

Cambridge Sub-Regional Model 2

CSRM2 F-series Transport Demand and Public Transport Model Development and Validation Report

Cambridgeshire County Council

May 2022

Notice

This document and its contents have been prepared and are intended solely as information for Cambridgeshire County Council and use in relation to Cambridge Sub-Regional Model 2

Atkins Limited assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

This document has 220 pages including the cover.

Document history

Document title: CSRM2 F-series Transport Demand and Public Transport Model Development and Validation Report

Document reference: P:\GBCBA\HandT\CQ\Projects\5202465-CSRM2 F-Series Base Year-SPOS6932\30 - Documentation\01 MDVR

Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
Rev 1.0	Final for issue (B-series)	RB	TJG	TJG	RLC	19/07/2017
Rev 2.0	C-series final draft for client comments	TJG	NP	CLFL	JML	18/12/2017
Rev 2.1	D-series draft, for review by CCC	YZ, SFA	NP	CLFL	RLC	17/10/2018
Rev 3.0	Final D-series for issue	SFA	NP	NP	RLC	24/10/2018
Rev 5.0	F-series version, for review by CCC	AS	NP	CLFL	RLC	12/10/2021
Rev 5.1	Additional disclaimer text requested by Strava Metro	NP			RLC	25/10/2021
Rev 5.2	F-series update following CCC comments (March 2022)	NP, ART	CLFL	MA	MA	24/05/2022

Client signoff

Client	Cambridgeshire County Council
Project	Cambridge Sub-Regional Model 2
Job number	5202465
Client signature/date	

Contents

Chapter	Page
1. Introduction	10
1.1. Background	10
1.2. Key Model Design Considerations	11
1.3. Proposed Uses of the Model	11
1.4. Report Structure and other CSRM2 documentation	12
2. Model Structure and Definitions	14
2.1. Model Structure and Software	14
2.2. Model Coverage (Study Area)	17
2.3. Model Zoning	20
2.4. Model Components	21
2.5. Dimensions and Units	22
2.6. Model Run Years	22
2.7. Demand Segmentation	23
2.8. TDM Mode Definitions	28
2.9. Choice Model Structure	29
2.10. Time Periods	34
3. Networks and Non-Car Assignment	39
3.1. Overview	39
3.2. Network Definitions and Link Types	44
3.3. Bus and Guided Bus Network and Services	47
3.4. Park & Ride (Bus and Guided Bus) Network and Services	56
3.5. Park & Active (Walk and Cycle) Network	57
3.6. Rail Network and Services	58
3.7. Walk and Cycle	67
3.8. Intrazonal Distances and Times	70
3.9. External Network	72
3.10. Generalised Cost Formulations	72
4. Travel Characteristics	73
4.1. Introduction	73
4.2. Vehicle Operating Cost, Vehicle Occupancies and Values of Time	73
4.3. Parking and Parking Charges	76
4.4. Public Transport Fares	83
For	90
4.5. PT Access and Wait Times	90
4.6. Weighting of Time	91
5. Travel Demand Input	93
5.1. Introduction	93
5.2. Segmented 2011 Population	93
5.3. Derivation of Trip Attractions	96
5.4. Growth from 2011 to 2015 to 2019	98
5.5. Trip Generation	99
6. Implementation of the Transport Demand Model	105
6.1. Discrete Choice Model and Parameters	105
6.2. Walk and Cycle Parameters	106
6.3. Time of Day and Mode Choice Parameters	109

6.4.	Sub-Mode Choice	110
6.5.	Cost Damping	111
6.6.	TDM to SATURN Linkage	112
6.7.	Obtaining Highway Distance, Cost and Time Skims	113
6.8.	Converting Person Trip Matrices by Time Period to Peak Hour Highway Matrices	114
6.9.	Pivoting the Highway Matrix	114
6.10.	Growth Zones	115
6.11.	Smoothing	118
6.12.	Goods Vehicles and External-External Demand	118
7.	Demand Model Calibration and Validation	119
7.1.	Introduction	119
7.2.	Data Availability	120
7.3.	Mode Shares	121
7.4.	Trip Length Distributions	125
7.5.	Comparison of synthetic light vehicle trips with Highway Model	127
7.6.	Realism Testing Methodology	135
7.7.	Realism Test Results	136
8.	Public Transport and Cycle Calibration and Validation	142
8.1.	Introduction	142
8.2.	Data Availability	142
8.3.	Bus	143
8.4.	Park & Ride	151
8.5.	Rail	155
8.6.	Cycle	159
9.	Conclusions	163
9.1.	Summary of Model Development	163
9.2.	Summary of Calibration and Validation	163
9.3.	Conclusion on model uses	164
	Appendices	165
	Appendix A. Glossary	166
	Appendix B. Zone Definitions	168
	Appendix C. Link types and modes	185
	Appendix D. Gamma values used for NHB trip generation	188
	Appendix E. Trip Length Distribution graph comparisons with Census and NTS	201
E.1.	Comparisons between CSRM2 2011 and Census 2011, Home-Based Work	201
E.2.	Comparisons between CSRM2 2011 and NTS 2012-2014, Home-Based Work	205
E.3.	Comparisons between CSRM2 2011 and NTS 2012-14, Employer's Business	208
E.4.	Comparisons between CSRM2 2011 and NTS 2012-2014, Education	211
E.5.	Comparisons between CSRM2 2011 and NTS 2012-2014, Discretionary Purposes	214
	Appendix F. Additional Model Definitions	217
F.1.	Flow Type Definitions	217
F.2.	User Mode Definitions	218

Tables

Table 2-1 - Zone Details	20
Table 2-2 - Dimensions and units	22
Table 2-3 - Trip purposes in TDM	23
Table 2-4 - Purpose segmentation in each sub-model	23
Table 2-5 - Grouped Socio-economic Category (GSeC) defined from NS-SeC	25
Table 2-6 - HBW trips – segmentation by choice stage	26
Table 2-7 - HBEd trips – segmentation by choice stage	26
Table 2-8 - HB and NHB EB trips – segmentation by choice stage	26
Table 2-9 - Discretionary (HBPS, HBRV and NHBO) trips – segmentation by choice stage	27
Table 2-10 - Transport modes in the CSRM2	28
Table 2-11 - Access Modes available for PT Main Modes	29
Table 2-12 - Summary of choices modelled within the CSRM2	30
Table 2-13 - TDM demand units	32
Table 2-14 - Minimum Proportion Values	34
Table 2-15 - Time periods represented by each model component	35
Table 2-16 - Relationship between costs by time of travel and tour cost	36
Table 2-17 - Profile of return trips given time of outbound trip	37
Table 3-1 - 2019 coded schemes	39
Table 3-2 - Stages of travel defined in CSRM	45
Table 3-3 - Outline of link types within multi-modal networks	46
Table 4-1 - Fuel Cost Equation Parameters, 2015 (in 2015 prices)	74
Table 4-2 - Fuel Cost Equation Parameters, 2019 (in 2015 prices)	74
Table 4-3 - Average Network Speeds (kph), 2015 used for VOCs	74
Table 4-4 - Non-Fuel Cost Equation Parameters, 2015 and 2019 (in 2015 prices)	75
Table 4-5 - Vehicle Operating Costs in CSRM2, 2015 (pence per km, in 2015 prices)	75
Table 4-6 - Vehicle Operating Costs in CSRM2, 2019 (pence per km, in 2015 prices)	75
Table 4-7 - Vehicle Occupancies for Years 2015 and 2019	76
Table 4-8 - TDM Base Year (2015) Values of Time (VoT) per person (pence per minute in 2015 prices)	76
Table 4-9 - TDM PYV (2019) Values of Time (VoT) per person (pence per minute in 2015 prices)	76
Table 4-10 - Car park charges in Cambridge (2015 pence)	77
Table 4-11 - Car parking charges in Huntingdonshire (2015 pence)	78
Table 4-12 - Parking charges by geographical area in CSRM2 (2015 pence)	79
Table 4-13 - Parking Searching Time (minutes) by area	79
Table 4-14 - Parking search times at rail stations (minutes)	82
Table 4-15 - Car park charges at rail stations (2015 pence)	83
Table 4-16 - Estimated single journey (one-way) rail fares non-London (2016)	84
Table 4-17 - Estimated Fare Fraction Paid by Traveller Category	85
Table 4-18 - Day Rider Fares (Stagecoach, 2016)	85
Table 4-19 - Rider Fares Applied to Movements	86
Table 4-20 - P&R Bus Fares (Stagecoach, 2016)	87
Table 4-21 - Estimated single journey (one-way) distance-based bus fares (2016)	89
Table 4-22 - Cycle parking times	90
Table 4-23 - Weighting of time components in generalised cost	92
Table 5-1 - Tables used for 2011 Population	94

Table 5-2 - Home-based trip production segments and derivation of 2011 populations	95
Table 5-3 - Car availability definitions in CSRM2	95
Table 5-4 - Source of trip attraction weights	96
Table 5-5 - CSRM2 study area households (Hhs) composition by number of cars	98
Table 5-6 - HBW and HBEB Trip Rates: 24-hour weekday From Home trips/employed resident	100
Table 5-7 - Education Trip Rates: 12-hour weekday From Home trips/person in education	100
Table 5-8 - HBPS and HBRV Trip Rates: 24-hour weekday purposes/person	101
Table 5-9 - Time of Day Split Input to the Model	102
Table 5-10 - Education travel proportions: 12 hour trips split by time of day and direction	103
Table 5-11 - Income split by GseC for commuters	103
Table 6-1 - Distribution parameters for Car and Public Transport, with TAG default values	106
Table 6-2 - Calibrated impedance factors for cycle infrastructure	108
Table 6-3 - Distribution parameters for Walk and Cycle, with illustrative values (sourced by RAND Europe for CSRM1)	109
Table 6-4 - Relative sensitivity of main mode, time of day (TOD) and distribution choice	110
Table 6-5 - Relative sensitivity of main mode and distribution, with TAG default values	110
Table 6-6 - Sub-mode choice parameters	110
Table 6-7 - Car generalised cost damping parameters by trip purpose	111
Table 6-8 - PT cost damping parameters by trip purpose	111
Table 6-9 - N-hour to 1-hour vehicle trip ratios, by purpose	114
Table 7-1 - Mode Shares (CSRM2 2011 vs NTS) by Purpose	121
Table 7-2 - Mode Shares (CSRM2 2015 vs NTS) by Purpose	122
Table 7-3 - Mode Shares (CSRM2 2019 vs NTS) by Purpose	122
Table 7-4 - Mode Shares (CSRM2 2011 vs Census), HBW	122
Table 7-5 - HBW Mode Shares (CSRM2 2011 vs Census) by Origin/Home District, AM	123
Table 7-6 - HBW Mode Shares (CSRM2 2011 vs Census) by Destination/Work District, AM	123
Table 7-7 - Implied Excess/Shortfall in Trip Origins by Mode (3 hour AM Peak period)	125
Table 7-8 - Implied Excess/Shortfall in Trip Destinations by Mode (3 hour AM Peak period)	125
Table 7-9 - Comparison of total matrix sizes	127
Table 7-10 - Analysis by Trip Origins: Proportion of car trip origins by District and Purpose	128
Table 7-11 - Sector-to-Sector spread of movements: AM Peak	129
Table 7-12 - Sector-to-Sector spread of movements: Inter Peak	130
Table 7-13 - Sector-to-Sector spread of movements: PM Peak	131
Table 7-14 - TDM Car Fuel Cost Elasticities, Study Area Residents Only	137
Table 7-15 - TDM Car Fuel Cost Elasticities, Study Area Residents Only, HBW by GSeC	138
Table 7-16 - HAM Matrix Car Fuel Cost Elasticities, Internal Origins Only	139
Table 7-17 - HAM Network Car Fuel Cost Elasticities, on Links in Study Area	139
Table 7-18 - TDM Car Fuel Cost Elasticities (20% increase), Study Area Residents Only	139
Table 7-19 - Public Transport Own-Cost Elasticity	140
Table 7-20 - Demand Model Synthetic Matrix Car Own-Cost Elasticity (Car trips with respect to an increase in journey times)	141
Table 8-1 - Bus Survey Sample Rates	144
Table 8-2 - Comparison between modelled and observed bus passenger journeys, Cambridge Radial Cordon, excluding education	147
Table 8-3 - Comparison between modelled and observed Guided Bus passenger journeys, Cambridge Radial Cordon	148

Table 8-4 - Comparison between directional distribution of bus trips into Cambridge	149
Table 8-5 - Attributes of the Observed Datasets and Modelled Data	152
Table 8-6 - Comparison between ORR and CSRM2 daily station usage (2015)	156
Table 8-7 - Comparison between ORR and CSRM2 daily station usage (2019)	157
Table 8-8 - Comparison between DfT Passenger Count and CSRM2, arrivals and departures at Cambridge Station (2015)	158
Table 8-9 - Comparison between DfT Passenger Count and CSRM2, arrivals and departures at Cambridge Station (2019)	159
Table 8-10 - CSRM2 2015 versus CCC data: number of cyclists	160
Table 8-11 - CSRM2 2019 versus CCC data: number of cyclists	161
Table B-1 - List of CSRM2 Base Model Zones	175
Table C-1 - Link types (AM Peak IDs) and relevant network modes	185
Table D-1 - Gamma values for generating NHBEB trips	188
Table D-2 - Gamma values for generating NHBO trips	192
Table F-1 - Flow Type Definitions in CSRM2 F-series	217
Table F-2 - User Mode Definitions in CSRM2 F-series 2015 and 2019	218

Figures

Figure 2-1 - CSRM2 modelling framework	15
Figure 2-2 - Input of policy options within CSRM2 modelling tool	16
Figure 2-3 - CSRM2 study area, showing internal Districts and External zones	18
Figure 2-4 - Zone plan showing all external zones	19
Figure 2-5 - CSRM2 model structure including demand and assignment sub-models	21
Figure 2-6 - Public transport hierarchical design	29
Figure 2-7 - Main levels of choice hierarchy	30
Figure 2-8 - Choice hierarchy for HBW and HBEB	31
Figure 2-9 - Sub-mode tree for car main mode	31
Figure 2-10 - Sub-mode tree for public transport main mode	32
Figure 3-1 - TDM 2015 multi-modal network – Study area	40
Figure 3-2 - TDM 2015 multi-modal network – Cambridge Zoom	41
Figure 3-3 - TDM 2019 multi-modal network – Study area	42
Figure 3-4 - TDM 2019 multi-modal network – Cambridge Zoom	43
Figure 3-5 - Link connectivity for bus journeys without car access	48
Figure 3-6 - Link connectivity for Guided Bus journeys without car access	49
Figure 3-7 - 2015 Base Year Bus and Guided Bus services networks – Study Area	50
Figure 3-8 - 2015 Base Year Bus and Guided Bus services networks – Cambridge	51
Figure 3-9 - 2019 Base Year Bus and Guided Bus services networks – Study Area	52
Figure 3-10 - 2019 Base Year Bus and Guided Bus services networks – Cambridge	53
Figure 3-11 - 2015 External Bus Access Links	54
Figure 3-12 - 2019 External Bus Access Links	55
Figure 3-13 - Link Connectivity for P&R Journeys	56
Figure 3-14 - Zones in the city centre within which P&R is discouraged	57
Figure 3-15 - Link Connectivity for P&A Journeys	58
Figure 3-16 - Link Connectivity for Rail Journeys without Car Access	59

Figure 3-17 - Link Connectivity for Rail Journeys with Car Access	59
Figure 3-18 - 2015 and 2019 Rail Network	61
Figure 3-19 - 2015 Catchment area of major rail stations for car access	62
Figure 3-20 - 2019 Catchment area of major rail stations for car access	63
Figure 3-21 – 2015 and 2019 Catchment area of local rail stations for car access	64
Figure 3-22 - Map showing external rail connections by rail, and external rail connections by other mode	66
Figure 3-23 - Link connectivity for Pedestrian journeys	67
Figure 3-24 - Link connectivity for Cycle journeys	67
Figure 3-25 - 2015 cycle network infrastructure	68
Figure 3-26 - 2019 cycle network infrastructure	69
Figure 3-27 - Intrazonal distances by zone (circle diameter represents relative intrazonal distance)	71
Figure 4-1 - Zones / areas with car parking charges	80
Figure 4-2 - Parking search time areas	81
Figure 4-3 - Rail Fare Functions	84
Figure 4-4 - 'Day Rider' Zones (2016 Estimate)	88
Figure 4-5 - 2016 Bus fares by distance (2016 prices)	89
Figure 4-6 - Relationship between PT wait time and service frequency	91
Figure 5-1 - Map showing weights of university floorspace attractions	97
Figure 6-1 - Distribution of users on the different types of cycle infrastructure	107
Figure 6-2 - Car generalised cost damping function for HBPS and HBRV	112
Figure 6-3 - Model structure, showing relationship between the Transport Demand Model and the SATURN Local Highway Model	113
Figure 6-4 - 2019 Growth Zones	117
Figure 7-1 - 2011, 2015 and 2019 NTS trend in mode shares	121
Figure 7-2 - Core 13 Sector System	124
Figure 7-3 - Trip Length Distribution Comparison between CSRM2 and Census for HBW, all modes, 2011	126
Figure 7-4 - AM origin trip ends scatter plot	132
Figure 7-5 - AM destination trip ends scatter plot	132
Figure 7-6 - IP origin trip ends scatter plot	133
Figure 7-7 - IP destination trip ends scatter plot	133
Figure 7-8 - PM origin trip ends scatter plot	134
Figure 7-9 - PM destination trip ends scatter plot	134
Figure 8-1 - Cambridge Radial Cordon and other HAM screenlines and cordons	145
Figure 8-2 - Comparison between modelled and observed bus passenger journeys, Cambridge Radial Cordon	147
Figure 8-3 - Comparison between modelled and observed Guided Bus passenger journeys, Cambridge Radial Cordon	148
Figure 8-4 Map showing the North, East, South, West division for bus corridor analysis	150
Figure 8-5 - Comparison between modelled and observed person flows (2015)	153
Figure 8-6 - Comparison between modelled and observed person flows (2019)	154
Figure 8-7 - Comparison between modelled and observed vehicle flows (2015)	154
Figure 8-8 - Comparison between modelled and observed vehicle flows (2019)	155
Figure 8-9 - Graph showing comparison between ORR and CSRM2 daily station usage (2015)	156
Figure 8-10 - Graph showing comparison between ORR and CSRM2 daily station usage(2019)	157
Figure 8-11 - Graph showing comparison between DfT passenger count and CSRM2 for arrivals and departures at Cambridge Station (2015)	158

