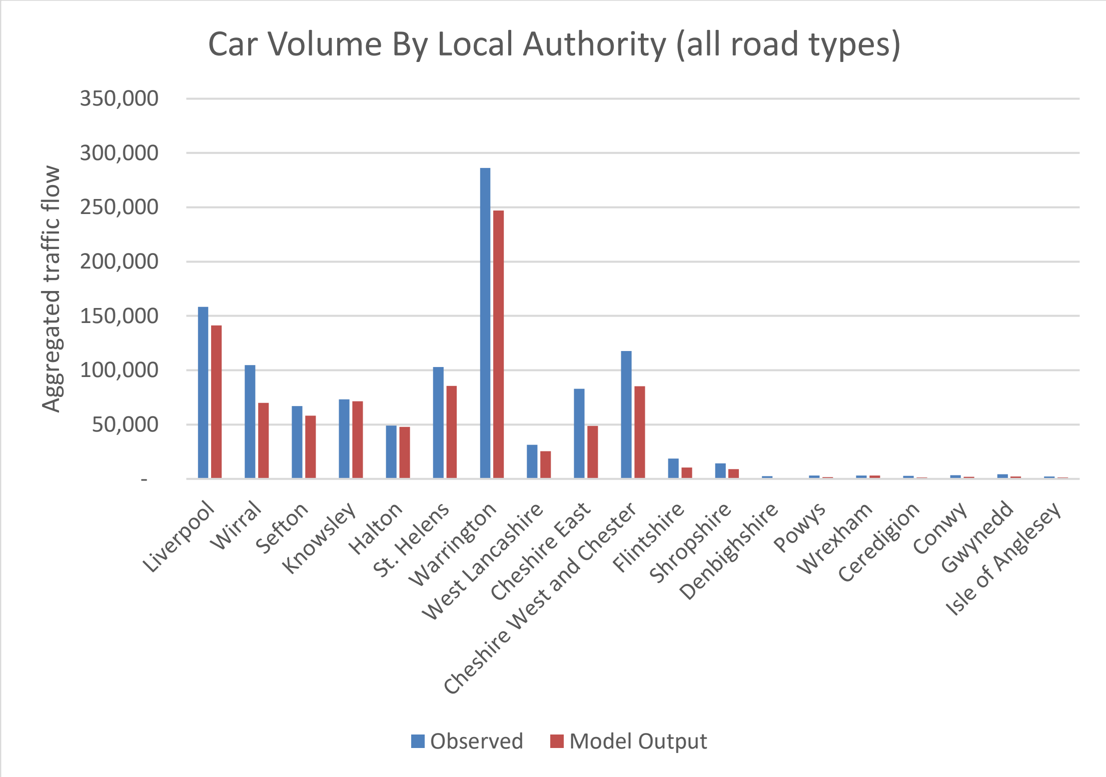


Figure 31: Traffic Levels Comparison for the AM average hour (all road types)

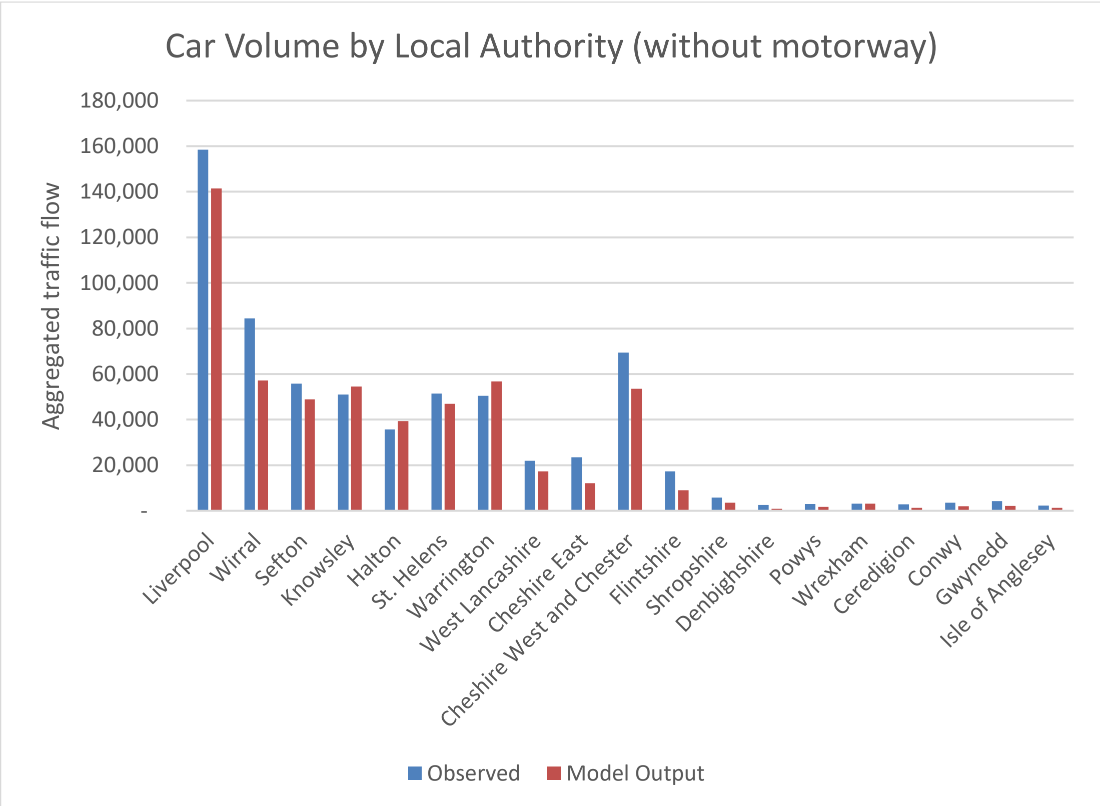


Figure 32: Traffic Level Comparison for the AM average hour (without motorway)

Figure 33 shows a similar comparison for the whole model region split by road type. As in Figure 31 and Figure 32, the Charge model produces slightly less traffic than is observed. We believe this is due to a combination of reasons:

- We have not included through-trips in the network model, that is, trips which pass through the model area but are not generated within Manweb. These longer distance trips typically travel on the motorway network which helps explain why counts are lower on this road type.
- We do not model external trips that are generated outside of the core area and travel into the internal region. The use of the intermediate area helps to mitigate the effect of this, but count comparisons around the periphery of the model indicate that the model does not represent all traffic in these areas.
- Intrazonal trips, i.e. trips that stay within the origin zone, get created by the demand model but do not get assigned onto the network. In some areas where model zones are larger, the proportion of modelled intrazonal car trips is >30%. In such cases, these shorter trips do not create traffic on the network that can be compared to observed counts.
- The counts are obtained from different sources and are likely to contain inconsistencies in accuracy.