Figure 8-12 - Graph showing comparison between DfT passenger count and CSRM2 for arrivals and departures at Cambridge Station (2019)	159
Figure 8-13 - Map of Cambridge cycle counts on Radial Cordon, River screenline and Route Monitoring sites	162
Figure B-1 - Zone Plan: Study Area	168
Figure B-2 - Cambridge Zone Detail	169
Figure B-3 Huntingdon Zone Detail	170
Figure B-4 Ely Zone Detail	171
Figure B-5 St Ives Zone Detail	172
Figure B-6 St Neots Zone Detail	173
Figure B-7 Northstowe Zone Detail	174
Figure E-1 - Trip Length Distribution: all modes (HBW, vs Census)	201
Figure E-2 - Trip Length Distribution: car (HBW, vs Census)	202
Figure E-3 - Trip Length Distribution: bus (HBW, vs Census)	202
Figure E-4 - Trip Length Distribution: rail (HBW, vs Census)	203
Figure E-5 - Trip Length Distribution: cycle (HBW, vs Census)	203
Figure E-6 - Trip Length Distribution: walk (HBW, vs Census)	204
Figure E-7 - Trip Length Distribution: all modes (HBW, vs NTS)	205
Figure E-8 - Trip Length Distribution: car (HBW, vs NTS)	205
Figure E-9 - Trip Length Distribution: bus (HBW, vs NTS)	206
Figure E-10 - Trip Length Distribution: rail (HBW, vs NTS)	206
Figure E-11 - Trip Length Distribution: cycle (HBW, vs NTS)	207
Figure E-12 - Trip Length Distribution: walk (HBW, vs NTS)	207
Figure E-13 - Trip Length Distribution: all modes (EB, vs NTS)	208
Figure E-14 - Trip Length Distribution: car (EB, vs NTS)	208
Figure E-15 - Trip Length Distribution: bus (EB, vs NTS)	209
Figure E-16 - Trip Length Distribution: rail (EB, vs NTS)	209
Figure E-17 - Trip Length Distribution: cycle (EB, vs NTS)	210
Figure E-18 - Trip Length Distribution: walk (EB, vs NTS)	210
Figure E-19 - Trip Length Distribution: all modes (Edu, vs NTS)	211
Figure E-20 - Trip Length Distribution: car (Edu, vs NTS)	211
Figure E-21 - Trip Length Distribution: bus (Edu, vs NTS)	212
Figure E-22 - Trip Length Distribution: rail (Edu, vs NTS)	212
Figure E-23 - Trip Length Distribution: cycle (Edu, vs NTS)	213
Figure E-24 - Trip Length Distribution: walk (Edu, vs NTS)	213
Figure E-25 - Trip Length Distribution: all modes (Other, vs NTS)	214
Figure E-26 - Trip Length Distribution: car (Other, vs NTS)	214
Figure E-27 - Trip Length Distribution: bus (Other, vs NTS)	215
Figure E-28 - Trip Length Distribution: rail (Other, vs NTS)	215
Figure E-29 - Trip Length Distribution: cycle (Other, vs NTS)	216
Figure E-30 - Trip Length Distribution: walk (Other, vs NTS)	216

1. Introduction

1.1. Background

The original Cambridge Sub-Regional Model (CSRM1) was developed between 2006 and 2009 by WSP and Atkins, on behalf of Cambridgeshire County Council (CCC) and the Highways Agency. The model was originally designed to support both the A14 upgrade and the Transport Innovation Fund (TIF) work for CCC. As such, the model was designed to be a fully integrated multi-modal transport model, compliant with the Department for Transport's (DfT's) Transport Analysis Guidance (TAG) with respect to those schemes assessed, including major scheme business case development for multi-modal schemes.

In early 2015, it was recognised that the 2006 base year validation of CSRM1 made it less suitable for work going forward, and it was agreed that a complete model refresh should take place. Following preliminary scoping work by WSP and Atkins (Phase 1 of model development), CCC commissioned Atkins to carry out an update and re-validation of CSRM1, to provide a refreshed model which is termed CSRM2 and has a base year of 2015.

The motivation for the CSRM2 update was that CCC required an up-to-date model developed using best practice as set out in TAG, to carry out testing and development of the Greater Cambridge Partnership (GCP) transport schemes, together with more general strategic planning and business case work, major site development and other transport scheme / transport strategy development. The main changes addressed during the refresh can be summarised as follows:

- The Land Use model previously part of CSRM1 has been removed, and replaced with a more standard approach of developing the trip ends by purpose externally from the model based on planning data as set out in Chapter 5 of this report;
- The network for the SATURN Highway Assignment Model (HAM) has been substantially reviewed, re-built and re-validated, using traffic counts, mobile phone data, traffic signal settings, network surveys and Trafficmaster travel time data. This process is described in the Local Model Validation Report (LMVR¹);
- Elements of the transport demand and public transport model have been improved where possible, particularly the modelling of Park & Ride (P&R) site choice as summarised in Section 2.9 of this report;
- The public transport services for bus, guided bus, rail and P&R have been fully updated and more explicitly linked to published electronic timetables. Walk and cycle networks have also been refreshed, with detail added and improved representation of footpaths and cycleways;
- P&R modelling was further refined to extend the modelling of P&R beyond services to and from Cambridge City centre; and
- Following the above changes, the variable demand model (VDM) calibration, public transport and active mode assignment have been validated against observed data, as described Chapters 7 and 8 of this report.

CSRM2 has been developed with a base year of 2015, which applies to the data collection, transport network and public transport services. Approximately annually, a new version of the base model is released, which incorporates updates to coding (including additional detail, if appropriate, in areas that have been the subject of specific studies) and TAG sourced parameters. These model versions are denoted by letters:

- the A-series was used in autumn 2016;
- the B-series was released in summer 2017;
- the C-series was released in December 2017;
- the D-series was released in winter 2018;
- the E-series was released in winter 2019; and
- the F-series was released in summer 2021.

The CSRM2 F-series was developed in 2020-2021 to enhance the representation of cycling in the model with differentiated cycling facilities impacting travellers' choices of mode and route; and extending the modelling of P&R to enable users to park and continue their journey by bus or by active modes (walk and cycle) – this is termed “Park & Active” (P&A). The F-series also improved the level of detail in areas that are the focus of current transport scheme projects, and added a 2019 Present Year Validation (PYV) to extend the life of the

¹ 'Cambridge Sub-Regional Model 2: F-Series Highway Local Model Validation Report', CSRM2 F-Series Highway LMVR_v5.0.pdf (Atkins, September 2021)

model until such time as a whole new base year can be created (once the disruption to travel behaviour and patterns caused by the COVID-19 pandemic has settled to a “new normal” state).

Throughout this report, the original CSRM is referred to as CSRM1, and the refreshed model as CSRM2

1.2. Key Model Design Considerations

CSRM2 retains many of the design principles and considerations of the original CSRM1, the design of which was informed by the need for major scheme business cases to be developed for the A14 upgrade and Transport Innovation Fund (TIF) programme of the time. The software also remains the same, though updated to the latest versions: namely, a combination of MEPLAN (for the VDM and PT/active mode assignments) and SATURN (for the HAM), stitched together with scripts written in Batch, Python and Perl. With this in mind, the model has the following key design features:

- Integration of a synthetic VDM for personal travel with a validated highway model, implemented incrementally;
- Inclusion in the VDM of trips covering all purposes, modes and trip lengths, to allow a full range of demand responses to be considered;
- Future growth in trip ends informed by detailed assessments of land use change, demographics and development areas;
- Modelling of private, public and active transport modes including explicit representation of journey stages and costs, and local sub-modes such as P&R, P&A and the Cambridgeshire Guided Busway (CGB);
- Modelling of cycling commensurate with the higher-than-average use of this mode in and around Cambridge;
- A separately validated HAM, using the SATURN software to include modelling of queues and junction delays at a strategic level so that changes to the highway network can be fed through in more detail than if the whole model were solely in MEPLAN;
- Segmentation of the travel demand in the VDM and HAM sufficient to represent variations in value of time (VoT) by travel purpose, and traveller type including income;
- Impacts of traffic congestion on private vehicles and (where relevant) public transport journey times; and
- Use of TAG default VDM structures and parameters, adjusted appropriately to local calibration data where this is available.

1.3. Proposed Uses of the Model

The primary proposed use of CSRM2 is to support the assessment of transport schemes, taking account of all modes of transport and the interaction between transport supply and travel demand, including the influence of land use change. With high growth expectations in both housing and employment in Cambridgeshire, it is critical to have evaluation frameworks of a size capable of capturing change and the longer-term equilibrium of the sub-region. Funding required to support schemes being considered in the sub-region are at such a scale that almost all schemes would be classed as “Major Schemes” with associated higher-level business case requirements.

With explicit representation of public transport supply and demand, CSRM2 can capture and evaluate the benefits of new infrastructure (highway, Public Transport (PT) and sustainable modes) as well as modified service patterns (PT) and active modes (walk and cycle). Trends in land use can be taken into account, including housing and employment, as well as demographic shifts and levels of in- and out-commuting.

In order to support the development of business cases for major schemes, forecasts conducted need to be able to project sufficiently far into the future to capture the severity of growing congestion through time.

The four key districts within CSRM2 (Cambridge City, South Cambridgeshire, Huntingdonshire and East Cambridgeshire) all have ambitious growth aspirations and CSRM2 can be used to assess the transport impacts of alternative development options to inform updates to the Local Plans.

1.3.1. Greater Cambridge Partnership

Greater Cambridge Partnership (GCP) status was agreed with central government in June 2014, supporting the creation of 45,000 jobs and a combination of private and public funding totalling £5 billion, with £1 billion directed towards transport infrastructure projects. The transport schemes being considered are a mix of public transport, highway network capacity management/re-allocation and other demand management such as workplace parking levies.

CSRM2 is specifically tailored to cover the GCP initiatives which radiate out from Cambridge City through into South Cambridgeshire district. The overall strategic impact of schemes in terms of corridor-based changes in demand, traffic assignment and consequential impact on journey times can be examined using CSRM2, subject to localised benchmarking validation checks. More localised assessments, such as individual junctions, could require use of local modelling informed by CSRM2. Outputs from CSRM2 can be passed through the DfT's economic appraisal software TUBA, allowing long term economic cost benefit analysis to be performed.

CSRM2's enhanced representation of cycling in the F-series, including the concept of P&A using the city's existing P&R sites, is tailored towards the types of scheme that GCP are working on.

1.3.2. Local Authority Districts

The internal area of CSRM2 covers the Local Authority Districts (LADs) of Cambridge City, South Cambridgeshire, Huntingdonshire and East Cambridgeshire. As with CSRM1, the model has been designed for the purpose of modelling transport and land use changes in each of the four LADs. The assessment of Local Plans was particularly considered in this respect, and work on the Huntingdonshire Local Plan was undertaken using the CSRM2 A-series in December 2016, whilst the F-series is being used for the Greater Cambridge (Cambridge City and South Cambridgeshire) Local Plan.

1.3.3. Cambridgeshire and Peterborough Combined Authority

The Cambridgeshire and Peterborough Combined Authority (CPCA) is a combined authority covering the ceremonial county of Cambridgeshire. The authority was established on 3 March 2017 and it includes the following local councils: Cambridgeshire County Council, Peterborough City Council, Cambridge City Council, East Cambridgeshire District Council, Fenland District Council, Huntingdonshire District Council and South Cambridgeshire District Council. Key ambitions for the CPCA include doubling the size of the local economy, accelerating house building rates to meet local and UK need and delivering connectivity in terms of transport and digital links.

Although the CSRM2 study area does not cover the whole CPCA administrative boundary, the model can forecast many of the impacts that wider regional transport schemes would have within the sub-region. The areas covered by the combined authority lying outside the CSRM2 study area are represented by external zones in more detail than more distant areas as outlined in Section 1.3.4.

1.3.4. External areas

As the model considers only four LADs of Cambridgeshire (excluding Fenland District) as internal areas, there is some limitation in the dynamic predictions of travel to and from adjacent areas. Trips from these areas into and out of the internal study area are considered for external zones, which include Peterborough, Newmarket and Royston, as well as adjacent areas of Essex, Norfolk, Suffolk, Bedfordshire and Fenland itself. More detail was added in external areas near Mildenhall and Tempsford to improve the representation of potential strategic transport schemes such as the Cambridge Autonomous Metro (CAM) and East West Rail.

For these external areas, the level and nature of interaction with the internal area follows growth trajectories rather than any dynamic predictions of demand activity, and, while still informative, should be considered as an exogenous assumption in the model.

1.3.5. Developer and other applications

Historically, CSRM1 was used for the impact assessments of larger proposed development sites such as the National Institute of Agricultural Botany (NIAB), Cambridge North West, Northstowe, Alconbury Weald and Cambourne West. Whilst the expectation that the base model would be able to match observations of individual movements at junctions may be unrealistic, localised modelling informed by strategic assessments using CSRM2 can be appropriate for modelling the impact of individual developments. It is anticipated that CSRM2 F-series will be used for developer testing in the wake of the modelling work for the Greater Cambridge Local Plan.

1.4. Report Structure and other CSRM2 documentation

This report describes the overall CSRM2 model structure, with detail on the transport demand model (TDM), the public transport and walk/cycle assignment, and the interactions between these elements and the SATURN HAM. The calibration and validation of the TDM, Public Transport (PT) and cycle assignment are also included here.

The previously issued version of this document (v3.0 in 2018) documented the D-series version of CSRM2. For the E-series model version, an addendum was released in 2019. This version reports the F-series version of the model. All model outputs and analysis in this report have been updated to reflect the F-series version of the model.

The separate LMVR records the development and validation of the SATURN HAM. Further to this, the CSRM2 Forecasting Model is described in the Forecasting Report, with details of how future transport demand and supply assumptions are added, and results of the Baseline scenario³ model runs for 2026 and 2041.

Report Structure

The remainder of this report is structured as follows:

Chapter 2: Outline of the overall model structure, zoning system, segmentations and choice structure;

Chapter 3: Model networks, link types and interchanges in the public transport, walk and cycle models;

Chapter 4: Input characteristics, describing the vehicle operating costs, vehicle occupancies, values of time, parking and public transport fare costs within the model;

Chapter 5: Travel Demand Input, outlining how Production and Attraction trip ends are derived from land use data and used within the model;

Chapter 6: Detailed description of the TDM, including the choice parameters linkage to the HAM and supply-demand iteration;

Chapter 7: Details and evidence of the TDM calibration and validation; and

Chapter 8: Details and evidence of the public transport and cycle network calibration and validation.

Appendices

Appendix A – Glossary of terms;

Appendix B – Zoning maps and list of model zone numbers;

Appendix C – Model network link types (MEPLAN);

Appendix D – Gamma values used for non-home-based trip generation; and

Appendix E – Additional validation information (Trip Length Distribution graphs)

Appendix F – Additional Model Definitions

³ See definition of 'Baseline scenario' in Appendix A, Glossary

2. Model Structure and Definitions

2.1. Model Structure and Software

CSRM2 has been developed in line with TAG for strategic multi-modal transport models and uses a standard and well understood four-stage transport modelling approach. The model allows the forecasting of future travel demand, including traffic levels, PT patronage and congestion.

The essential features of the CSRM2 model structure, shown in Figure 2-1 are:

- Trip ends generated from input numbers of dwellings, jobs and school places by zone as well as relevant background data from 2011 Census of Population;
- A Transport Demand Model (TDM), as described in this report, using MEPLAN software. It considers traveller responses including choice of mode/sub-mode, change of (macro) time of travel, and trip redistribution among destinations. Travel demand is segmented by income, trip purpose and car ownership. This model is compliant with current Department for Transport (DfT) guidance for variable demand modelling;
- A public transport, walk and cycle assignment sub-model (PT-Walk-Cycle) also implemented in MEPLAN; and
- A highway assignment sub-model (HAM) using Atkins' SATURN software for light and heavy good vehicle (HGV) assignment, described in detail in a separate Local Model Validation Report.

Differences between CSRM1 and CSRM2

The overall model structure retains most features of CSRM1 used from 2009 to 2015, but the base data has been updated from 2006 to 2015, including updates to highway and PT networks and re-calibration based on 2015 population, employment and observed travel behaviour. For the F-series a 2019 Present Year Validation has also been undertaken.

CSRM2 has removed the Land Use model which was part of CSRM1, and replaced this with a simpler approach where the population, employment and land use in each zone is processed in a trip end spreadsheet and trip ends directly input into the model.

In addition, the zoning system has been updated to align with 2011 Output Areas and Workplace Zones defined by the Office of National Statistics (ONS) and is now consistent across all components of the model, and the transport network coverage and detail have been thoroughly audited and brought in line with the 2015 base year.