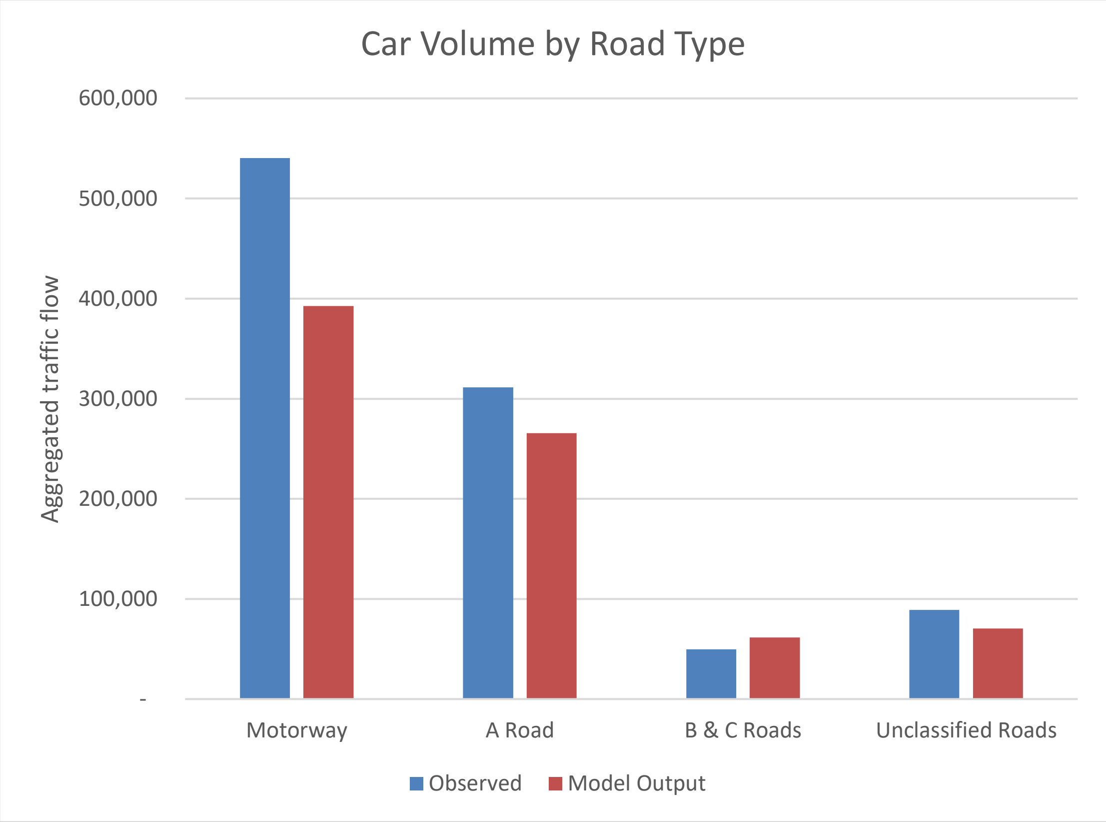


Figure 33: Traffic Level Comparison for the AM average hour by Road type

Count Cordon Comparisons

The count comparisons above consider all traffic flows in varying directions and rely on accurate trip routing in the model representing local conditions (which is not always the case in a model of this size). As a result, there are cases where the model assigns traffic along a parallel route to one that is used more often in reality. To help combat this effect when comparing, count **cordons** can be constructed to capture all flow moving into or out of a particular area, regardless of the particular roads that are being used. The traffic surveys carried out for LCRTM specified these locations such that cordons could be constructed to observe all movements into or out of a particular area. The locations of these cordons are shown in Figure 34.

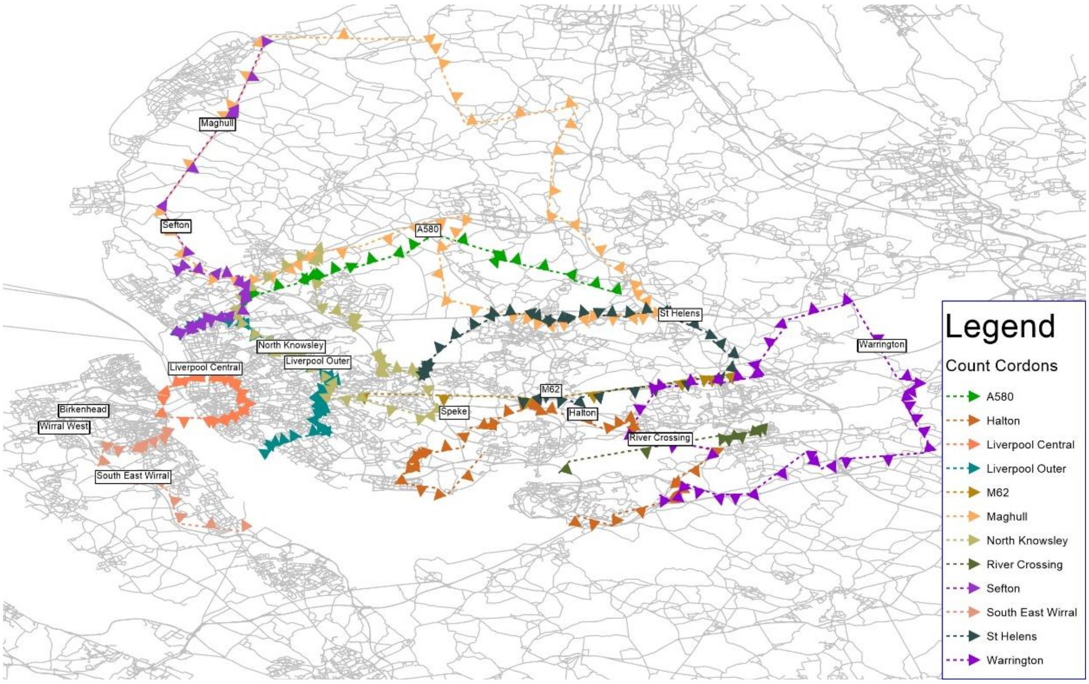


Figure 34: Count Cordon locations around Liverpool

Figure 35 shows the comparison of observed traffic against model flow for the cordons defined above. Here, the model flows are relatively close to the observed values and overall, the difference in flow is only 1% out (~245,000 car movements observed vs ~247,000 estimated by the model). This suggests that the model is accurately representing the arrival and departure of trips in and around the Liverpool area.