The modelling of mixed mode trips, namely P&R/P&A and rail accessed by car, has been restructured with choice of P&R site and rail station being made for the round trip (from and to home). The model now uses SATURN software version 11.5.05H and MEPLAN software version 6.1.

Royston and Whittlesford rail stations have been changed from 'local' stations to 'main' stations, meaning that they can now be accessed by as many zones as are defined to be in their catchment areas, rather than only being accessible to travellers with trip ends in zones for which they were their nearest station. (These upgrades took place in the CSRM2 C-series for Royston and F-series for Whittlesford). These changes reflect improvements in rail services through the stations, and their use by South Cambridgeshire residents for accessing the fast mainline services to London Kings Cross. The other 'main' stations in the base year model are Cambridge, Huntingdon, St Neots and Ely (see Sections 2.9 and 3.6 for further details).

The latest updates for CSRM2 F-series introduce improved modelling of cycling, with Park and Ride trips being further split into those using bus and those walking or cycling to their final destination.

Limitations

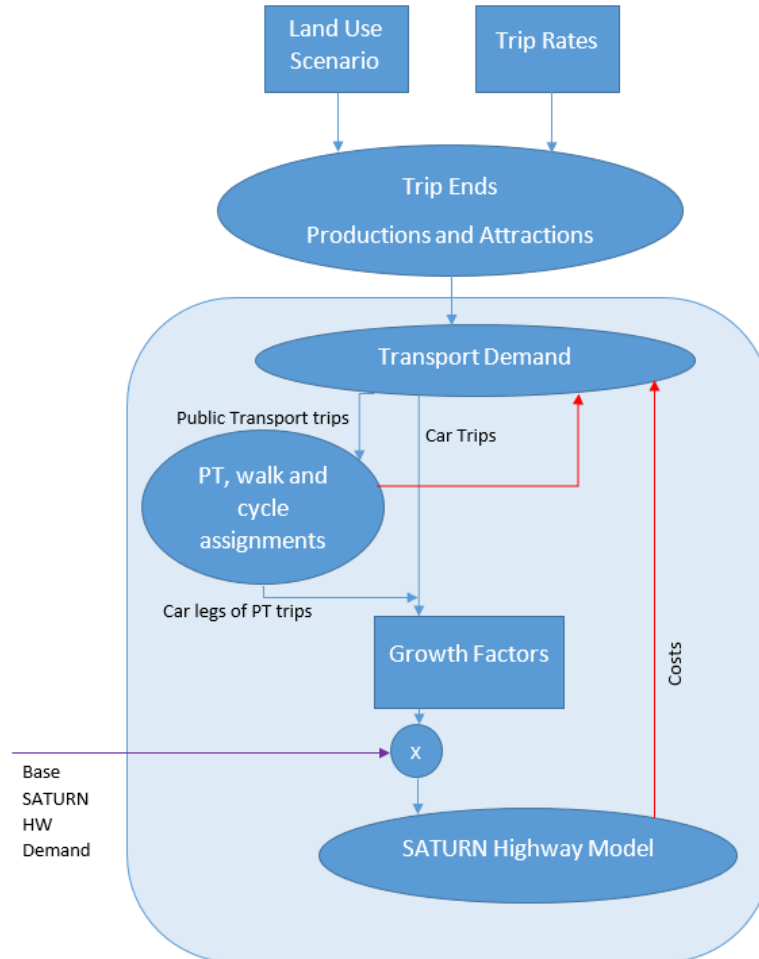
The model will naturally be limited in the accuracy of its forecasts due to uncertainties in the input assumptions and data. Those uncertainties can be grouped as follows:

- **Uncertainties in input assumptions:** This might include issues such as uncertainty about employment growth, car ownership and fuel costs. CSRM2 model runs make use either of client specific scenario assumptions (development growth), or accepted DfT assumptions (TAG data book, NTEM dataset);
- **Uncertainties in transport supply:** There are necessarily some limitations to the detail with which transport infrastructure and services can be represented, and this is often most crucial in terms of future changes to the networks; and

- **Uncertainties in transport choices:** The model represents the transport choices and trade-offs made by individuals as best they can be estimated using national and local data from 2015.

Forecasting accuracy will also be affected by the base year model design and data including the level of detail and accuracy of data used in the base year.

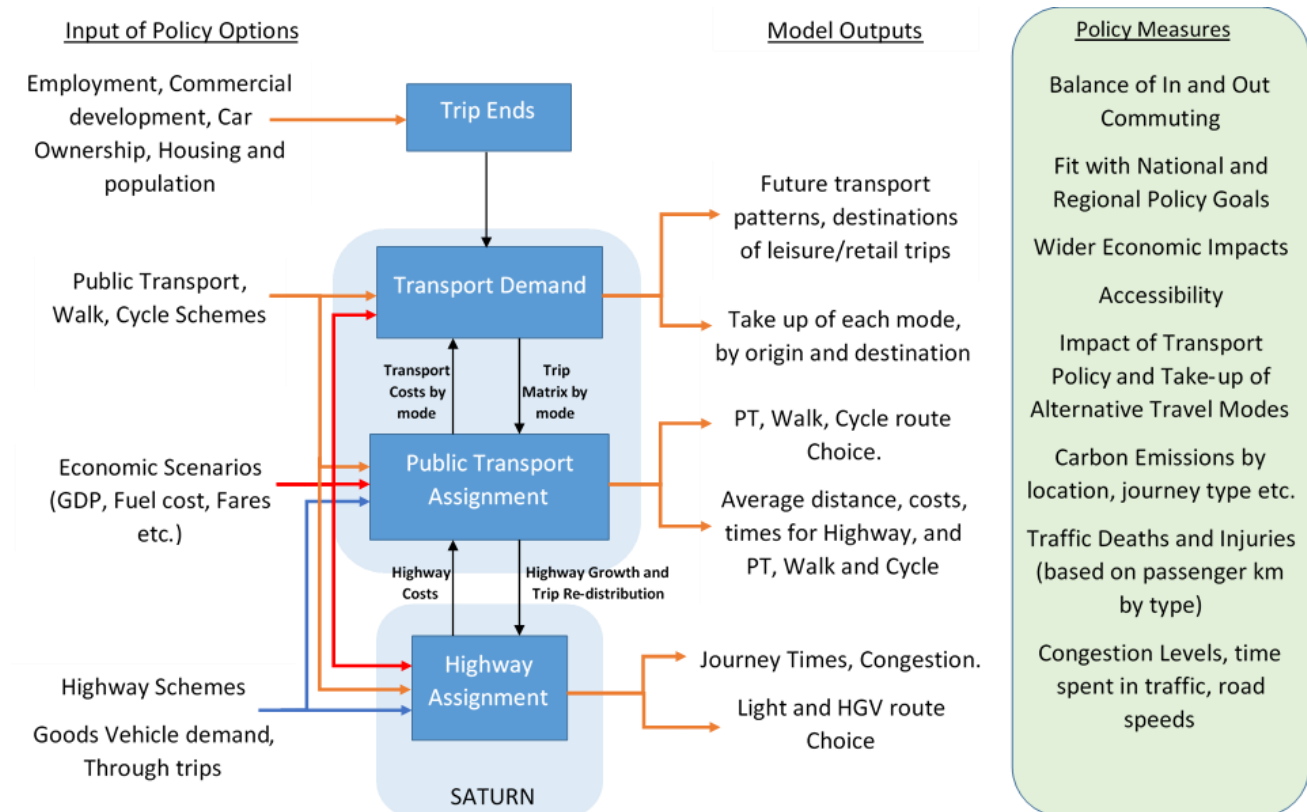
Figure 2-1 - CSRM2 modelling framework



In addition to highway infrastructure and public transport schemes, the CSRM2 modelling tool is designed to address a variety of policy options, as represented by Figure 2-2.

The demand model does not include demand responses for HGVs other than their route choice within the HAM, see Section 6.12 for details.

Figure 2-2 - Input of policy options within CSRM2 modelling tool



This report provides an overview of the design, development, performance against observation and capabilities of the CSRM2 Transport Demand Model (TDM), as well as the PT-Walk-Cycle assignment sub-model.

The modelling methodology for CSRM2 incorporates all components of the traditional “four-stage” model: trip generation; choice models for mode/sub-mode, time of day and distribution; and assignment of modal trips to routes.

The CSRM2 modelling tool consists of a SATURN highway assignment sub-model (HAM) (described in more detail in the LMVR), a Transport Demand Model (TDM), and a PT-Walk-Cycle assignment sub-model implemented in MEPLAN. Cost and trip matrices are exchanged between both the HAM and the TDM components.

The planning data and economic inputs for the Base Model (2015) and Present Year Validation (2019) are derived from 2011 Census data and updated to 2015 and 2019 using employment information from the East of England Forecasting Model (EEFM), school places from the government School Census, and dwellings completion data from CCC. The population is then calculated from the 2015 / 2019 mid-year ONS population estimates at an Output Area level, and the resulting population per dwelling ratios calculated at a zonal level for sense-checking. The Trip Ends process takes numbers of jobs, dwellings and school places by zone and calculates numbers of trip ends (productions and attractions) based on trip rates derived from the National Travel Survey (NTS) applied to population data. Census data is used to determine the numbers of trips by people in different socio-economic groups.

Trip ends for future years are determined from the projected population (calculated from forecast dwellings), and projected changes in jobs and school places. See Chapter 5 for more details on the derivation of trip ends.

The TDM takes as an input 24-hour trip productions, except for the education purpose for which 12-hour trip productions are used, on the assumption that no Off Peak education trips are generated. The model derives a main mode share (dividing between car, public transport, walk and cycle) for each segment. The trips are then split by trip production time period – AM Peak, Inter Peak, PM Peak and Off Peak for home-based working and employer’s business trips (24 hours) and AM Peak, Inter Peak and PM Peak for education and all other discretionary trips (12 hours), Off Peak discretionary trips are not retained. Trip productions by time period are then divided into sub-modes and distributed. For details of the time of day proportions expected for each mode, please refer to Section 5.5 Table 5-9. Summaries of the modelled purposes, modes and sub-modes are given in Sections 2.7 and 2.8. The trip matrices produced within the TDM will be influenced by transport costs and journey times derived from the transport networks by time period, see Chapters 3 and 4 for more details.

Both the PT-Walk-Cycle and HAM assignment sub-models are implemented for three time segments:

- The PT-Walk-Cycle assignment model uses morning peak from 07:00 to 10:00, the Inter Peak period from 10:00 to 16:00 hours, and the evening peak from 16:00 to 19:00;
- The highway assignment is implemented for weekday peak and Inter Peak hours from 08:00 to 09:00, a one hour average for the time period 10:00-16:00, and 17:00-18:00.

The PT-Walk-Cycle assignment model covers all relevant bus, rail and Guided Bus services in the Cambridge sub-region. Section 2.7 gives more detail on the demand model segmentation; the structure and relationship between modelled time periods is further described in Chapter 6. PT crowding is not modelled in CSRM2, see Section 4.5 for more details.

By comparing policy runs of the TDM with the base year (2015) results, growth factors are produced which can be used to scale the base year HAM matrices for forecasting, as described in Chapter 6.

2.2. Model Coverage (Study Area)

The choice of study area boundary and subdivision of this geographic area into model zones is key to the geographic resolution and forecasting capabilities of the model. The chosen study area is defined by the local authority districts which closely match the definition of the Cambridge Sub-Region. These are:

- Cambridge City;
- South Cambridgeshire;
- East Cambridgeshire; and
- Huntingdonshire

Figure 2-3 shows the CSRM2 internal study area. The rest of Great Britain outside the study area is represented as an external area. The study area boundaries are consistently represented throughout the modelling system – in the TDM, PT-walk-cycle assignment and HAM. The model study area boundaries were reviewed as part of the CSRM2 refresh project, and it was concluded that the existing model study area should be maintained rather than expanded⁴.

Whilst all trip-making activities (i.e. trip productions and trip attractions) are modelled throughout the study area, in terms of zone size and network detail there is some variation. Rural zones are generally larger, as is appropriate to the lower population density and sparser transport networks. There is slightly less detail in East Cambridgeshire and Ely than the other districts of the sub-region. Since CSRM1, more detail has been added in St. Neots, St. Ives, Ely, Cambridge and some nearby external areas.

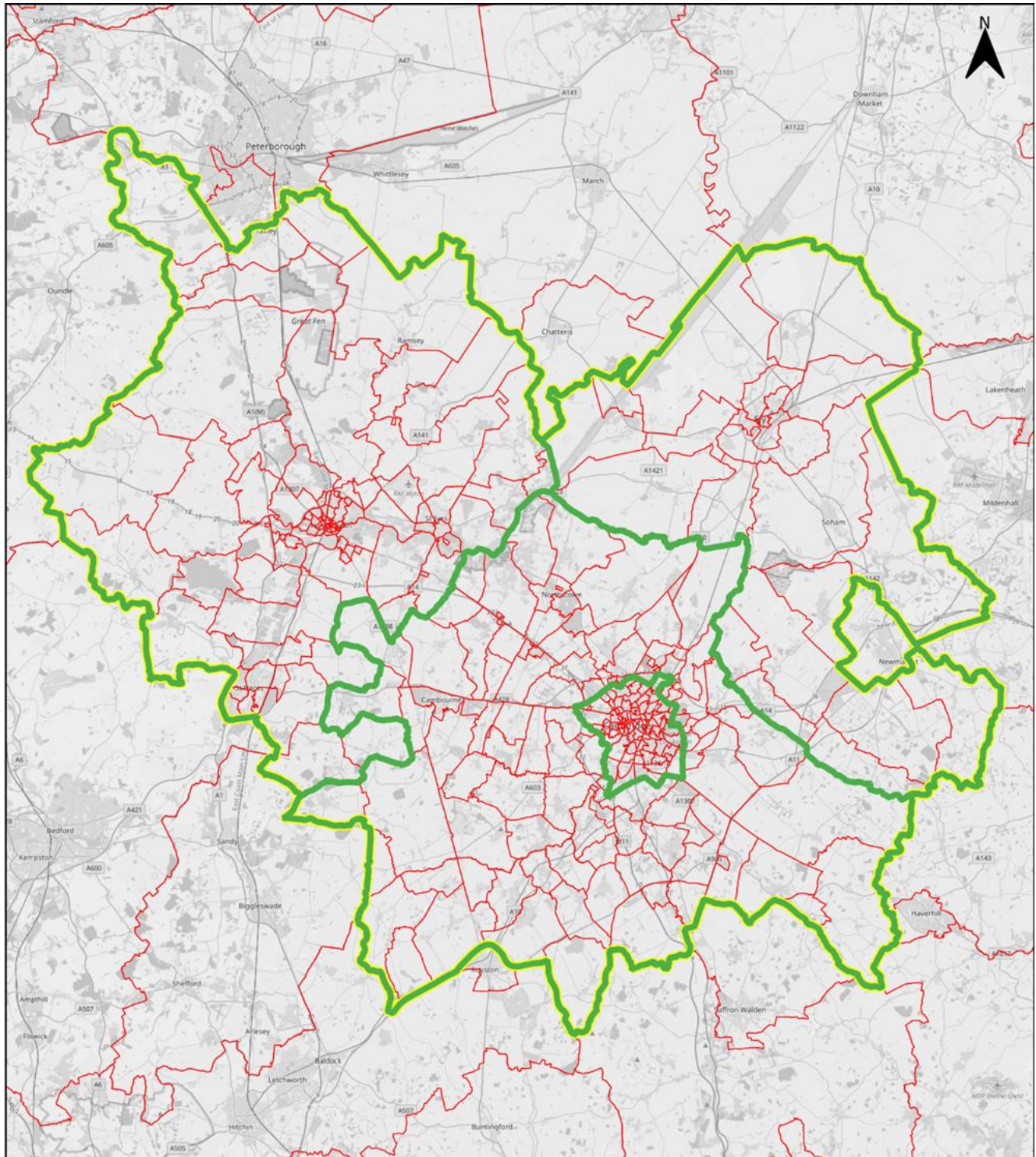
Internal and External areas

The model includes ALL journeys wholly within the four districts: Cambridge City, South Cambridgeshire, East Cambridgeshire and Huntingdonshire. For the model purposes these define the Cambridge Sub Region, which is referred to as the 'Study Area'. Trips to/from external areas (with only one trip end within the study area) are considered as part of the demand modelling process. Trips crossing the Study Area, but NOT having an origin or destination in the Study Area are NOT considered by the TDM but are considered as a fixed input to the HAM which can be varied for future years/scenarios.

Section 2.3 contains more detail on the model zoning system, and Appendix B contains a full set of zoning maps and list of zones.

⁴ This is outlined in the Technical Note 1.1 (6th January 2016) prepared by WSP and Atkins as part of Phase 1 of the model refresh.

Figure 2-3 - CSRM2 study area, showing internal Districts and External zones



CSRM2 Zone Plan

Cambridgeshire District Boundaries
 Study Area
 CSRM2 Zones

Drawn: EW, 09/08/2021

Checked: AS, 25/08/2021

Reviewed: CLFL, 25/08/2021

Version: 1.0

Reference: "P:\GBCBA\HandT\CQ\Projects\5202465-CSRM2 F-Series Base Year-SPOS6932\30 - Documentation\01 MDVR\Maps_For_MDVR\01_Zoning_System\Map of External Zones.qgz"

1:725,000

0 12 24 km



SNC • LAVALIN

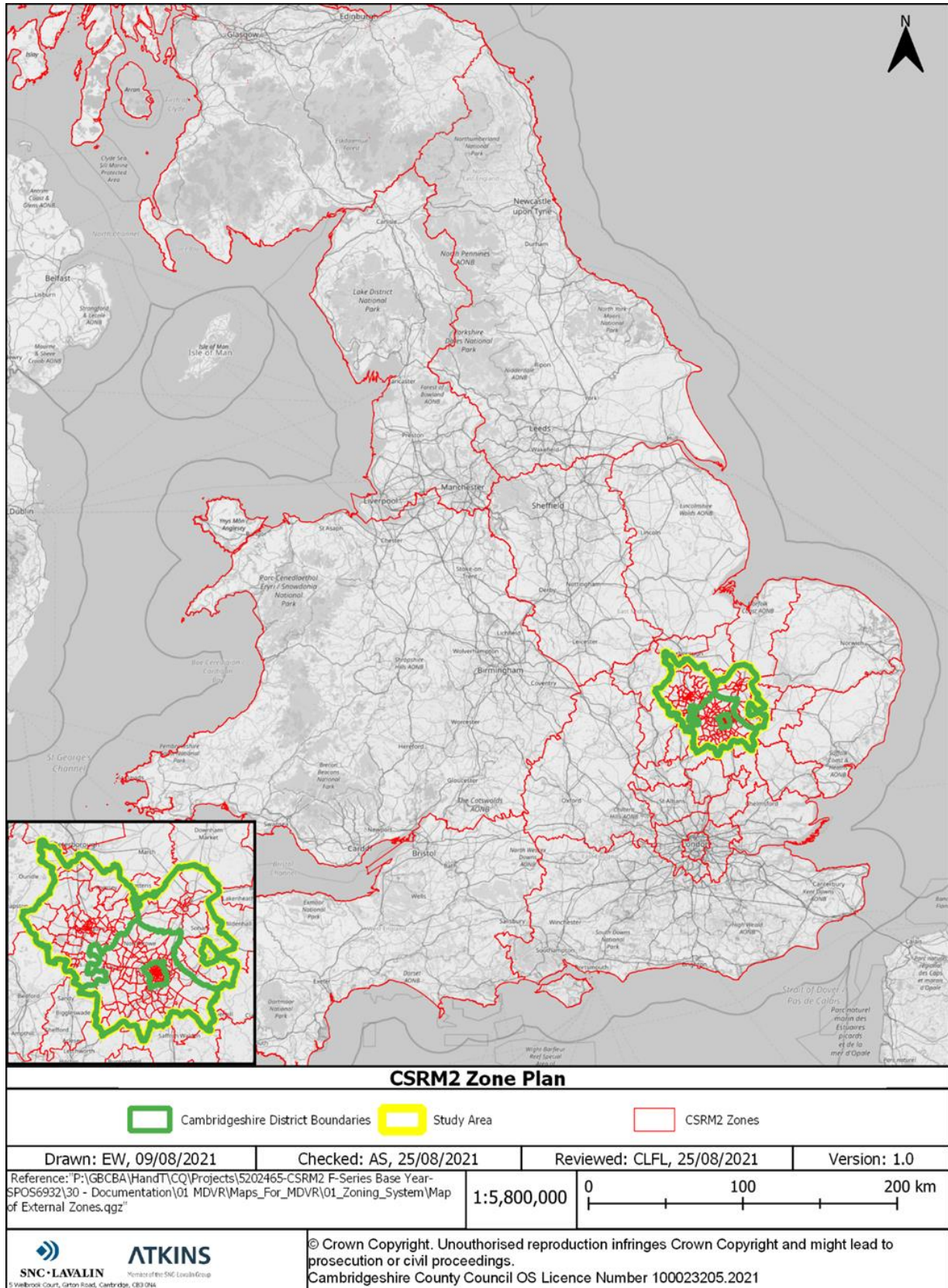


ATKINS

Member of the SNC-Lavalin Group
5 Watbrook Court, Gorton Road, Cambridge, CB3 0JL

© Crown Copyright. Unauthorised reproduction infringes Crown Copyright and might lead to prosecution or civil proceedings.
Cambridgeshire County Council OS Licence Number 100023205.2021

Figure 2-4 - Zone plan showing all external zones⁵



⁵ See Appendix B for more detail on the CSR2 zone structure

2.3. Model Zoning

A complete review of the CSRM1 zoning system was undertaken as part of the model refresh, with changes made to ensure compatibility with UK Census Output Areas and district boundaries. The new zone system also includes increased granularity in and around the satellite market towns. The HAM zoning system in CSRM2 is now consistent with the wider CSRM TDM.

For the F-series, a further review was undertaken to identify areas that would benefit from more detail to better capture upcoming scheme testing, building on work carried out for a number of GCP schemes as well as incorporating new near external zones for East-West Rail (EWR) and the Cambridge Autonomous Metro (CAM) which were being proposed at the time. The new zones added were:

- Two in the Grange Road area of Cambridge, to improve the detail in the area where the Cambourne to Cambridge GCP scheme reaches the city centre;
- One for the John Lewis depot in Trumpington, so that its traffic movements could be separated from P&R demand and the rest of the surrounding area;
- The Milton village zone was split into two (east and west) to allow more scope for capturing the variations between potential routes of the Waterbeach to Cambridge PT corridor scheme;
- The division between Landbeach and Waterbeach was realigned along the A10 and a new zone was added for the Cambridge Research Park to allow its future expansion to be better represented;
- Granta Park and the Babraham Research Campus were separated from their respective residential zones, to improve the level of detail in the corridor of the Cambridge South East Transport Study;
- Mildenhall was separated from the Norfolk zone to allow better representation of CAM; and
- Bedford was separated from the Sandy/Tempsford area to allow better representation of EWR.

Zones are numbered by the district that they lie within, with the first digit representing the district number (1xx for Cambridge, 2xx for South Cambridgeshire, etc.). All existing P&R sites, including Cambridge Guided Busway P&R, have an allocated zone in the 9xx series.

A pool of 99 development zones (6xx series) are included in the base matrix. These zones have zero trips in the base and are reserved for activation as required during forecasting. Details of the zone numbering system and quantity of zones by district are shown below in Table 2-1. A full set of the zone descriptions is reported in Appendix B.

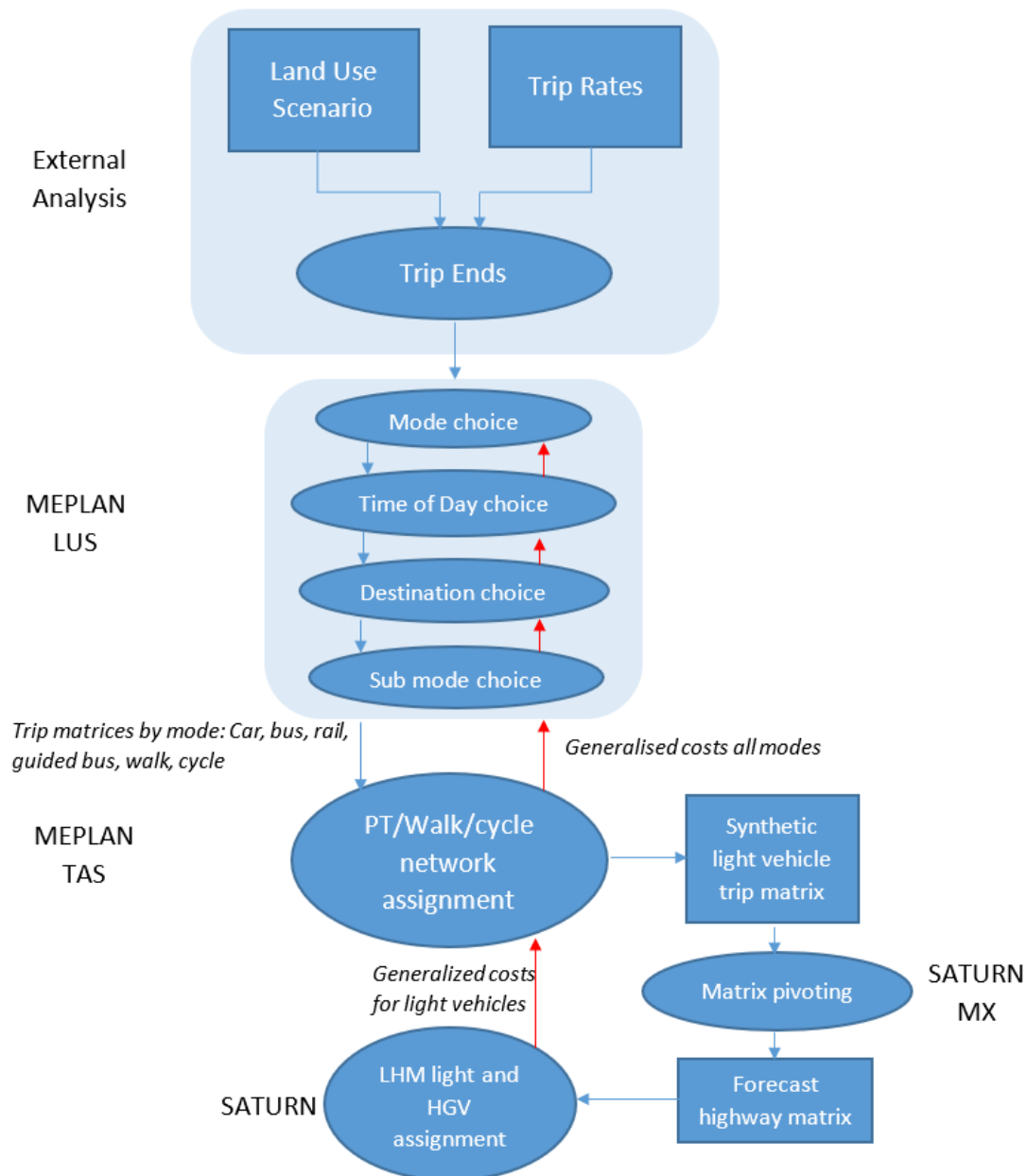
Table 2-1 - Zone Details

District / Area	Number of Zones	Zone Number Range
Cambridge	81	101-181
South Cambridgeshire	101	201-302
East Cambridgeshire	23	401-423
Huntingdonshire	99	501-599
Total Internal	304	101-599
Future Development Zones	99	601-699
External	34	701-742
Park & Ride	28	971-998
Grand Total	465	101-998

2.4. Model Components

Figure 2-5 shows the structure of the CSRM2 model, including sub-models.

Figure 2-5 - CSRM2 model structure including demand and assignment sub-models



The Transport Demand Model (TDM) has been designed to:

- represent the passenger movements between model zones; and
- represent the choice between different transport modes, between different time periods, and between different destination zones.

The TDM is provided with trip productions by purpose and demand segment for each model zone, and for each of these trip productions the model estimates:

- choice of main travel modes: car, PT, walk and cycle;
- the split of outward journeys between different time periods of the day: AM, IP, PM and Off Peak time periods;
- the distribution of the trips (trip attraction location); and
- choice of sub-mode of travel (bus, rail, Guided Bus, car versus car P&R).

All of the above are determined on a Production-Attraction basis (P-A), and the resulting P-A matrices used to create Origin-Destination (O-D) matrices by time period.

A further sub-mode choice is then carried out on an O-D basis to estimate the split of the P&R trips between Bus P&R versus P&A for each site.

The TDM is fully integrated with the two network sub-models used for the path building / assignment on the networks for each of the following modes: car, P&R, P&A, bus, guided bus, rail, cycle and walk. The MEPLAN assignment model is used for all of these modes, except for light vehicles (mainly cars plus LGVs) and HGVs which are assigned using the SATURN highway model.

Matrices of congested journey distances, costs and times by travel purpose and income level (SATURN User Class) from the highway model for the three assigned hours are read directly into the TDM. Generalised costs between each relevant zone pair for each mode for each time period modelled are constructed from these matrices by the demand model for the different traveller types using appropriate values of time.

The composite costs are passed consistently up the choice hierarchy from the network level using the conventional log-sum formulation in hierarchical logit models of discrete choice.

When scenario testing, the travel demand and network models iterate until a converged equilibrium solution is achieved for travel demand and congestion estimation.

2.5. Dimensions and Units

The TDM and assignment sub-models have been implemented in the following dimensions and units. All cost related inputs and outputs are in 2015 prices.

Table 2-2 - Dimensions and units

Dimension	Units	
	TDM and PT-Walk-Cycle assignment	Highway assignment
Distance	Kilometres	Metres
Time	Minutes	Seconds
Cost / Money	Pence (in 2015 prices)	Pence (in 2015 prices)
Speed	Kilometres per hour	Kilometres per hour
Disutility	Generalised minutes: combination of time and costs	Generalised seconds: combination of time and costs

Trips are either home-based (have one end at home) or non-home-based. The unit of demand for all home-based (HB) travel within the TDM is a simple tour, represented by a single P-A pair in the P-A matrix. A simple tour is defined as a round trip starting and finishing at the traveller's home with one destination. Each P-A pair is converted to two trips (outward and return), separated into relevant time period specific Origin-Destination matrices.

NHB movements are modelled as trips comprising a single leg from the origin to the destination. They are generated from HB trip ends (e.g. Persons arriving at work) using an approach similar to that embedded within the DfT's National Trip End Model.

2.6. Model Run Years

The model is implemented for a starting year of 2011 making use of the Census data, and then updated to a base year of 2015 for consistency with the highway model validation.

Validation of HB Work (HBW) trips has been carried out in 2011, for direct comparison with 2011 Census Journey to Work data. All other model calibration and most validation has been carried out in the 2015 base year, specifically using transport supply and demand data from November 2015 wherever available. The growth between 2011 and 2015 is described in Section 5.4, and full details of the model calibration and validation results are presented in Chapters 7 and 8. Due to the age of the model and underlying data, a "Present Year" 2019 forecast has also been implemented to demonstrate how well the model reflects changes through time and continues to provide a sound basis for assessing the impacts of alternative development and transport scenarios.

The model can theoretically be run for any individual future year as a forecast, and each forecast year is standalone (no interim year model running is necessary) – but inputs have only been prepared for five year steps from 2026 to 2041. The CSRM2 model Forecasting Report provides more information on model forecasting procedures and future year assumptions.

2.7. Demand Segmentation

The segmentation of traveller demand in the TDM, and assignment sub-models has been designed in a way to capture the differences in behavioural responses relevant to the choices being modelled. Good segmentation is important for different groups within the model to be able to respond realistically, but additional segmentation also imposes a computational cost. The design is based on a balance between realism and practicality, using a combination of past experience, research, and TAG guidance. This basic structure has been maintained as in CSRM1, with only minor modifications to the age groups of school pupils to align with the 2011 Census (see Table 5-2).

Journey Purposes

There are a maximum of five HB and two NHB journey purposes represented within the TDM as shown in Table 2-3.

Table 2-3 - Trip purposes in TDM

Abbreviation	Purpose	Value of time category
HBW	Home-Based Work	Non-work non-discretionary
HBEd	Home-Based Education	Non-work discretionary
HBPS	Home-Based Personal business and Shopping	Non-work discretionary
HBRV	Home-Based Recreation and Visiting friends and relatives	Non-work discretionary
NHBO	Non-Home-Based Other	Non-work discretionary
HBEB	Home-Based Employer's Business	Work
NHBEB	Non-Home-Based Employer's Business	Work

These seven purposes are an aggregation of those used in the DfT NTEM dataset.

Table 2-4 shows how the trip purposes from the TDM are aggregated for use in both the PT-Walk-Cycle and the HAM assignment models.

Table 2-4 - Purpose segmentation in each sub-model

TDM trip purpose	PT-Walk-Cycle assignment sub-model	Highway assignment sub-model (HAM)
HBW	HBW	HBW
HBEd	HBEd	HBEd
HBPS	Other	Other
HBRV		
NHBO		
HBEB	EB	EB
NHBEB		

Travel purposes are further segmented in various ways depending on the trip purpose. The segmentation also varies at different stages of the model depending upon what choices have been made higher up the hierarchy, and what is important for modelling behaviour. For example, household car availability is very important in mode choice but less important in distribution, so it is dropped at lower levels of the hierarchy to reduce the size of the model.

Segmentation Definitions

The following segmentation definitions are adopted for different choice stages and travel purposes of the TDM.

- **Car availability:** the following classification of households that combines information on number of cars with that on number of adults within the household was used:
 - None: households that do not have a car available for private use;
 - Part availability: households of two or more adults having only one car available for private use; and
 - Full availability: one adult household with at least one car, or two or more adults with two or more cars available for private use.

- **Employment status:** whether the person is in:
 - Full-time work (31 hours or more per week); or
 - Part-time work (30 hours or less per week).

- **Socio-economic classification:** which represents differences in occupation and economic status. TDM uses an aggregation of the standard National Statistics socio-economic classification (NS-SeC), called Grouped Socio-economic Classification (GSeC) as defined in Table 2-5. GSeC is somewhat correlated with income. However, for commuting travel, GSeC is better able to capture the variation in behaviour (especially trip length and different location of jobs) than income and data is available from the Census to assist in calibrating the model. For this reason, in CSRM2 the travel to work (HBW) tour distribution stage is segmented by the four employed GSeC categories rather than by income. This demand is then segmented by income for the sub-mode choice and assignment stages, as described below.

- **Income band:** based on gross annual household income in 2015 prices:
 - Low income (< £20,000);
 - Medium income (£20,000 to £40,000); and
 - High income (>£40,000).