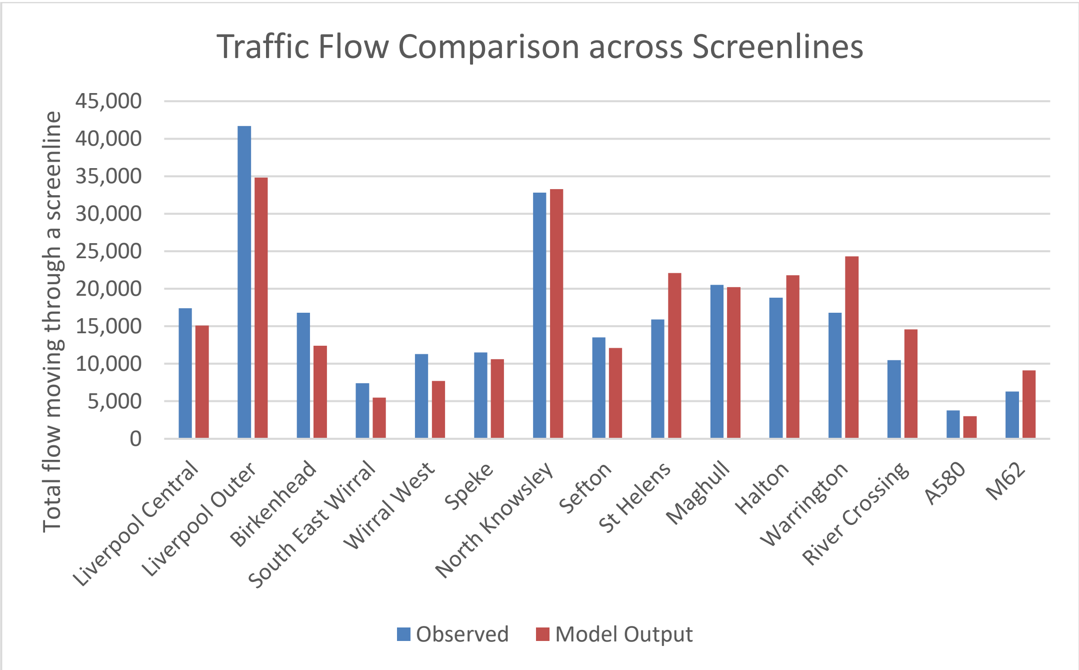


Figure 35: Flow Difference across Screenlines (AM average hour)

10. Summary

10.1. Transport Model Build

This report describes how the Charge transport model has been built, calibrated, and validated using a wide range of input and comparison data. The Charge model fuses this data and various components in demand and network models to form a variable demand model. This has been built using best practice in PTV's Visum software, and has the following characteristics:

- Ability to represent traffic and movements across the Manweb region
- Contains current population distributed at the LSOA level and split into various person groups based on location, employment status, car ownership, and income
- Represents people's movements as daily tours, which comprise a sequence of activities (i.e. Home to Work to Shopping to Home)
- Contains a detailed geo-referenced network model containing a road network with link types, speed, and capacity; and a public transport network containing routes, services, and timetables
- Contains an intermediate and external region covering the rest of the UK to allow for the representation of trips out of and back to Manweb
- Is controlled with a sophisticated demand model which produces trips according to the interaction of population, land use, and the utility of travel
- Allows for the output of key indicators at a zonal level, including the trip length distribution of trips entering and leaving the zone, the time of day that trips arrive and depart, the mode of transport used, and the purpose of the trip being undertaken

10.2. Model Calibration and Validation

The priority with the Charge transport model is to assess a range of future forecast scenarios to understand how car usage is likely to affect the demand for electricity in the coming years. So that the model can be used to produce these forecasts, it is important that the trip patterns in the base year are representative of the local population and that the model is reliably sensitive to changes that will be assumed for future scenarios. To achieve this, the base model has firstly been calibrated and adjusted through a series of steps as explained in section 8. The model has then been validated by comparing the model outputs to a range of independent data sources as described in section 9. The calibration and validation steps help demonstrate that the model is:

- Reproducing the scale of trip making within the model area that is commensurate with the population and the activities that take place in the region.
- Reliably reproducing aggregate trip distribution patterns across the model area for a typical weekday
- Producing a representative number of car trips by various trip purposes

- Accurately representing car trip lengths for various purposes

These results suggest the model is suitable for the purposes of the Charge project, including:

- Representing the share of trips that take place by car
- Forecasting the daily distances that are likely to be driven by electric vehicles in the future
- Forecasting the trip patterns of cars throughout the day, including where they are likely to reside at various times of day (i.e. at home, work, or elsewhere)

10.3. **Forecasting and Scenario Modelling**

With the base model complete, our next steps are to create future scenarios and model the impact of electric vehicles. This will involve creating a model variation for each scenario where different input values have been changed and the outputs are compared.

We expect that each scenario identified in the Scenario Planning Framework will be a combination of an underlying future transport scenario, combined with alternative assumptions regarding electric vehicle ownership and charging behaviour as described in Figure 36 below.

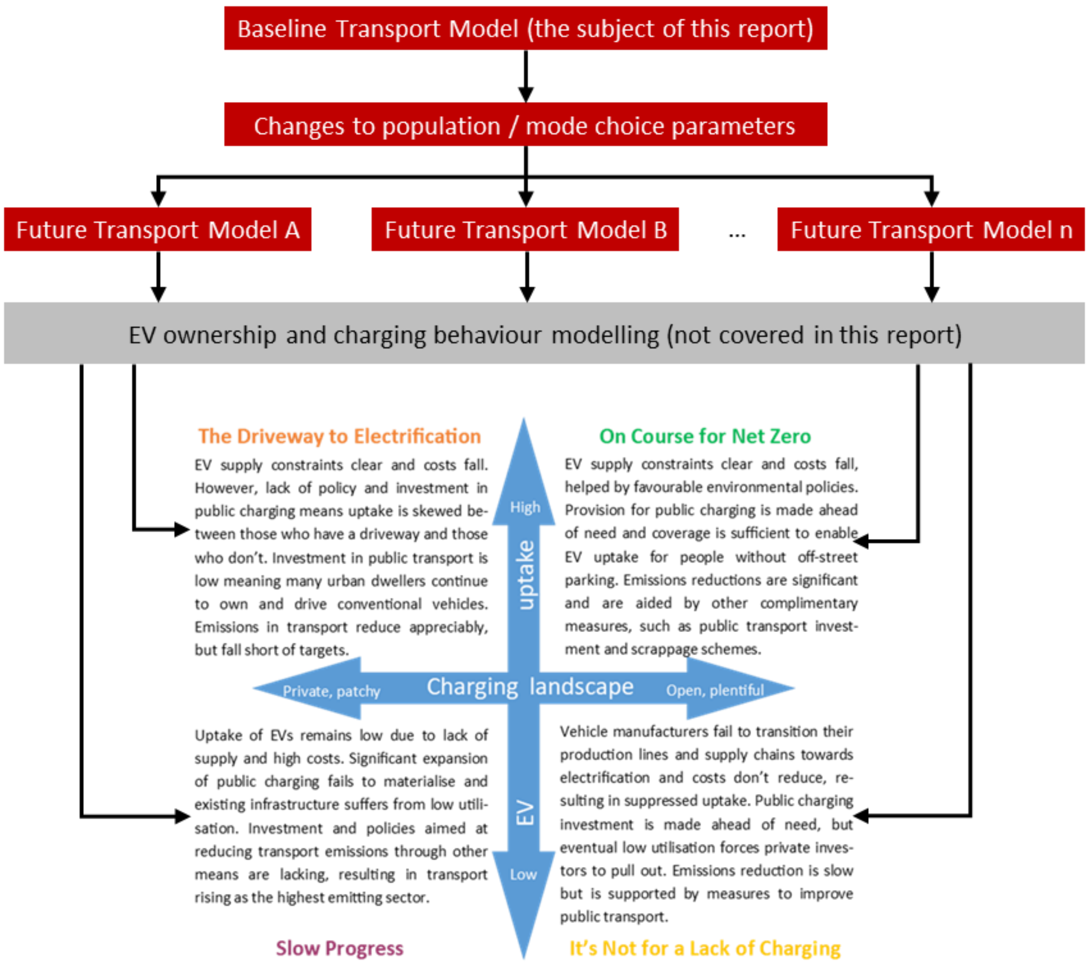


Figure 36: Workflow for Scenario Modelling

The main model inputs that we expect will be adjusted as part of the scenario modelling are the population and mode choice parameters, to reflect fundamental shifts in societal behaviour towards car or public transport. Most of the scenario alternative modelling will involve processing the outputs of the model and modifying the parameters for electric vehicle choice and charging behaviours.

11. Appendix A

This appendix contains the starting parameter values that were used in the Charge demand model prior to calibration. Detail on the purpose of the parameter has also been provided.

In the tables that follow, W stands for Work, B for Business, O for Other, S for Shopping, E for Education and H for Home.

11.1. Fixed Parameters

The following parameters have been kept fixed in the model and have not changed during calibration.

Fixed Parameter – Value of Time

Values of time (VOT) represent how valuable a person's time is, in relation to the purpose of their trip and other costs involved in making the trip. The VOT values used here are a combination of TAG and the PRISM model[23] – a similar strategic transport model for the West Midlands which splits VOT by income bands. Our starting VOT values are shown in Table 9. These values imply that business, work, and education are more sensitive to travel time than shopping and other. It is also assumed that higher income person groups have higher VOTs and thus are more likely to choose a faster option.

Table 9: VOT values in the Charge model

	Charge Values (£p/h)					
Income	**W**	**B**	**O**	**S**	**E**	**H**
Low	9.64	18.27	3.93	2.98	13.45	6.44
Medium	11.56	18.27	4.71	3.56	13.45	7.70
High	15.12	18.27	6.16	4.67	13.45	10.03

Fixed Parameter – Vehicle Operating Cost

Vehicle Operating Costs (VOCs) represent the monetary costs incurred by car drivers and passengers and are generally split into fuel and non-fuel components. The fuel component takes into account the cost of each type of fuel and associated taxes, while the non-fuel component includes vehicle maintenance and depreciation. Both of these components are calculated on a per-kilometre basis. The fuel and non-fuel components are further dependent on the average speed of the car along the journey according to the following equation:

$$Cost = Distance \times \left(\frac{a}{v} + b + c \times v + d \times v^2 + a1 + \frac{b1}{v}\right)$$

Where v is the average vehicle speed.

There are two sets of parameter values set out in TAG, or business and non-business travel due to the difference in perception of taxes (fuel for business purposes is VAT-exempt for example) and maintenance costs for the vehicle.

[23] https://www.tfwm.org.uk/media/47391/prism52_modelvalidationreport_v20_20190906.pdf

Table 21 - VOC values in the Charge model

Activity	a	b	c	d	$a1$	$b1$
B	45.399	7.973	-0.084	0.0006	5.757	158.732
E, H, O, S, W	54.478	9.564	-0.101	0.0007	0.000	0.000

Fixed Parameter – Occupancy Rate

The occupancy rate of a vehicle is the average number of people in a car (driver and passengers). This varies by activity and the initial values are set out in TAG, where values are provided for business, commuting, other and the average across all activities.

Table 22 - Occupancy

Activity	Occupancy
B	1.19
H	1.49
W	1.17
E, O, S	1.67

11.2. Variable Parameters

The following parameters have been subject to change during calibration. The values presented here show the starting values that were used.

Variable Parameter – Mode Specific Constants

Mode specific constants are derived parameters representing factors that are not explicitly modelled within the generalised cost equation and are used to influence mode share. These could be factors such as ownership and cost of bikes, comfort or additional features of public transport including WiFi access and charging facilities. These vary by activity and are initially set to 0 and revised during calibration following assessment of mode shares.

Variable Parameter – Cost Damping

Cost damping is a mechanism used to decrease the sensitivity to cost changes with increasing trip length, in other words an additional 10 mins of journey time will have a smaller impact on a journey of 2 hours versus a journey of 15 minutes. It is recommended in TAG that models are initially run without any cost damping, and it is introduced during model development as required if there is a shortage of longer trips. Hence, for the Charge model, the function $IF\left(D > 30, \left(\frac{Distance}{k}\right)^{-\alpha}, 1\right)$ has been implemented to multiply the generalised cost by the damping factor, with initially $\alpha = 0$ to ensure that the factor is 1 in all cases.

Variable Parameter – Mode Sensitivity

The mode sensitivity parameter, λ, represents the sensitivity of mode choice to cost changes. Example parameters are not provided in TAG for a model of this type and hence a heuristic approach was taken to derive the initial parameter values. Experience with similar models was used to inform the patterns of values by activity, where business and work trips have been shown to be less sensitive to cost changes than discretionary trips such as shopping or other.

Table 23: Initial mode sensitivity parameters

Activity	λ
B	0.15
E	0.50
H	0.25
O	0.45
S	0.45
W	0.25

Variable Parameter – Destination Sensitivity

The destination sensitivity parameter, θ, defines the relative sensitivity to cost between mode and destination choice. For example, a value of 1 would indicate that mode choice and destination choice are equally sensitive to changes in cost, while a value less than 1 would suggest that destination choice is less sensitive to cost change. Initially, a value of 1 was input for all activities based on experience with similar models.