- **Time of Day (TOD):** four time periods within the average weekday:
 - AM Peak: 07:00–09:59;
 - Inter Peak: 10:00–15:59;
 - PM Peak: 16:00–18:59; and
 - Off Peak: 00:00–06:59 and 19:00–23:59. The Off Peak is modelled for HBW and HBEB trips, but only as a “sink” (volume is allocated the choice model but not assigned in the network models). This is because HBW and HBEB trips are more likely than other purposes to start in the Off Peak and return before 19:00 (or vice versa), hence requiring the return/outward leg to be modelled (see also Table 2-17 below). For other purposes (except education) the Off Peak period is included within the trip rates themselves, but is explicitly excluded in the stage of time of day split (proportion values of AM Peak, Inter Peak and PM Peak over 24 hour total are available in the model). For education, 12 hour trip rates are used as there are assumed to be no Off Peak trips.

- **Main mode choice:** Car / light vehicle, Public Transport, Walk and Cycle. See Table 2-10.

- **Age group of the pupil for education trips:**
 - Primary: age 5-11;
 - Secondary: 12-16;
 - Sixth form: 17-18; and
 - Tertiary/higher education adult: 19 and over.

Table 2-5 - Grouped Socio-economic Category (GSeC) defined from NS-SeC

Grouped Socio-economic Category (GSeC)	National Statistics Socio-economic Classification (NS-SeC) as used in 2011 Census
GSeC1	1.1 Large employers and higher managerial occupations
	1.2 Higher professional occupations
GSeC2	2. Lower managerial and professional occupations
GSeC3	3. Intermediate occupations
	4. Small employers and own account workers
	5. Lower supervisory and technical occupations
GSeC4	6. Semi-routine occupations
	7. Routine occupations
Not used	8. Never worked and long-term unemployed
Not used	- Persons over retirement age not in employment

Source: Table 3, National Statistics socio-economic classification user manual. Page 9

Derivation of school age bands

Note that age is not necessarily the same as curriculum year. In particular, students typically move from a primary school to a secondary school somewhere around the age of 11-12 rather than on their birthday. This means that the "Primary" segment may actually include some secondary school students and vice-versa. This can also be true of few students moving to a separate 6th form college at the age of 15-16.

This age segmentation is necessary because the model is based on the population data from the Census at the home end, which is tabulated by age. Fortunately, the proportion of students affected is small, and the model should still be superior to models which combine all school years into a single segment. Observed school pupil data by age and curriculum year has been used to adjust school size terms in the model appropriately. Base year (2015) and Present year (2019) schools data was obtained from the government's Schools Census database. See Chapter 5 for more details.

Transport Demand Model segmentations

Table 2-6 to Table 2-9 give the segmentation of the TDM travel demand at the main mode, time of day, tour distribution, sub-mode and route choice stages for each of the trip purposes modelled. Further commentary is provided below the tables.

Table 2-6 - HBW trips – segmentation by choice stage

Choice Stage	Number of segments	Dimension A	Dimension B	Dimension C	Dimension D
Main mode	24	Car availability[3]	GSeC[4]	F-/P-time[2]	
Time of Day (TOD)	32	Main mode[4]	GSeC[4]	F-/P-time[2]	
Distribution	128	TOD[4]	Main mode [4]	GSeC[4]	F-/P-time[2]
PT Sub-mode and P&R site choice	64	TOD[3]	Main mode [2]	GSeC[4]	F-/P-time[2]
Highway assignment (HAM)	9	TOD[3]	Income[3]		
Assignment: PT legs	144	TOD[3]	Income[3]	Sub-mode[24] (bus, GB, rail, P&R/P&A [7], rail P&R [7])	
Attraction constraints	8	GSeC[4]	F-/P-time[2]		

Note: Assignment PT sub-modes include 7 P&R sites for P&R and P&A, and 7 rail stations (6 major stations plus local station) in the base bear, but the number can be expanded in future years. See Section 2.9.

Table 2-7 - HBEd trips – segmentation by choice stage

Choice Stage	Number of segments	Dimension A	Dimension B	Dimension C	Dimension D
Main mode	36	Age[4]	Income[3]	Car availability[3]	
Distribution	48	Age[4]	Income[3]	Main mode[4]	
PT sub-mode and P&R site choice	24	Age[4]	Income[3]	Main mode[2]	
Highway assignment (HAM)	3	TOD[3]	Income[1]		
Assignment: PT legs	144	TOD[3]	Income[3]	Sub-mode[24] (bus, GB,rail, P&R/P&A [7], rail P&R [7])	
Attraction constraints	4	Age[4]			

Table 2-8 - HB and NHB EB trips – segmentation by choice stage

HB / NHB trips	Choice Stage	Number of segments	Dimension A	Dimension B	Dimension C
HBEB	Main mode	9	Car availability[3]	Income [3]	
	TOD	12	Main mode[4]	Income[3]	
	Distribution	48	TOD[4]	Main mode[4]	Income[3]
	PT sub-mode and P&R site choice	24	TOD[4]	Main mode[2]	Income[3]
NHBEB	Distribution	36	TOD[3]	Main mode[4]	Income[3]
	PT sub-mode and P&R site choice	18	TOD[3]	Main mode[2]	Income[3]
HB & NHB combined	Assignment: car legs	3	TOD[3]	Income[1]	

HB / NHB trips	Choice Stage	Number of segments	Dimension A	Dimension B	Dimension C
	Assignment: PT legs	144	TOD[3]	Income[3]	Sub-mode[24] (bus, GB,rail, P&R/P&A [7], rail P&R [7])

Table 2-9 - Discretionary (HBPS, HBRV and NHBO) trips – segmentation by choice stage

Purpose	Choice Stage	Number of segments	Dimension A	Dimension B	Dimension C
HBPS	Main mode	9	Car availability[3]	Income [3]	
	TOD	12	Main mode[4]	Income[3]	
	Distribution	36	TOD[3]	Main mode[4]	Income[3]
	PT sub-mode and P&R site choice	18	TOD[3]	Main mode[2]	Income[3]
HBRV (same as HBPS)	Main mode	9	Car availability[3]	Income [3]	
	TOD	12	Main mode[4]	Income[3]	
	Distribution	36	TOD[3]	Main mode[4]	Income[3]
	PT sub-mode and P&R site choice	18	TOD[3]	Main mode[2]	Income[3]
NHBO	Distribution	36	TOD[3]	Main mode[4]	Income[3]
	PT sub-mode and P&R site choice	18	TOD[3]	Main mode[2]	Income[3]
All discretionary HB & NHB combined	Assignment: car legs	9	TOD[3]	Income[3]	
	Assignment: PT legs	144	TOD[3]	Income[3]	Sub-mode[24] (bus, GB,rail, P&R/P&A [7], rail P&R [7])

Below the sub-mode choice stage for commuting travel, each GSeC and Full/Part time combination is subdivided into the percentage in each of the three income groups using National Travel Survey (NTS) data 2012-14 to provide the proportional split by income group for each GSeC category. The results are then aggregated into income categories, prior to carrying out the assignment for income-based user classes: Low (less than £20,000); Medium (from £20,000 to £40,000), and High (higher than £40,000) of gross annual household income in 2015 prices.

Commuting tours are generated at the residence (production) end and are constrained at the workplace (attraction) end. The trip ends at the residence zones are segmented by the 24 categories listed at the main mode choice stage in Table 2-6 above, whereas the attractions are constrained by GSeC and for full / part time workers since information on car availability at the workplace is not readily available.

HBEEd tours are generated at the residence (production) end and are constrained at the school/college (attraction) end, except for higher education tours which are singly constrained. The trip productions at the residence zones are segmented by the 36 categories listed at the main mode choice stage Table 2-7.

Unlike the HBW and HBEEd travel purposes, there is no comprehensive source of local data describing modal travel patterns on HBEB or for discretionary travel (HBPS and HBRV). Hence, these trip purposes are represented as singly constrained tours within the model.

NHB movements are represented for two distinct purposes: NHBEB, and NHBO which is defined as all remaining purpose categories combined. They are modelled as singly constrained trips not tours. No explicit time of day (TOD) choice or main mode choice stage is included here. Instead, NHB trips are generated using

fixed trip rates by time period and main mode, which are applied only to those zonal attractions that have already arrived in the previous or current time period.

2.8. TDM Mode Definitions

The main modes for mode choice are car, PT, walk and cycle. Car further subdivides into car and P&R (car plus bus/Guided Bus) or P&A (car plus walk/cycle); PT into bus, guided bus and rail, while rail further divides into rail trips with and without car access. (See Figure 2-9 and Figure 2-10.) The modes and sub-modes are identical to CSRM1; however, adjustments have been made to the treatment of P&R site-choice to ensure that a single P&R site is used for outward and return journeys on a given day. In addition, as part of the F-series model version, users have now an alternative active mode choice to the conventional bus / Guided Bus at the P&R sites.

The path building and assignment is carried out for each of the following individual modes: car, P&R / P&A, bus, Guided Bus, rail, cycle and walk. Path building uses the PT-Walk-Cycle assignment sub-model (MEPLAN based software) for all of these modes, except for car and the car legs of P&R and rail trips, which are assigned in the SATURN based HAM.

The main modes of travel defined in the TDM are shown in Table 2-10.

The modes shown are defined as the 'main' mode of travel. Travellers using public transport main modes can access that mode by another 'access' mode. For example, driving to the station or walking to the bus stop. The combinations of access modes allowed for each main mode of travel have been defined to ensure representation of realistic travelling patterns.

Table 2-10 - Transport modes in the CSRM2

Main mode	Sub-mode	Description
Car / light vehicles	Car	Both car drivers and passengers. Includes cars, motorcycles, taxis and other light vehicles (vans) used for personal travel* (Work / business car is differentiated from non-work car).
	P&R	Car plus either bus or Guided Bus at current or future P&R sites
	P&A	Car plus walk or cycle or a combination of both, at current or future P&R sites
Bus	Bus	Local and regional bus services
Rail	Rail, drive to station	Timetabled services from, to and within study area. Note that "Rail, drive to station" is frequently referred to as "Rail P&R".
	Rail, no car leg	
Guided Bus	Guided Bus	Higher quality bus services using the Cambridgeshire Guided Busway.
Walk		Journeys entirely on foot.
Cycle		Journeys entirely by bicycle.

*Note: *The demand model trip rates have taken account of LGV movements in the National Travel Survey (i.e. LGV used for personal travel especially for HBW and Employer's Business) and so the TDM's travel demand includes both personal and employer's business trips by LGVs. The NTS however does not include trips primarily for goods delivery or delivery rounds. See Section 6.12 regarding Goods Vehicle modelling.*

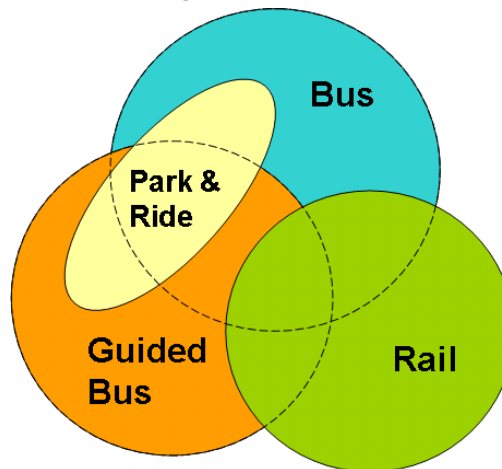
Hierarchy of modes for multi-leg journeys

OD trips in the assignment model can be multi-stage, incorporating legs by multiple modes and interchange between them. For walk, cycle and car trips, the hierarchy is intuitively simple:

- Where walk and cycle are allowed as access to other modes, the mode being accessed is reported as the main mode for the trip;
- Car trips can feature walk (but no other mode) as an access mode to/from the trip destination; and
- Bus or Active modes P&R is a sub-mode of car, but rail P&R (driving to a railway station) is a sub-mode of rail.

Public transport definitions conform to a hierarchical design, as shown in below Figure 2-6. Where a trip includes a rail element, it is a rail trip. If a trip includes a Guided Bus element and no rail element, it is a Guided Bus trip. If a trip includes a Guided Bus element and a bus element, it is a Guided Bus trip. Trip in this case is defined by the overarching main mode.

Figure 2-6 - Public transport hierarchical design



P&R trips are those that use bus, Guided Bus or both with a car drive leg of the journey at one end. P&R cannot use rail services (interchange is prohibited). This is partly related to the hierarchical design issue, and also to the assumption that bus-based P&R is not used to access rail. A passenger who walks to a P&R site and catches the bus is making a bus trip and not a P&R trip, even though it is a P&R branded bus, and similarly if they walk to a Guided Bus site they are making a Guided Bus trip without car access.

P&A trips are those that use walk or cycle after they have driven to a P&R site.

“Kiss & Ride” trips, i.e. drop-offs at P&R sites, are not captured explicitly in CSRM2, although the car legs are implicitly included within the validated highway model and the bus ridership is also validated against observed bus ticket sales – but in theory the volume of such trips could be underrepresented due to lack of car availability. There are no car parking capacity restraints within the model, so capturing these trips as ordinary P&R trips does not prevent others from using the car park.

More information on the interchange rules is given in Table 2-11, and detailed interchange diagrams provided in Chapter 3.

Table 2-11 - Access Modes available for PT Main Modes

PT Main Mode	Permitted Access Modes				
	Car	Walk	Cycle	Bus	Guided Bus
Rail	Y	Y	Y	Y	Y
Guided Bus	-	Y	Y*	Y	-
Bus	-	Y	-	-	-
P&R	Y	-	-	-	-

Note: * a cyclist can access Guided Bus only at designated sites such as P&R sites. “Y”=YES.

2.9. Choice Model Structure

The set of traveller choices represented in the TDM and their relative importance in the choice hierarchy is constructed in accordance with the DfT’s TAG Unit M2.1 Section 4.5 (DfT, May 2020) where appropriate local data is not available to determine the model structure. TAG M2.1 4.5.5 defines the following traveller’s choices and their relative sensitivity to travel cost and time differences, from least to most sensitive:

- Trip frequency may be represented as inelastic if all modes of transport including walking and cycling are considered;
- Main mode choice (i.e. between car, PT, walking and cycling) is as sensitive as macro time of day choice; in turn, macro time of day choice is less sensitive than micro time of day choice;

- Both main mode and macro time of day choices are significantly less sensitive than destination choice;
- Micro time of day choice for peak spreading on road is more sensitive than everything except route choice; and
- Finally, route choice among alternative paths in the network appears most sensitive of all of the choices, i.e. to travel costs and times of the options available.

For each travel purpose the TDM assumes a fixed trip frequency by traveller type since all modes including walk and cycle are represented in the model. The TDM then maintains the following choice sequence, from top (least sensitive) to bottom (most sensitive):

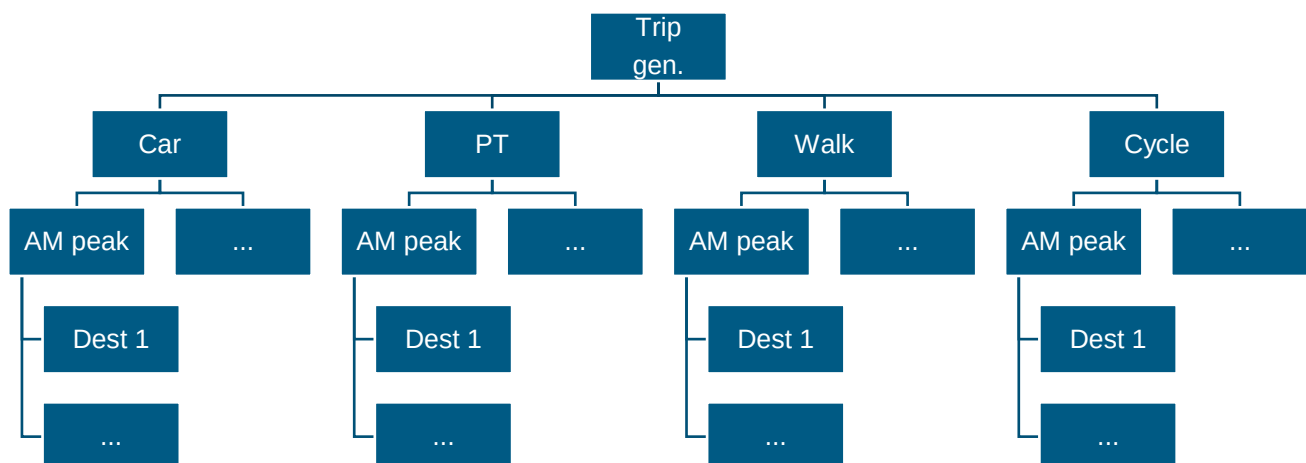
- Main mode choice: car versus public transport (PT) versus walk versus cycle;
- Macro time period choice for the outbound leg of modal tours for commuting, employer's business and discretionary travel. Education has no time of day choice;
- Tour distribution individually for each combination of main mode and outward time period;
- Sub-mode choice⁶: car versus P&R – this followed by choice of P&R site; bus versus guided bus versus rail –this followed by rail with no car access versus park at rail station; and
- PT-Walk-Cycle route choice. Light vehicle and HGV assignment is implemented in HAM.

A summary of the choices modelled with an indication of the part of the model (i.e. module) used within CSRM2 is presented in Table 2-12 and Figure 2-7.