Variable Parameter – Public Transport Cost Weights

TAG Unit M3.2[24] sets out the form of the generalised time for a public transport trip, which includes the following time components:

- Walking (access/egress) time
- Wait time
- Interchanges
- In-vehicle time

This guidance suggests that these time components are perceived differently by travellers and hence should be weighted accordingly to derive the overall generalised time. For each component, and indicative range of weighs is defined relative to the in-vehicle time:

- Walk time – 1.5 - 2.0
- Wait time – 1.5 - 2.5
- Interchanges – 5 - 10 minutes per interchange

Initially, the following values were applied:

- Walk time – 2
- Wait time – 2
- Interchanges – 5

[24] https://www.gov.uk/government/publications/webtag-tag-unit-m3-2-public-transport-assignment-modelling

Variable Parameter – Parking Costs

Parking costs are applied to all car journeys in addition to vehicle operating costs. For simplicity, this has been applied as a fixed cost of **£1.50** for every trip. This parameter could have been subject to change but was held constant throughout calibration.

Variable Parameter – Public Transport Fares

Public transport fares could have been changed during calibration but have been held constant because this form of assessment is not a core requirement of the Charge model. Therefore, a simple fare system has been used to define the fare related costs of public transport trips, as follows:

- A minimum fare of **£2.50** is assumed for all trips
- For every trip greater than 12.5kms, a distance-based fare of **£0.20 per km** is applied

As an example of this fare system, the trips in Table 24 have been compared against real fare prices.

Table 24: Example Public Transport Fares

From	To	Distance	Assumed mode	Modelled fare (single)	Real fare (single)
Liverpool	Manchester	55kms	Train	£11	£5 - £15.70 (advance and anytime)[25]
Liverpool	Runcorn	24kms	Train	£4.80	£5.20 (anytime)
Chester	London	326kms	Train	£65	£36 - £151.50 (advance and anytime)
Caernarfon	Bangor	15kms	Bus	£3 (or £6 return)	£6 (Daysaver)[26]

[25] http://ojp.nationalrail.co.uk/service/timesandfares/Liverpool/MAN/tomorrow/0830/dep

[26] https://www.arrivabus.co.uk/wales/bus-tickets/multi-journey-saver-tickets-in-wales/

12. Appendix B

This appendix provides validation comparisons to highlight how the distribution of trips in the Charge model compares to observed or external sources of data.

12.1. Mobile Phone Sector Comparisons

The following tables show the sector to sector movements for mobile phone data, compared to the Charge model. A more detailed description of this analysis can be found in section 9.4.

Interpeak Period Comparisons

These matrix comparisons represent the pattern of movements on a typical weekday between 10AM – 4PM.

MND_Road_IP				MOBILE PHONE DATA										
No. 20	Intra-sector vv	**591,112**	137,208	Core										
	381,705	128,468	**856,788**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**5.1**	**5.2**	**6.1**	**7.1**
		Sum		84%										
				92589	115441	46151	62256	39095	41606	64412	28715	29899	75855	123561
Chester	2.1		94109	40,717	14,077	4,651	12,452	6,404	1,061	464	198	35	1,563	2,522
The Wirral	2.2		115423	13,404	65,873	1,676	1,410	3,292	436	232	85	24	287	687
Northwich	2.3		47133	4,689	1,823	17,737	523	194	143	101	35	5	282	9,634
Wrexham	3.1		62674	12,472	1,483	488	33,650	3,094	809	362	1,096	69	5,351	718
Clwyd	3.2		39214	6,252	3,357	171	3,111	14,726	7,779	823	160	10	162	156
Llandudno	4.1	85%	40754	944	393	101	734	7,587	21,752	6,490	645	32	139	138
Anglesey	4.2		64541	438	276	94	324	789	6,739	50,269	3,317	92	131	147
Central Mid Wales	5.1		28894	249	88	31	1,035	180	738	3,468	13,480	3,000	4,631	64
South Mid Wales	5.2		30593	36	21	5	72	20	48	135	3,102	18,812	391	17
Shropshire MND	6.1		76402	1,520	285	250	5,294	184	181	140	4,706	434	41,883	2,369
Cheshire East MND	7.1		128583	2,607	752	9,609	804	207	160	128	68	17	2,499	62,806

Car 10:00:00-16:00:00				CHARGE MODEL (Trips >4km)										
603	Intra-sector vv	**484,989**	76,032	Core										
	357,919	78,551	**639,572**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**5.1**	**5.2**	**6.1**	**7.1**
		Sum		88%										
				62,195	84215.9	39714.15	51,752	30,164	26897.32	52724.59	31,662	32,093	60383.47	91,738
Chester	2.1	88%	63639.98	30,107	10,206	3,398	9,173	4,377	230	36	131	13	1,187	1,160
The Wirral	2.2		84,629	10,405	60,180	1,117	706	658	77	24	37	5	111	227
Northwich	2.3		39,861	3,108	1,006	17,184	289	73	14	3	11	1	149	8,330
Wrexham	3.1		51720.52	8,384	682	293	32,100	2,123	415	30	1,054	69	4,499	360
Clwyd	3.2		30388.55	4,197	610	66	2,065	18,338	4,321	120	113	4	44	30
Llandudno	4.1		26,624	184	60	11	336	3,821	18,701	2,586	524	4	16	8
Anglesey	4.2		52,256	28	18	3	23	90	2,243	48,751	829	4	5	2
Central Mid Wales	5.1		31596.53	87	25	8	714	74	471	899	21,729	2,232	2,951	16
South Mid Wales	5.2		30706.38	9	6	1	29	3	4	5	1,551	26,416	338	2
Shropshire MND	6.1		58814.67	905	98	149	4,128	47	19	6	3,223	395	37,353	1,203
Cheshire East MND	7.1		90,785	1,078	226	7,886	385	35	10	3	22	3	1,292	47,061

Afternoon Peak Period Comparisons

These matrix comparisons represent the pattern of movements on a typical weekday between 4PM – 7PM.

MND_Road_PM				MOBILE PHONE DATA										
No. 22	Intra-sector vv	**337,132**	79,112	Core										
	214,849	85,670	**501,914**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**5.1**	**5.2**	**6.1**	**7.1**
		Sum		84%										
				52285	75459	29944	37789	22638	21233	31638	15071	14428	45524	76793
Chester	2.1		60232	24,016	10,344	3,169	8,359	4,607	677	230	135	9	1,161	1,667
The Wirral	2.2		67633	7,051	38,834	1,141	927	1,888	167	97	37	6	154	389
Northwich	2.3		26283	2,227	1,003	9,727	374	105	47	24	5	1	179	5,865
Wrexham	3.1		36993	7,180	991	363	20,085	1,882	441	110	680	25	3,434	426
Clwyd	3.2		21500	3,408	2,084	99	1,708	8,186	4,438	413	103	3	81	69
Llandudno	4.1	83%	20416	472	217	36	377	4,158	11,077	3,010	347	8	65	58
Anglesey	4.2		32218	209	94	28	142	391	3,418	25,637	1,619	38	45	36
Central Mid Wales	5.1		13635	83	26	15	465	73	274	1,413	6,850	1,496	2,333	24
South Mid Wales	5.2		14084	9	4	2	10	9	14	35	1,467	9,181	132	3
Shropshire MND	6.1		43323	800	125	128	3,148	63	55	31	3,048	181	23,845	1,230
Cheshire East MND	7.1		79927	1,435	517	6,383	547	97	34	47	24	4	1,748	37,411

Car 16:00:00-19:00:00				CHARGE MODEL (Trips >4km)										
604	Intra-sector vv	**333,681**	51,045	Core										
	234,506	74,159	**458,885**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**5.1**	**5.2**	**6.1**	**7.1**
		Sum		89%										
				44,874	64582.2	30428.25	36,892	21,397	19721.94	34783.5	21,193	21,733	43106.44	69,129
Chester	2.1		47208.63	19,931	8,781	2,618	7,099	3,797	312	34	107	9	705	865
The Wirral	2.2		58,586	7,327	41,592	981	749	733	93	19	38	4	110	215
Northwich	2.3		27,220	2,319	918	10,716	306	92	16	3	12	1	124	5,653
Wrexham	3.1		35254.34	6,457	780	336	20,533	1,779	407	28	600	27	2,904	328
Clwyd	3.2		20746.54	2,878	555	64	1,527	11,673	3,505	108	78	3	37	24
Llandudno	4.1	84%	17,965	156	46	9	248	2,571	12,637	1,739	340	3	12	6
Anglesey	4.2		34,764	16	8	2	17	77	1,995	31,915	593	3	3	1
Central Mid Wales	5.1		19990.27	65	16	6	609	59	422	742	13,652	940	2,204	10
South Mid Wales	5.2		20238.85	3	1	0	15	2	5	8	1,542	17,199	377	1
Shropshire MND	6.1		38952.45	859	115	193	3,711	63	24	6	2,317	218	23,409	1,129
Cheshire East MND	7.1		63,800	1,073	279	6,432	442	45	11	3	24	3	886	31,250

Off-Peak Period Comparisons

These matrix comparisons represent the pattern of movements on a typical weekday between 7PM – 7AM.

MND_Road_OP				MOBILE PHONE DATA										
No. 21	Intra-sector vv	**252,003**	61,283	Core										
	163,812	65,866	**379,152**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**5.1**	**5.2**	**6.1**	**7.1**
		Sum		84%										
				43242	55706	21891	29450	16764	13458	23371	10332	9912	32734	61009
Chester	2.1	83%	44317	19,926	6,746	2,126	6,112	3,104	304	158	70	14	620	1,074
The Wirral	2.2		54374	6,416	29,276	891	629	1,683	126	82	20	8	106	384
Northwich	2.3		20811	1,641	677	7,479	255	51	12	35	12	2	96	4,641
Wrexham	3.1		29855	5,974	597	340	16,509	1,266	177	119	403	23	2,502	394
Clwyd	3.2		16851	2,846	1,792	92	1,264	6,419	3,021	277	58	7	53	62
Llandudno	4.1		13670	351	112	36	228	2,889	7,299	2,013	179	7	31	48
Anglesey	4.2		22993	145	77	25	80	258	1,805	18,786	1,151	17	40	41
Central Mid Wales	5.1		9798	81	23	10	298	40	127	1,003	4,736	961	1,873	16
South Mid Wales	5.2		9624	10	2	1	24	2	8	23	919	6,429	93	5
Shropshire MND	6.1		32994	654	100	102	2,447	58	32	55	2,144	128	18,018	1,116
Cheshire East MND	7.1		57999	862	253	4,336	276	46	32	49	19	6	1,062	28,935

Car 19:00:00-07:00:00				CHARGE MODEL (Trips >4km)										
601 + 605	Intra-sector vv	**214,557**	40,162	Core										
	151,107	42,435	**297,154**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**5.1**	**5.2**	**6.1**	**7.1**
		Sum		86%										
				29,781	40000.8	18749.01	23,510	13,375	12389.78	22590.3	13,365	13,748	26624.72	42,857
Chester	2.1		29608.09	12,847	5,152	1,627	4,468	2,092	142	15	53	3	481	631
The Wirral	2.2		39,887	5,209	27,110	627	503	414	42	8	16	1	74	163
Northwich	2.3		18,489	1,559	583	6,891	208	49	8	2	6	1	109	3,992
Wrexham	3.1		23035.37	4,294	482	210	13,228	980	202	14	375	10	2,185	268
Clwyd	3.2		13928	2,230	420	52	1,183	7,552	2,094	57	43	1	34	23
Llandudno	4.1	86%	11,934	156	46	8	212	1,837	8,147	1,137	241	3	12	6
Anglesey	4.2		22,669	16	8	2	15	59	1,266	20,781	437	4	3	2
Central Mid Wales	5.1		12742.86	51	17	6	340	40	250	426	8,629	786	1,354	12
South Mid Wales	5.2		13319.83	3	2	1	9	1	2	3	627	11,121	164	1
Shropshire MND	6.1		25766.76	468	70	95	2,038	31	11	3	1,489	202	14,706	628
Cheshire East MND	7.1		43,339	593	153	3,802	233	21	5	1	11	1	637	20,095

12.2. LCRTM Sector Comparisons

The following tables show the sector to sector movements for the Liverpool City Region Transport Model compared to the Charge model. A more detailed description of this analysis can be found in section 9.4.

Interpeak Period Comparisons

These matrix comparisons represent the pattern of movements on a typical weekday between 10AM – 4PM.