Table 2-12 - Summary of choices modelled within the CSRM2

Demand response	Implemented in Module
Mode – Sub-mode choice	TDM (LUSA)
Time of day choice	TDM (LUSA)
Trip destination / attraction choice	TDM (LUSA)
P&R sub mode choice (PT or Active modes)	TDM (TASA)
PT, walk, cycle route choice	PT-Walk-Cycle assignment (TASA)
Highway light and HGV route choice	HAM assignment (SATURN)

Figure 2-7 - Main levels of choice hierarchy



The choice hierarchy adopted for all HBW and HBEB trips is shown in more detail in Table 2-8. The hierarchy for HBEd is the same except that there is no time of day choice, and for home-based discretionary trips (HBPS and HBRV) it is the same but with no Off Peak period. For space reasons, the hierarchy in Figure 2-8 has been

⁶ TAG M2.1 (section 4.5) gives no firm guidance on the position of sub-modes in the choice hierarchy, but suggests that sub-modes can be handled via assignment. In CSRM1 and CSRM2, sub-mode choice is placed just above assignment, which is consistent with that guidance and intuitively reflects the most critical choices made by residents.

expanded only on the car/P&R mode branch, but time-of-day and destination choices are the same for the other main mode choices. These branches are further expanded in Figure 2-9 and Figure 2-10. Walk and cycle have no sub-mode split.

Figure 2-8 - Choice hierarchy for HBW and HBEB

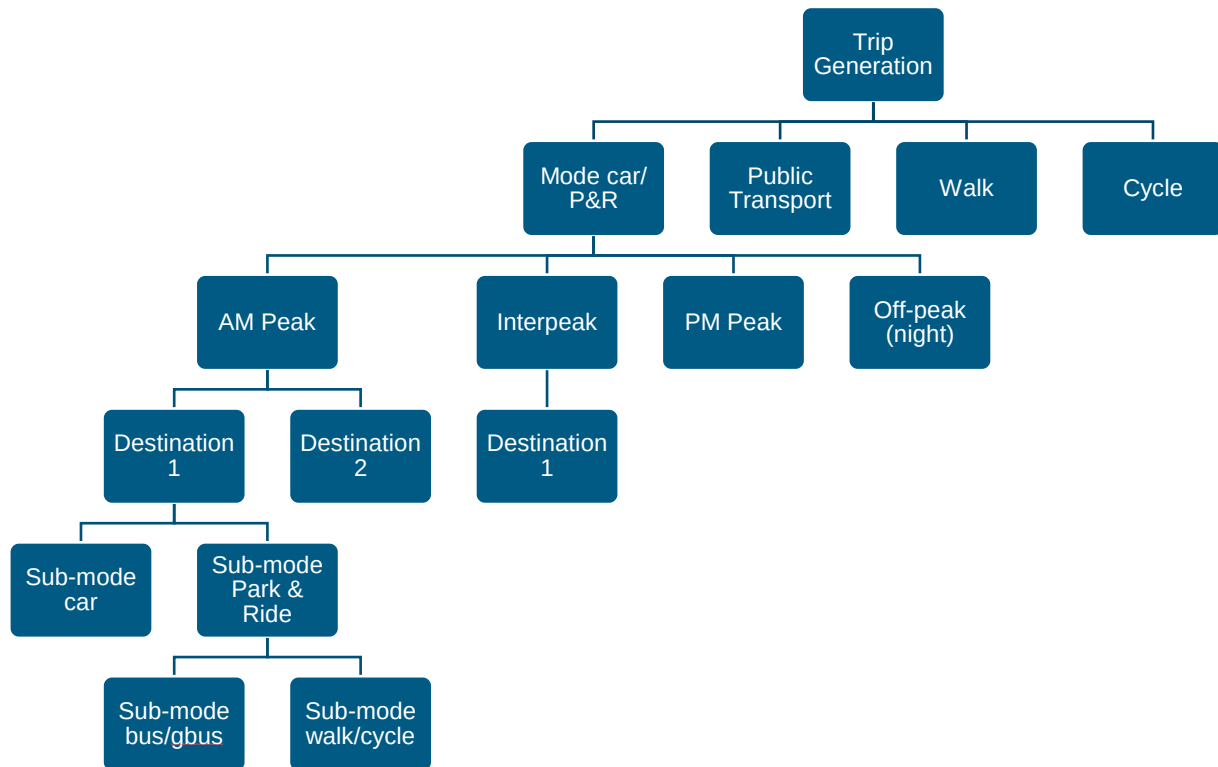


Figure 2-9 - Sub-mode tree for car main mode

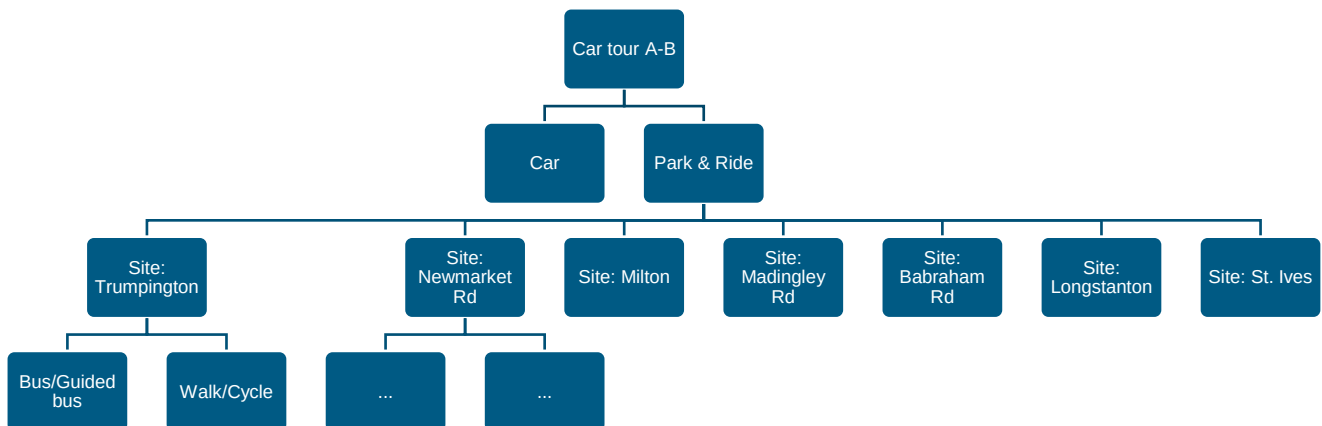
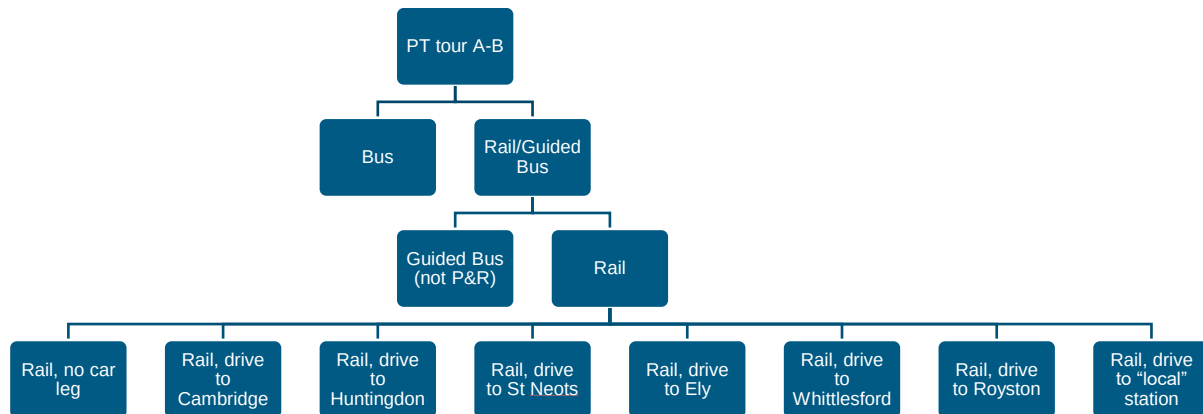


Figure 2-10 - Sub-mode tree for public transport main mode



Both main mode and macro time of day choices are less sensitive than destination choice, and the destination choice in turn is less sensitive than sub-mode choice, i.e. between car and bus-based P&R, or between bus, and Rail/GB. The Rail/GB mode as shown in Figure 2-10 further subdivides into Rail versus Guided Bus. Rail is split further into eight sub-modes: Rail with no car access and Rail with parking at either Cambridge, Huntingdon, St. Neots, Ely, Royston, Whittlesford or a predefined (by zone) “local” station. See Section 3.6 for more information on the rail services.

The P&R sub-mode (Figure 2-9) comprises a car leg plus the choice to continue the journey by either bus (or Guided Bus) or active modes from one of the seven P&R sites serving Cambridge in 2015 (Trumpington, Babraham Road, Madingley Road, Milton, Newmarket Road, Longstanton and St Ives) to destination zones. The proportional choice of each individual site for a specific zone to zone movement is calculated using a logit choice between the set of sites. The feeder mode choice from the P&R site is a hierarchical logit model choice between bus/Guided Bus and active modes (walk and cycle). As shown on Figure 2-7 to Figure 2-10, these are two further levels down within the travel demand choice hierarchy for the sub-mode P&R.

The Rail component models the ability to:

- drive to one of the six major rail stations within the study area (Cambridge, Huntingdon, St. Neots, Ely, Whittlesford or Royston) and park before catching a rail service. In the appropriate forecast years (2017 onwards), Cambridge North station at Chesterton is modelled as a further major station;
- drive to a “local” (nearest) station, park and catch a rail service. The definition of “local” is pre-determined and input to the model for each zone; and
- access a station with no car leg, with the option of walking, cycling, using a bus, or a Guided Bus to get there. In this case the choice of station is part of the route choice.

The distances, costs and times of car legs in P&R and rail movements are taken from skims by user class output from the HAM’s congested SATURN assignment, whereas the characteristics of the PT and Active modes legs are taken from the PT-Walk-Cycle network sub-model.

As noted previously the main choice stages are carried out for the HB tours. Prior to assignment to the network these tours are converted into the trips to and from home. The details of the travel demand unit (tour, trips) for each of the choice stages for each travel purpose are specified in Table 2-13.

Table 2-13 - TDM demand units

Trip Purpose	Main mode	TOD	Distribution	PT Sub-mode and P&R site choice ⁷	P&R bus v active choice	Assignment light and HGV	Assignment PT, Walk, Cycle
HBW	Tour (PA)	Tour (PA)	Tour (PA)	Tour (PA)	Trip (OD)	Trip (OD)	Trip (OD)
HBE	Tour (PA)	Tour (PA)	Tour (PA)	Tour (PA)	Trip (OD)	Trip (OD)	Trip (OD)
HBPS	Tour (PA)	Tour (PA)	Tour (PA)	Tour (PA)	Trip (OD)	Trip (OD)	Trip (OD)

⁷ The PT sub-modes include choice of rail station and are included alongside the choice of bus P&R site here, because each takes place in the MEPLAN software between distribution and assignment.

HBRV	Tour (PA)	Tour (PA)	Tour (PA)				
NHBO	No choice – generate by mode and TOD		Trip (OD)	Trip (OD)	N/A		
HBEB	Tour (PA)	Tour (PA)	Tour (PA)	Tour (PA)	Trip (OD)	Trip (OD)	Trip (OD)
NHBEB	No choice – generate by mode and TOD		Trip (OD)	Trip (OD)	N/A		

All the choices that are labelled “PA” in Table 2-13 are based on the combined characteristics of the outward plus the return leg of the tour. CSRM2 differs from CSRM1 in that all PT sub-mode and P&R site choices are considered as P-A tours, rather than at the O-D stage. This ensures that each tour uses the same sub-mode, rail station or P&R site for out and return journey legs. The choice hierarchies themselves are unaffected. The additional choice for bus or active mode to complete the P&R trip is made on an OD basis meaning that some P&R trips may use bus in one direction and walk in the other.

For every available O-D path through the network, the mode is determined based on the modal hierarchies (see Figure 2-6) as long as certain minimum proportion criteria have been met. For example, in order for a trip from Waterbeach to Central Cambridge to be available by rail mode, at least 10% of the journey distance must be carried out by rail (for a trip with walk access to the station) and at least 30% (for a trip with car access to the station). The minimum proportions specified in CSRM2 are shown in Table 2-14.

Table 2-14 - Minimum Proportion Values

User Mode		Available Network Mode(s)	Minimum Proportion
Walk		Walk	(100%)
Cycle		Cycle	(100%)
Rail (no car)		Rail ride	10%
		Rail access/egress, guided bus ride, guided bus access/egress, bus ride, bus access/egress, walk, cycle feeder, cycle interchange	No minimum
Guided Bus (no car)		Guided bus ride	10%
		Guided bus access/egress, bus ride, bus access/egress, walk, cycle feeder, cycle interchange	No minimum
Car		N/A – assigned in SATURN model	
Bus (no car)		Bus ride	10%
		Bus access/egress, walk	No minimum
Rail (station accessed by car)		Rail ride	30%
		Car interchange (at car park)	0.01%
		Rail access/egress, car drive to rail, walk	No minimum
P&R urban sites (accessed by car)	PT stage	Bus ride or guided bus ride	2%
		Car interchange (at car park)	0.01%
		Bus access/egress, guided bus access/egress, car drive to P&R, walk	No minimum
	Active modes stage	Walk or Cycle	No minimum
		Car interchange (at car park)	0.01%
		Car drive to P&R	0.1%
P&R rural sites (accessed by car)	PT stage	Bus ride or guided bus ride	5%
		Car interchange (at car park)	0.01%
		Bus access/egress, guided bus access/egress, car drive to P&R, walk	No minimum
	Active modes stage	Walk or Cycle	No minimum
		Car interchange (at car park)	0.01%
		Car drive to P&R	0.1%

2.10. Time Periods

Different time periods are used at different stages in the model. The time periods covered by each of the sub-models are shown in Table 2-15. There are three main sets of time periods defined:

- The day (12 or 24 hours) for trip generation, mode choice and input to time of day choice;
- The 3- or 6-hour time periods output from the time of day choice used for distribution, sub-mode choice and the PT-walk-cycle assignment; and
- The 3 individual hours used for the highway assignment.

The definitions used at each stage are shown in Table 2-15.

Table 2-15 - Time periods represented by each model component

Stage	HBW and HBEB	HB discretionary (HBPB and HBRV)	HB Education
Trip generation	Weekday 24 hours	Weekday 24 hours	Weekday 12 hours (0700 – 1859)
Main mode	Weekday 24 hours	Weekday 24 hours	Weekday 12 hours (0700 – 1859)
Time of day (TOD)	AM (0700-0959) IP (1000-1559) PM (1600-1859) OP (1900-0659)	AM (0700-0959) IP (1000-1559) PM (1600-1859) OP (1900-0659)	Not applicable
Distribution,	AM (0700-0959) IP (1000-1559) PM (1600-1859)	AM (0700-0959) IP (1000-1559) PM (1600-1859)	Weekday 12 hours (0700 – 1859)
Sub-mode	AM (0700-0959) IP (1000-1559) PM (1600-1859)	AM (0700-0959) IP (1000-1559) PM (1600-1859)	Weekday 12 hours (0700 – 1859)
PT-Walk-Cycle assignment	AM (0700-0959) IP (1000-1559) PM (1600-1859)	AM (0700-0959) IP (1000-1559) PM (1600-1859)	AM (0700-0959) IP (1000-1559) PM (1600-1859)
Highway assignment (HAM)	AM hour (0800-0859) IP hour (average hour, 1000-1559) PM hour (1700-1759)	AM hour (0800-0859) IP hour (average hour, 1000-1559) PM hour (1700-1759)	AM hour (0800-0859) IP hour (average hour, 1000-1559) PM hour (1700-1759)

The characteristics by time period which are used to generate the cost of travel for a tour starting in each period are shown in Table 2-16. These time periods were selected based on analysis of NTS data shown in Table 2-17. to identify which was the dominant return time period for each outward time and mode. (Note that some of these values, highlighted green in Table 2-17, were calibrated during the development of the model and are therefore not calculated directly from NTS.) Although Table 2-16 shows that some characteristics were taken from the Off Peak period, this period is not typically run. The derivation of these Off Peak characteristics is explained in Section 2.10.1 below.

The values in Table 2-17 are also used directly in the model to determine the return time period for any given trip.

Table 2-16 - Relationship between costs by time of travel and tour cost

Purpose		Tour	Outward leg (from home)	Return leg (to home) used for tour cost
HBW		1	AM Peak	PM Peak
		2	Inter Peak	Off Peak
		3	PM Peak	Off Peak
		4	Off Peak	Walk and cycle: Inter Peak Other modes: PM Peak
HBEd (no TOD choice)		1	AM Peak	Walk and cycle: Inter Peak Other modes: PM Peak
HBEB		1	AM Peak	PM Peak
		2	Inter Peak	PT: PM Peak Other modes: Inter Peak
		3	PM Peak	Off Peak
		4	Off Peak	Off Peak
HB Discretionary	HBPS	1	AM Peak	Walk and cycle: AM Peak Other modes: Inter Peak
		2	Inter Peak	Inter Peak
		3	PM Peak	PM Peak
	HBRV	1	AM Peak	Walk and cycle: AM Peak Other modes: Inter Peak
		2	Inter Peak	Inter Peak
		3	PM Peak	Walk and cycle: PM Peak Other modes: Off Peak

Since the CSRM2 does not model HBPS or HBRV trips in the Off Peak (OP), there are no OP From Home return trip breakdowns for these purposes.

Table 2-17 - Profile of return trips given time of outbound trip

Purpose	Period from home	Main mode	Main "to home" for supply	Time period to home			
				AM	IP	PM	OP
HBW	AM	Car	PM	0.9%	10.0%	83.3%	5.8%
		PT	PM	0.0%	6.2%	66.5%	27.3%
		Walk and cycle	PM	0.7%	23.0%	71.8%	4.5%
	IP	Car	OP	0.0%	25.0%	37.0%	38.0%
		PT	OP	0.0%	10.0%	33.4%	56.6%
		Walk and cycle	OP	0.0%	26.2%	26.9%	46.9%
	PM	Car	OP	0.0%	0.0%	21.5%	78.5%
		PT	OP	0.0%	0.0%	2.4%	97.6%
		Walk and cycle	OP	0.0%	0.0%	13.4%	86.6%
	OP	Car	PM	8.8%	36.5%	39.2%	15.5%
		PT	PM	15.0%	30.1%	41.9%	12.9%
		Walk and cycle	IP	9.5%	47.8%	34.6%	8.2%
HBEB	AM	Car	PM	1.7%	19.6%	69.3%	9.4%
		PT	PM	0.0%	16.1%	57.7%	26.2%
		Walk and cycle	PM	8.0%	28.7%	63.3%	0.0%
	IP	Car	IP	0.0%	46.4%	44.6%	9.0%
		PT	PM	0.0%	23.8%	43.6%	32.6%
		Walk and cycle	IP	0.0%	63.8%	36.2%	0.0%
	PM	Car	OP	0.0%	0.0%	21.8%	78.2%
		PT	OP	0.0%	0.0%	0.0%	100.0%
		Walk and cycle	OP	0.0%	0.0%	2.7%	97.3%
	OP	Car	OP	9.3%	22.2%	16.6%	51.9%
		PT	OP	0.0%	30.1%	0.0%	69.9%
		Walk and cycle	OP	0.0%	0.0%	0.0%	100.0%
HBPS	AM	Car	IP	15.0%	63.1%	19.2%	2.7%
		PT	IP	3.4%	90.0%	4.9%	1.7%
		Walk and cycle	AM	54.2%	42.2%	1.0%	2.6%
	IP	Car	IP	0.0%	81.0%	18.0%	1.0%
		PT	IP	0.0%	77.8%	20.2%	1.9%
		Walk and cycle	IP	0.0%	90.5%	9.2%	0.3%
	PM	Car	PM	0.0%	0.0%	63.2%	36.8%
		PT	PM	0.0%	0.0%	62.0%	38.0%
		Walk and cycle	PM	0.0%	0.0%	88.2%	11.8%
HBRV	AM	Car	IP	12.9%	61.2%	17.3%	8.6%
		PT	IP	0.0%	60.4%	27.7%	11.9%
		Walk and cycle	AM	58.0%	38.9%	2.5%	0.6%
	IP	Car	IP	0.0%	45.0%	44.3%	10.7%
		PT	IP ⁸	0.0%	38.3%	46.7%	15.0%
		Walk and cycle	IP	0.0%	76.9%	19.3%	3.8%
	PM	Car	OP	0.0%	0.0%	26.0%	74.0%
		PT	OP	0.0%	0.0%	3.9%	96.1%
		Walk and cycle	PM	0.0%	0.0%	63.1%	36.9%
HBEd	AM	Car	PM	29.2%	30.6%	38.2%	1.9%
		PT	PM	1.5%	25.7%	71.4%	1.4%
		Walk and cycle	IP	35.5%	43.3%	20.4%	0.8%

Source: Derived from National Travel Survey, 2012-2014, excluding London and metropolitan areas

⁸ Although PM is slightly larger in this case, IP is used for consistency with HBPS IP PT

2.10.1. Off Peak period

CSRM2 does not fully model the weekday Off Peak period (00:00-07:00 and 19:00-24:00). It is never assigned, nor is there sub-mode split or congestion modelling for it. The Off Peak exists in the model as a choice (“sink”) for HBW and HBEB time of day, so that these trips can choose to travel before or after the peak periods. Many of these trips are likely to be in the shoulder periods of 06:00-07:00 and 19:00-20:00, but no explicit assumptions have been made about their distribution within the Off Peak period.

It is therefore necessary to have skims HBW and HBEB for all four main modes in the Off Peak period. This is done as follows:

- Off Peak car takes distance and time skims from an Inter Peak SATURN HAM run where a matrix of very small values has been assigned. This estimates the network times without congestion. These values are then taken as fixed and do not respond to changes in the number of Off Peak trips;
- Off Peak Public Transport takes distances and costs from the Inter Peak model, and times from the Inter Peak but with 15 minutes added to represent additional waiting times; and
- Walk and cycle level of service does not vary by time period in the model so the Inter Peak skims are also used for the Off Peak.

The demand model for HBRV uses Off Peak cost skims for the return leg when calculating the costs for tours starting in the PM Peak, as in Table 2-16.

3. Networks and Non-Car Assignment

3.1. Overview

As outlined in Section 2.1, CSRM2 comprises two assignment models – a SATURN model used for detailed highway assignment plus a multi-modal network sub-model providing inputs for all other modes to the TDM. This chapter of the report describes the network sub-model for public transport, walk and cycle. The highway assignment model is described separately in the CSRM2 Local Model Validation Report (LMVR).

An integrated multi-modal transport network has been defined comprising a set of links and nodes for different modes of travel. The main components of the network are a representation of the public transport (PT), walk, cycle and intrazonal links. A series of access links are coded to connect each zone within the model to the appropriate modal network.

The road network used in the PT-Walk-Cycle assignment sub-model is based upon the SATURN HAM. Every SATURN link (excluding zone connectors) is converted to a highway network link for the assignment of bus services. This includes Guided Busway links, which are coded within the SATURN model for buses only. Cycle trips are also permitted to use all of these links (except for motorways and non-urban dual carriageways) which are classified according to the available cycle provision (painted or segregated cycle lane or shared with the motor users). A shadow copy of every highway link (excluding motorways and dual carriageways) is created for pedestrians – representing a “pavement network”. Dedicated walk and cycle routes are added to the networks derived from SATURN. A “drive link” connects each zone to P&R sites and rail stations. A separate additional network of rail track links is coded in addition to the above SATURN-derived components.

The intrazonal “network” consists of non-physical links that connect the zone centroid with itself, which are used for the assignment of intrazonal walk and cycle movements. Intrazonals are also defined for the car mode, although they are not assigned in the HAM. The model assumes public transport is not used for intrazonal movements, as the TDM zones are typically too small for this to be a sensible option.

Output congested highway link times from the HAM are transferred to the network sub-model (excluding links with bus lanes, which are assumed to be uncongested), and these times affect the route choice of bus and P&R journeys in the *PT-Walk-Cycle* network sub-model.

Figure 3-1 and Figure 3-2 show the base year TDM multi-modal network with an indication of highways, physical rail track, cycle/walk, and bus-only lanes.

For 2019, the 2015 base year multi-modal network has been modified to incorporate changes to the PT, walk and cycle network following the changes in Bus and Rail services, the full operation of Cambridge North station, the temporary rerouting of the Guided Bus services following the closure of the Guided Busway due to the A14 Roadworks and the completion of cycle schemes in the Cambridge area. In addition, development zones active in 2019 and their relevant connections to the highway network have been added. A full list of the schemes captured is listed in Table 3-1, while Figure 3-3 and Figure 3-4 show the equivalent 2019 multimodal network.

Table 3-1 - 2019 coded schemes

Scheme	Comment
Arbury Road cycleway	Conversion to segregated cycleway
Huntingdon Road cycleway	Conversion to segregated cycleway
Cambridge North station	Rail station as well as cycle access facilities and car park provision
Hills Road and Addenbrooke's Corridor	Conversion to segregated cycleway
Cherry Hinton High Street	Conversion to segregated cycleway
Trumpington Road	Conversion to segregated cycleway
A10 Frog End to Melbourn	Completion of the segregated cycleway
Bus and Guided Bus timetables	Updated as per October 2019 ATCO CIF file
Rail timetables	Updated as per October 2019 ATCO CIF file