LCRTM_Car_IP				LCRTM														
No.32		**124,981**	14,401	Core											External			
		14,190	**153,571**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
		Sum		91%											9%			
				8,144	18,601	8,997	6,631	4,852	11,507	3,554	3,247	33,939	28,979	10,719	5,560	1,468	5,516	1,858
Liverpool_Centre	1	91%	8,117	3,026	2,416	430	191	93	230	22	6	1,098	236	32	130	21	155	31
Liverpool_2	2		19,836	2,366	7,806	3,008	179	66	191	159	41	4,722	678	59	198	36	219	107
Liverpool_3	3		8,910	502	2,867	3,170	26	13	27	381	131	822	482	70	155	19	192	53
Wirral_Middle	4		6,691	225	175	38	2,251	1,038	2,191	3	14	118	40	298	43	101	137	19
Wirral_South	5		4,769	86	83	23	1,173	2,053	704	6	13	40	33	327	36	64	124	3
Wirral_North	6		11,363	320	134	37	2,033	944	6,604	7	11	85	32	749	55	167	166	18
Halton_North	7		3,438	34	155	361	6	4	4	1,144	320	235	769	43	130	20	186	27
Halton_South	8		3,257	3	22	53	17	18	6	317	1,049	59	751	122	167	39	609	25
Liverpool_North	9		33,028	1,030	3,711	876	136	51	174	214	73	22,441	1,818	42	955	28	494	985
Warrington_St.Helens	10		29,135	226	708	533	35	15	39	826	816	1,796	18,437	136	3,392	104	1,521	553
Chester	11		10,837	22	42	65	308	338	853	33	80	39	149	5,993	298	868	1,713	36
Salford	12	9%	5,987	128	183	140	54	25	60	118	147	1,027	3,794	311	256,624	356	11,639	10,281
North Wales	13		1,353	18	28	26	62	56	196	22	37	27	127	753	350	27,520	3,719	66
South England	14		5,183	139	223	211	146	132	207	280	489	430	1,167	1,760	12,451	4,532	72,765	1,265
Others	15		1,667	21	48	27	15	4	20	21	20	999	467	25	10,311	43	1,748	73,828

Car_IP _Avg1hr				CHARGE MODEL														
11		**136,501**	12,184	Core											External			
		11,118	**159,804**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Sum		92%											8%			
				4,727	20,082	9,613	6,077	6,394	11,839	5,686	5,096	38,036	32,118	7,951	6,257	1,159	3,604	1,165
Liverpool_Centre	1	93%	5,019	1,151	1,949	289	243	146	206	39	14	777	112	22	30	13	21	7
Liverpool_2	2		20,455	1,843	9,974	2,252	267	134	231	239	75	4,418	713	25	175	20	64	25
Liverpool_3	3		9,538	252	2,097	4,190	25	16	22	791	202	873	817	17	124	17	86	8
Wirral_Middle	4		6,223	267	278	26	2,483	929	1,867	4	5	104	16	137	10	48	46	2
Wirral_South	5		6,372	133	127	15	884	2,993	963	6	18	43	21	828	21	158	161	2
Wirral_North	6		11,790	201	223	21	1,829	968	7,598	5	12	89	22	556	23	127	113	3
Halton_North	7		5,694	30	215	731	4	6	6	2,098	498	308	1,455	25	157	20	130	9
Halton_South	8		5,125	11	71	194	5	17	13	486	2,649	100	806	85	146	47	490	6
Liverpool_North	9		38,195	685	4,267	890	100	45	94	324	100	27,061	2,179	18	1,320	23	169	921
Warrington_St.Helens	10		32,353	87	632	781	16	21	24	1,387	771	2,051	20,923	71	4,185	68	1,161	176
Chester	11		7,922	16	22	16	127	782	542	24	91	17	74	4,357	67	619	1,163	5
Salford	12	7%	5,429	22	136	106	9	20	24	132	127	1,191	3,601	61	97,447	326	4,235	1,877
North Wales	13		1,119	8	15	14	41	156	129	18	44	20	58	615	324	72,420	3,946	34
South England	14		3,511	14	56	79	42	158	117	123	484	163	1,144	1,130	4,508	4,127	117,940	173
Others	15		1,059	5	22	8	2	1	3	9	6	821	177	5	1,827	33	162	18,378

Afternoon Peak Period Comparisons

These matrix comparisons represent the pattern of movements on a typical weekday between 4PM – 7PM.

LCRTM_Car_PM				LCRTM														
No.33		173,769	22,194	Core											External			
		23,540	219,504	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Sum		90%											10%			
				9,282	26,950	12,609	8,148	6,837	15,893	7,103	5,927	46,762	42,625	15,175	9,085	2,265	7,841	3,003
Liverpool_Centre	1	89%	13,045	3,491	3,551	866	357	225	817	85	11	2,189	622	92	282	68	319	68
Liverpool_2	2		27,703	2,322	10,529	3,806	387	169	476	300	67	7,289	1,254	176	361	85	322	161
Liverpool_3	3		12,582	598	3,535	4,097	49	50	81	642	186	1,736	916	147	178	58	224	86
Wirral_Middle	4		9,506	255	296	92	2,848	1,622	2,921	5	39	223	104	545	94	181	258	24
Wirral_South	5		5,939	129	154	90	1,218	2,334	1,051	12	31	71	56	467	31	98	186	12
Wirral_North	6		13,130	480	177	138	1,882	1,124	7,715	14	7	80	52	994	46	234	179	7
Halton_North	7		6,407	39	382	610	4	8	13	2,134	597	603	1,277	96	149	80	367	49
Halton_South	8		5,940	2	55	79	28	34	29	544	1,873	150	1,264	197	458	120	1,005	100
Liverpool_North	9		42,802	1,064	5,336	1,354	289	85	301	424	181	27,143	2,819	91	1,536	70	597	1,511
Warrington_St.Helens	10		43,200	485	1,875	961	107	57	115	1,466	1,546	3,127	24,365	255	5,613	221	2,069	936
Chester	11		15,709	78	149	112	552	724	1,592	220	127	123	273	8,009	336	1,050	2,314	49
Salford	12	11%	10,348	121	402	162	110	47	137	241	353	1,608	6,747	420	350,494	648	17,534	14,906
North Wales	13		2,313	45	74	28	69	147	218	112	77	35	214	1,293	380	37,551	4,390	75
South England	14		7,911	156	369	183	232	203	402	855	777	439	1,938	2,358	19,217	7,279	100,130	1,547
Others	15		2,969	18	67	30	15	6	24	48	56	1,946	727	33	14,688	56	1,757	100,821

Car_PM _Avg1hr				CHARGE MODEL														
12		169,521	17,889	Core											External			
		18,321	205,732	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Sum		91%											9%			
				4,582	24,471	12,354	7,305	8,537	15,769	7,355	6,688	49,334	41,284	10,163	8,243	2,157	5,842	1,646
Liverpool_Centre	1	91%	8,660	1,293	3,130	625	441	323	495	118	46	1,602	324	70	79	36	57	19
Liverpool_2	2		26,097	1,786	11,420	2,962	443	262	504	432	159	6,320	1,228	63	278	44	142	54
Liverpool_3	3		12,022	243	2,500	4,719	45	35	52	1,050	342	1,298	1,258	43	192	42	188	16
Wirral_Middle	4		8,156	200	335	46	2,833	1,305	2,701	9	12	175	34	270	16	114	102	4
Wirral_South	5		7,819	101	148	24	995	3,327	1,426	11	32	68	37	1,056	27	297	267	2
Wirral_North	6		13,927	143	235	29	1,948	1,321	8,791	9	23	125	36	789	29	246	199	4
Halton_North	7		6,975	31	310	885	8	17	16	2,132	636	512	1,841	56	221	48	247	16
Halton_South	8		6,576	12	121	286	11	43	36	590	2,824	201	1,145	157	222	112	807	11
Liverpool_North	9		46,660	612	4,934	1,243	170	90	213	559	201	32,085	3,213	43	1,771	50	288	1,188
Warrington_St.Helens	10		40,731	93	931	1,130	32	56	65	1,874	1,175	3,129	24,259	165	5,323	164	2,010	324
Chester	11		9,787	14	31	29	196	1,060	837	45	142	34	131	4,635	87	1,003	1,536	7
Salford	12	9%	8,127	27	219	192	16	37	45	250	240	1,793	5,200	107	119,021	474	6,257	2,881
North Wales	13		2,078	7	20	26	80	325	298	37	96	35	114	1,041	361	87,085	5,371	38
South England	14		5,922	14	94	142	85	335	284	216	747	306	2,038	1,659	7,225	7,138	145,807	338
Others	15		2,194	6	41	16	3	2	5	22	13	1,652	425	8	3,087	46	220	22,263

13. Appendix C

13.1. Tour types

The following table shows the full set of tour types and the proportion represented in the Charge model. Tours are represented as starting and ending at home, where H is equivalent to Home, W (Work), O (Other), B (Business), S (Shopping), and E (Education).

Table 25: The set of tour types in the Charge model

Tour Type	Percentage of tours among population
HOH	32.57%
HWH	19.83%
HEH	16.86%
HSH	13.24%
HOOH	4.87%
HBH	3.60%
HOSH	2.28%
HWOH	2.04%
HEOH	1.36%
HOOOH	0.89%
HSOH	0.77%
HWSH	0.76%
HSSH	0.56%
HBBH	0.16%
HESH	0.06%
HEEH	0.05%
HOEH	0.04%
HOSOH	0.03%
HESEH	0.01%
HEEEH	0.01%
HEOOH	0.00%
HOWH	0.00%
HOOEH	0.00%
HEOSH	0.00%
HWSWH	0.00%
HWBH	0.00%
HEWEH	0.00%
HOEOH	0.00%
HOSEH	0.00%
HOOSH	0.00%
Grand Total	**100.00%**

14. Appendix D

14.1. Realism Tests

Realism tests are recommended model tests set out in TAG, which help assess the sensitivity of the model to various cost changes. Results from these tests help provide confidence that the model will still produce sensible results when being used as a forecast model.

There are three realism tests defined in TAG, with a range of target results that are considered plausible to specific interventions:

- Fuel cost increase of 10%. Does the modelling of car trips respond sensibly if the cost of fuel is increased?
- Public transport fare increase of 10%. Does the share of public transport trips respond sensibly if the fare is increased?
- Car journey time increase of 10%. What happens if car trip journey times are artificially increased?

The resulting target values (or elasticity ranges) when compared against the base scenario are benchmarked against values derived from extensive research. The range of elasticity values that are recommended are set out in TAG unit M2 as per the table below.

Table 6.2 Summary of Recommended Elasticity Ranges

	High	Low
Average Fuel Cost (kms)	-0.35	-0.25
PT Main Mode Fare (trips)	-0.9	-0.2
Bus Fare (trips)	-0.9	-0.7
Car Journey Time (trips)	No stronger than -2.0	

In the Charge model, all public transport modes are combined into a single mode. As such, we have not presented results for a bus fare test.

Fuel Cost Test

This test requires that the fuel cost component for car driver and passenger trips is increased by 10% and the demand and network models are iterated until a stable solution is achieved. The difference in vehicle kms is measured, with the elasticity recommended to lie between -0.35 and -0.25. The results of this test are set out in Table 26 below.

Table 26 - Fuel Cost Test Elasticity Values

Study Area Kms	Realism (FC +10%)	Base	Elasticity
B	4,282,739	4,391,078	-0.26
E	2,385,583	2,407,955	-0.10
H	33,027,916	34,162,738	-0.35
O	12,675,355	12,980,086	-0.25
S	4,489,556	4,700,908	-0.48

W	12,089,626	12,691,798	-0.51
Total	***68,950,775***	***71,334,563***	***-0.36***

The overall elasticity is -0.36, which is considered plausible given that TAG outlines that areas with longer than average trip lengths, such as in the rural areas of Wales modelled in Charge have a larger than average response. The patterns between activities are also considered plausible, with discretionary trips, such as shopping and other, having a higher elasticity than business trips.

Public Transport Fares Test

This test requires that the Public Transport fares are increased by 10% and the difference in Public Transport trips is measured against the base scenario. As for the fuel cost test, this requires that the demand and network models are iterated. It is recommended that the elasticities lie in the range -0.2 to -0.9, and the results for this test for Charge are presented in Table 27 below.

Table 27 - Public Transport Fare Test Elasticity Values

Study Area Trips	Realism (PT +10%)	Base	Elasticity
B	35,781	37,208	-0.41
E	142,267	142,641	-0.03
H	1,172,607	1,183,413	-0.10
O	281,634	289,973	-0.31
S	158,990	162,348	-0.22
W	276,443	279,657	-0.12
Total	***2,067,723***	***2,095,240***	***-0.14***

The patterns by activity are plausible with discretionary trips affected more than average. The overall value is outside of the recommended value however, suggesting the Charge model does not represent public transport costs sufficiently. However, this is deemed acceptable since the focus of the model is on private road transport instead.

Car Journey Time Test

This test involves increasing the car journey time and running the demand model to analyse the difference in the number of car trips produced. The elasticity results of this test are recommended to be less strong than -2.0 and are shown in Table 28 below for the Charge model.

Table 28 - Car Journey Time Test Elasticity Values

Study Area Trips	Realism (JT +10%)	Base	Elasticity
B	230,823	231,013	-0.01
E	312,815	312,725	0.00
H	3,375,742	3,384,457	-0.03
O	1,714,250	1,721,868	-0.05
S	668,956	670,596	-0.03
W	944,978	946,252	-0.01
Total	***7,247,564***	***7,266,912***	***-0.03***

The results from the Charge model meet the recommendation set out in TAG, with the fairly weak response plausible for a model with higher-than-average trip lengths such as Charge. This shows that the model is not particularly sensitive to changes in journey time, suggesting that the influence of congestion in the model is weak. However, this is deemed acceptable given that the main purpose of the model is to represent journey distances and volumes accurately (which is shown to be the case in sections 9.2, 9.3, and 9.4.