Figure 3-1 - TDM 2015 multi-modal network – Study area

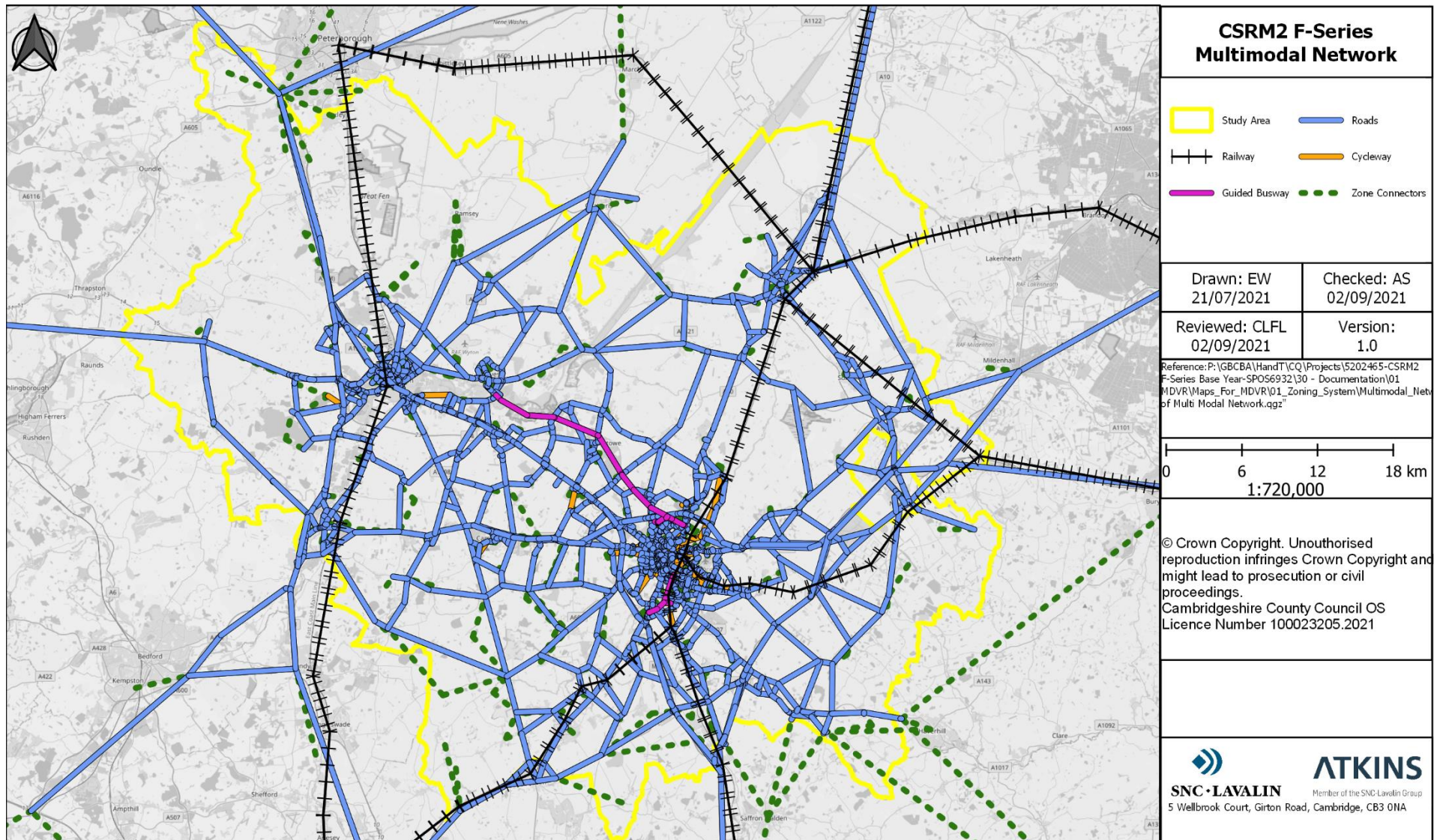


Figure 3-2 - TDM 2015 multi-modal network – Cambridge Zoom

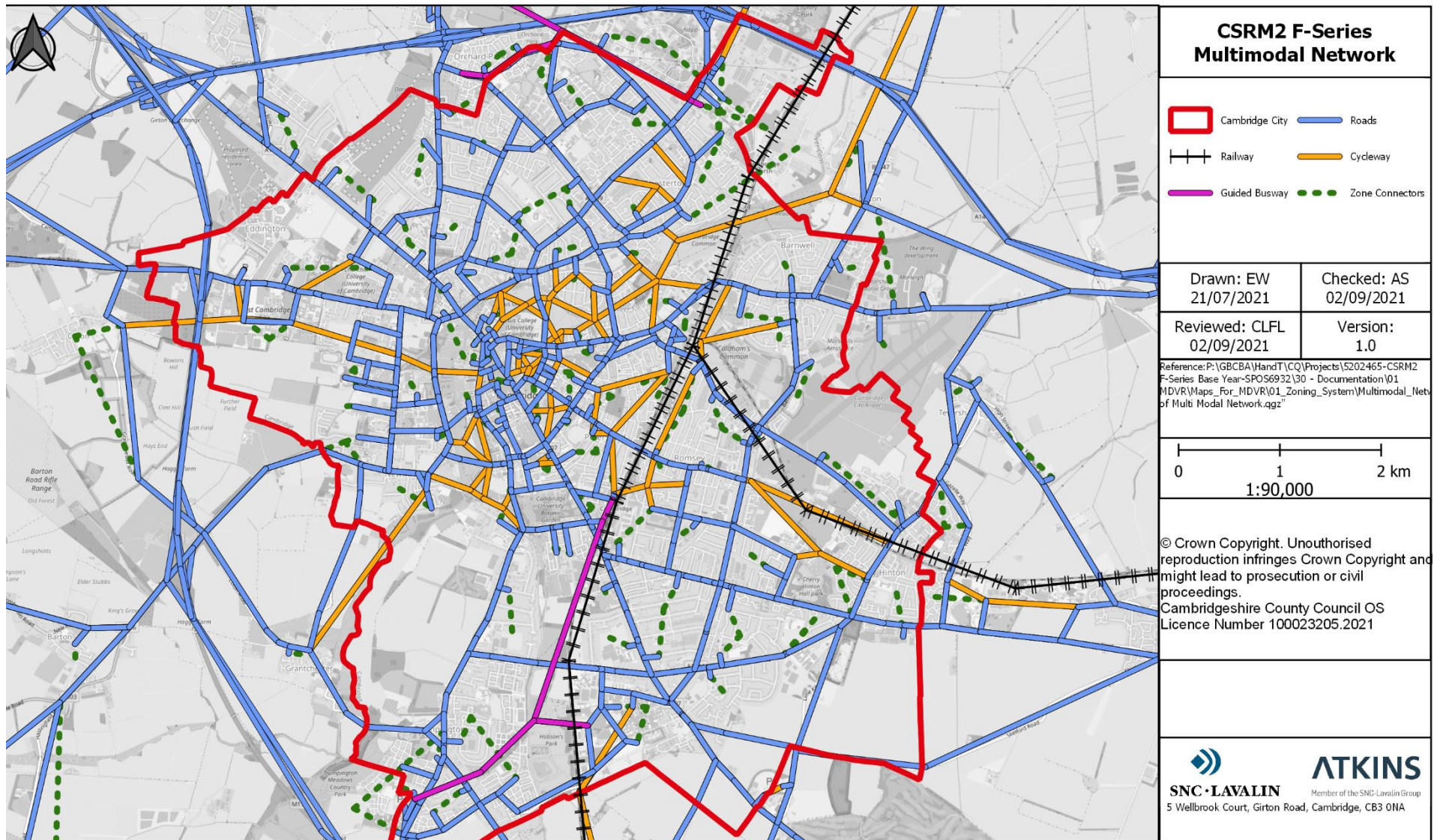


Figure 3-3 - TDM 2019 multi-modal network – Study area

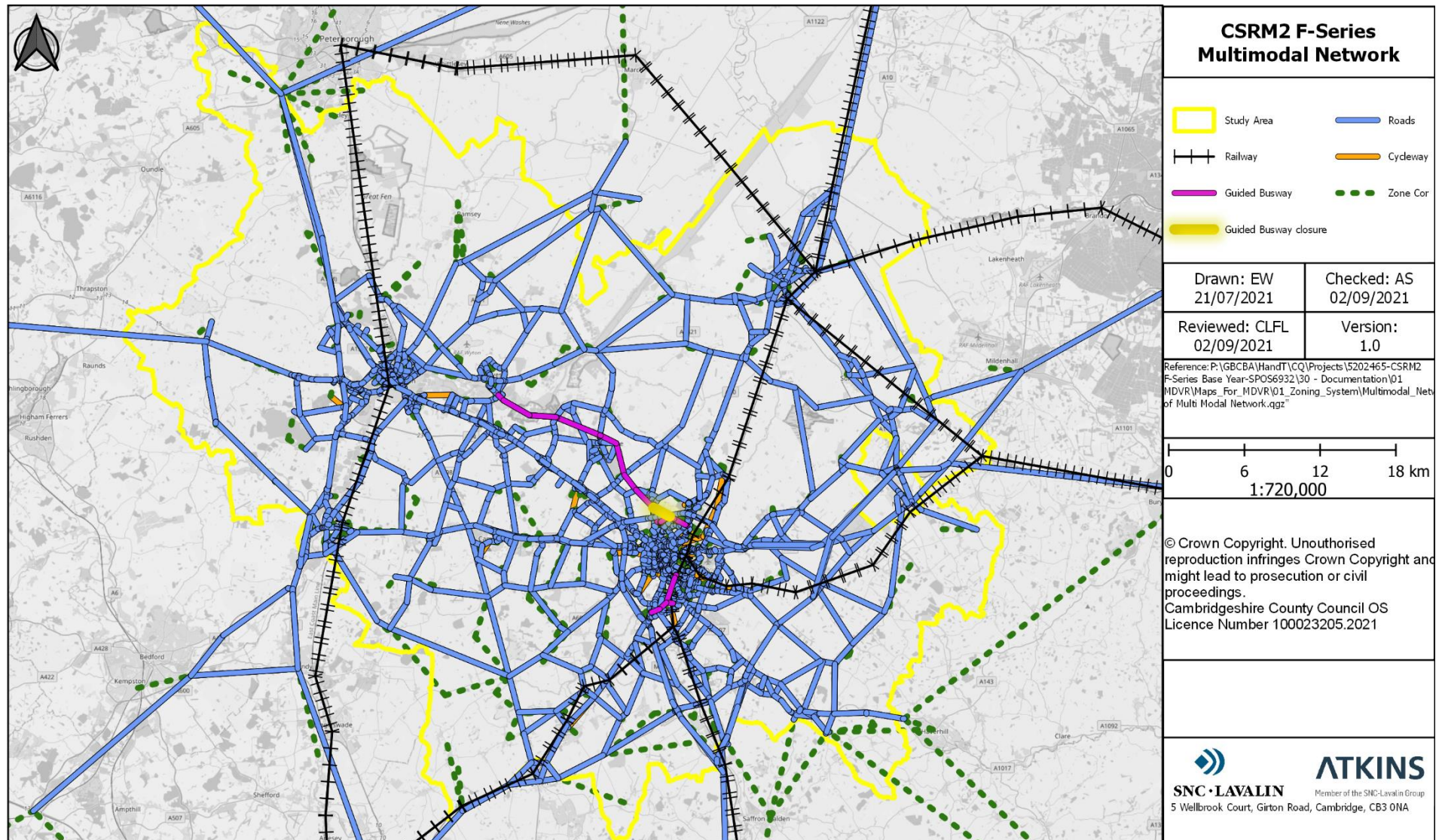
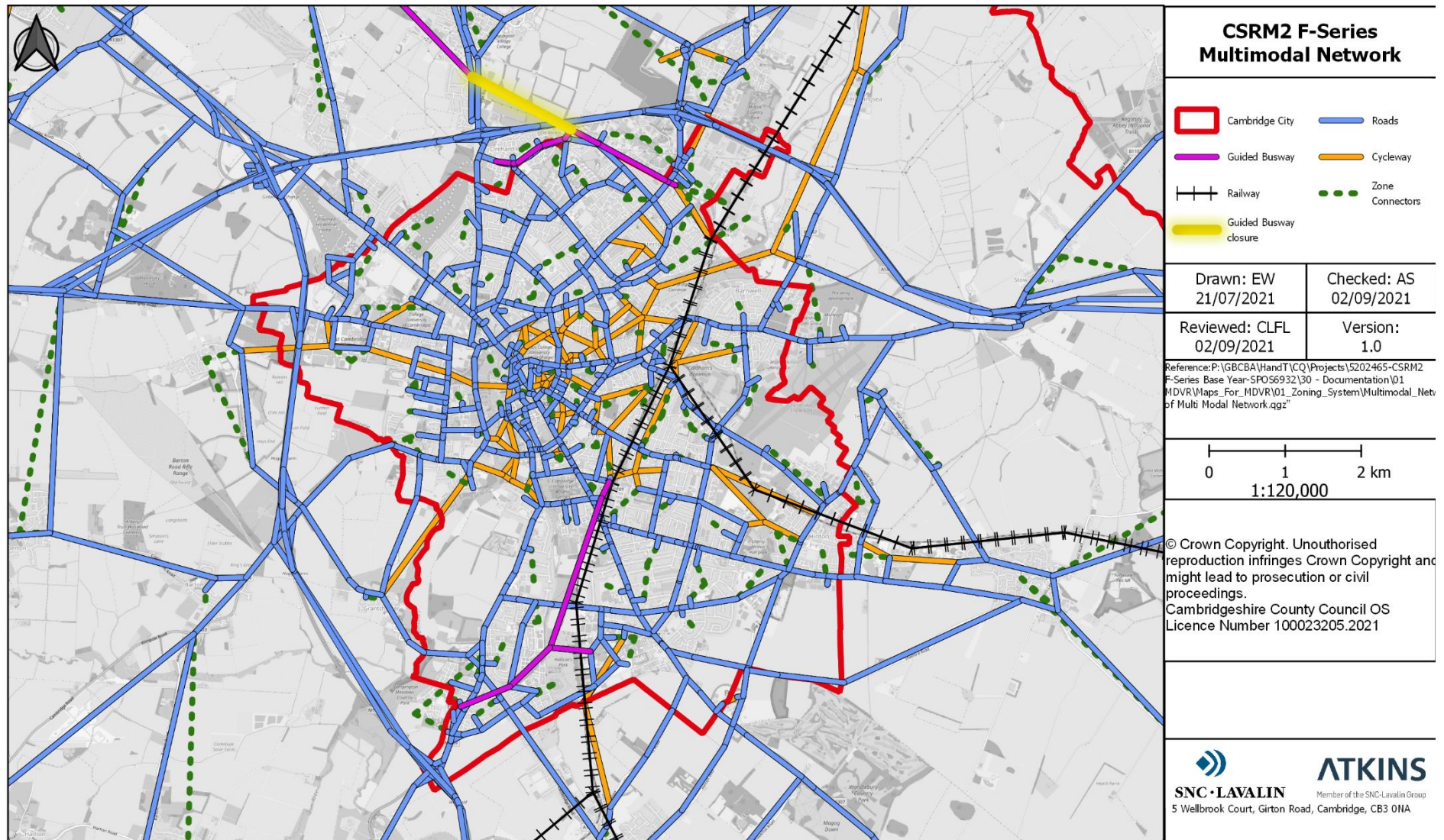


Figure 3-4 - TDM 2019 multi-modal network – Cambridge Zoom



The TDM network sub-model provides the cost, time and distance elements of the disutility (generalised cost) of travel between each relevant O-D zone pair for each mode in each of the time periods modelled. The travel costs are based on public transport fare functions that have been estimated from data assembled for the local area as described in Chapter 4. For the car access legs of P&R and rail trips, the distances and times are taken from the SATURN HAM and the costs calculated using the SATURN fuel cost parameters (ppk) as well as parking charges.

The path building on the networks is carried out for each of the following modes: P&R, bus, Guided Bus, rail, cycle and walk.

The modes walk and cycle have their supply characteristics determined by network paths that minimise the distance which is picked up from the road network links plus extra pedestrian/cycle links. Walk and cycle trips are assigned due to the number of specific facilities such as dedicated bridges and segregated facilities which currently exist and those which are proposed for Cambridge.

Bus supply characteristics are calculated by path building on a service by service basis using the congested SATURN HAM link times in the same fashion as for the bus leg of P&R. Rail path building also uses a service and headway representation of the options, together with feeder connections to stations. The impacts of any rail or bus overcrowding are not currently considered within the model.

The remainder of this chapter reviews the design of the multi-modal networks, the approach to path building and assignment, and the cost functions used to provide the supply characteristics for the demand model. This includes the intrazonal network and the network outside the study area.

3.2. Network Definitions and Link Types

The CSRM2 multi-modal network consists of:

- Roads for all traffic – with light vehicle/HGV journey assignment that is carried out in SATURN;
- Inter-modal connections such as rail and bus stations;
- Bus / cycle lanes (not for cars);
- Walk network (pavements and footpaths);
- Cycle infrastructure (painted cycle lanes, segregated facilities and on-road shared with motorised vehicles);
- Walk/cycle bridges;
- Rail links (railway track);
- Guided Busway (analogous to “track”);
- Bus and P&R services;
- Rail services;
- Drive to P&R and rail station links; and
- Intrazonal network representing roads for travelling within each model zone (for walk, cycle and car journeys only).

A multi-modal transport network comprises a set of links and nodes for different modes or stages of travel. Each type of link is defined to carry particular MEPLAN *network modes* (journey stages) e.g. walk to bus / rail, car ride to rail, PT wait.

The network modes / stages of travel defined in the CSRM2 are shown in Table 3-2.

Table 3-2 - Stages of travel defined in CSRM

Stage	MEPLAN ID “network mode”		
	AM	IP	PM
Walk	1	101	201
Cycle	2	102	202
Cycle feeder to P&R and Rail	3	103	203
Cycle to PT interconnection (cycle park)	4	104	204
Walk dummy (internal creation within PT-Walk-Cycle network sub-model) for entry/exit PT links	5	105	205
Bus feeder to rail services	9	109	209
Bus ride	10	110	210
Bus access/egress for PT service connectivity	11	111	211
Car drive to bus P&R interchange	12	112	212
Car drive from bus P&R interchange	13	113	213
Car drive to active P&R interchange	14	114	214
Car drive from active P&R interchange	15	115	215
Rail ride	20	120	220
Rail access/egress for PT service connectivity	21	121	221
Car drive to rail interchange	22	122	222
Car drive from rail interchange	23	123	223
Guided Bus feeder to Rail services	29	129	229
Guided Bus ride	30	130	230
Guided Bus access/egress for PT service connectivity	31	131	231
Car parks at Cambridge rail station	40	140	240
Car parks at Huntingdon rail station	41	141	241
Car parks at Ely rail station	42	142	242
Car parks at St. Neots rail station	43	143	243
Car parks at Local rail stations	44	144	244
Car parks at Cambridge North rail station (from 2019)	45	145	245
Car parks at Royston rail station	46	146	246
Car parks at Whittlesford rail station	48	148	248
Car parks at Milton bus P&R site	50	150	250
Car parks at Newmarket Road bus P&R site	51	151	251
Car parks at Babraham Road bus P&R site	52	152	252
Car parks at Trumpington bus P&R site	53	153	253
Car parks at Madingley Road bus P&R site	54	154	254
Car parks at St Ives Guided Bus P&R site	56	156	256
Car parks at Longstanton Guided Bus P&R site	57	157	257

Link types are defined to differentiate types of road, different access stages for public transport (access, wait, board, alight, interchange), main mode stage (car, bus ride, walking). The full set of link types which are defined in the *PT-Walk-Cycle* network sub-model for the AM Peak are shown in Appendix C with a summary shown in Table 3-3.

Table 3-3 - Outline of link types within multi-modal networks

Link type ID	Description
AM Peak period	
1	Highway links
2	Painted Cycle lane
3	Cycling on road whose modelled free-flow speed is ≤ 50 kph
4	Cycling on road whose modelled free-flow speed is > 50 kph and ≤ 70 kph
5	Cycling on road whose modelled free-flow speed is > 70 kph
11 to 16 and 51	Different stages of walk / cycle access
17	Cycle only links
21 to 23 and 27	Car drive to bus P&R sites, main and local rail stations
24 to 26 and 28	Car drive from bus P&R sites, main and local rail stations
30 to 39	Different bus access / interchange stages
40 to 49	Different rail access / interchange stages
50	Walk network
58 to 69	Car parking at different rail stations
70 to 79, 90, 91 and 97 to 101	Car parking at different P&R sites
80 to 89	Different Guided Bus access / interchange stages
95, 96	Links for intrazonal travel
Inter Peak period	
201 to 301	As for AM Peak, e.g. Type 201 is the same as type 1 AM Peak
PM Peak period	
401 to 501	As for AM Peak, e.g. Type 401 is the same as type 1 AM Peak

The IP link types are defined in the same way as the AM Peak types with 200 added to the link type, and PM Peak with 400 added. No network is defined for any other time periods.

The network is duplicated for each time period using the same node definitions. A similar definition of modes ensures that demand for travel in a time period occurs only on the network for that time period. Thus, the modes allowed to use link type 201 are the same as those on link type 1 with 100 added to the mode number.

Nodes have an XXX.YY form of numbering where XXX is conventionally used to denote the zone number in which the node is located. (Exceptions to this rule are trunk roads and the Cambridgeshire Guided Busway, which have their own numbering series unrelated to the zones they are passing through.) The PT transit (service) and interchange nodes are automatically generated when producing the bus, Guided Bus and rail transit lines. During that process a number of new wait, board/alight, access and egress links and nodes are created.

The main attributes defined on the network are the types of links (roads, railways), lengths, speeds or times and capacities. The following sections provide details on the connectivity of network and characteristics defined for each of the main modes of travel.

3.3. Bus and Guided Bus Network and Services

Bus and Guided Bus services are coded as MEPLAN “transit” lines, which make use of the physical highway network which has been defined from the SATURN highway network. The highway nodes are used as bus stops where appropriate.

Timetables used for the bus service coding were sourced from electronic ATCO-CIF format timetables covering the validation time period⁹. The ATCO-CIF timetables include individual bus service timings by bus stop. This information was transformed into transit lines with the following information:

- Individual bus services running through the strategic highway network were grouped by route code (e.g. Citi 1), direction (inbound or outbound) and time period, and each of these assigned a transit line code (e.g. C1A). Services with the same code, but following different routes, were coded separately.
- Bus stops were overlapped with the CSRM2 Highway nodes in GIS and only the ones showing a correspondence were retained from the ATCO file.
- The frequency of the transit line for each stop-to-stop link is represented by the headway, defined as the length of the period divided by the number of times a service calls in the period.
- The transit line time for each stop-to-stop link is measured based on the average timetabled time between representative bus stops.

Note that this arrangement allows for variations in bus frequency (headway) along a transit line. This can be used to represent bus routes with higher frequencies along part of the route, which is a common feature of Cambridgeshire bus services. The timetabled journey time between stops is treated as a minimum journey time. This is over-ridden automatically in the model in both base and future year runs should the journey time for on-road (with traffic) route sections be modelled by SATURN as slower than the timetabled time.

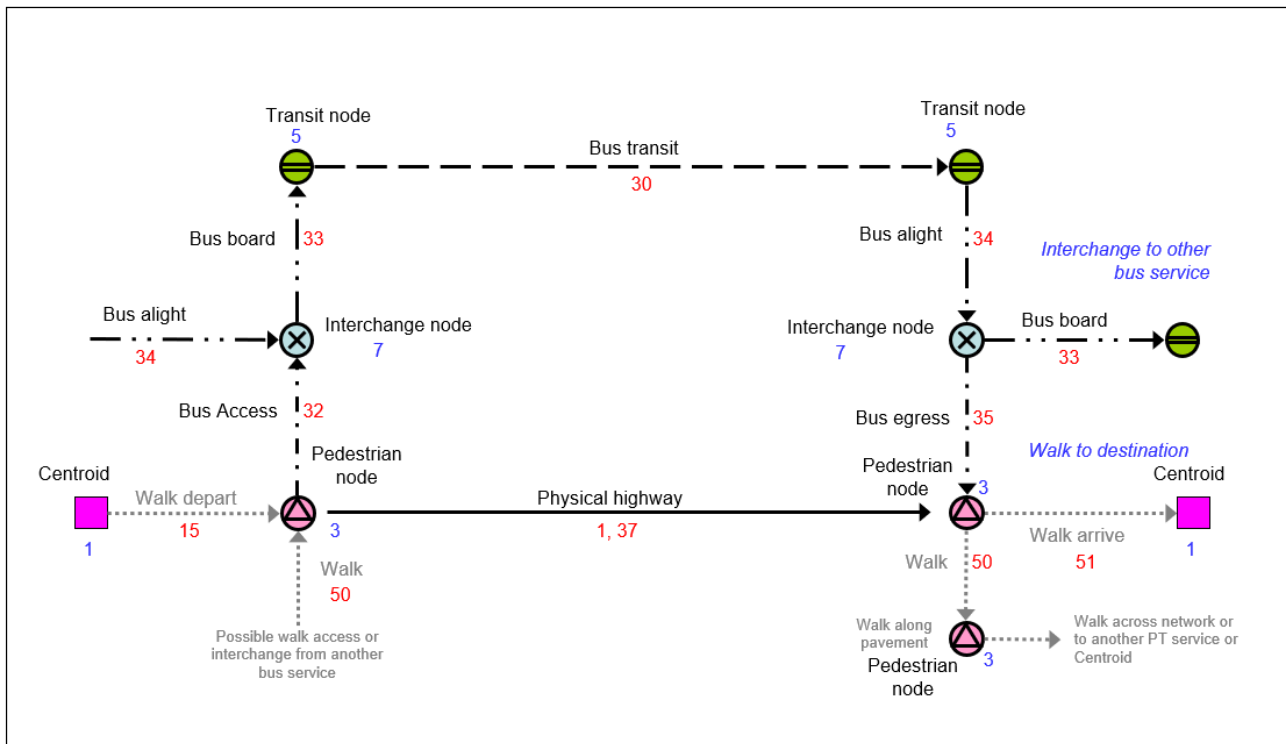
Figure 3-7 and Figure 3-8 show the internal bus network for the 2015 base year, including all bus and Guided Bus transit lines (public transport services), while Figure 3-9 and Figure 3-10 show the equivalent 2019 PYV bus transit lines.

In general, bus trips involve only bus ride and walk access mode. Buses are reached from the pedestrian network via a “*Bus Access*” link accessing the *Bus Interchange* node, which may be thought of as the bus stop.

Bus trips access the network via a two-way access/egress, or a combination of walk links towards a highway bus access node (walking to a bus stop) and then board onto the bus transit line as shown in Figure 3-5. This board time includes a wait time dependent on the headway (times between vehicles) of the transit line being boarded, plus a standard time of four minutes for boarding/buying a ticket. The board link connects the access bus node to a *transit node* where passengers can interchange between services. Passengers then ride along the bus transit line and connect back to a transit node and then highway node at the end of that part of the journey via an alight link. A standard time of 30 seconds is coded for alight links. The passenger may then either connect to a new bus transit line (via another board link) or egress via the access/egress link to the pavement network and walk to destination zone / centroid.

⁹ The ATCO-CIF data was extracted by Atkins from the Basemap ftp server (ftp.basemap.co.uk). The data obtained covers October 2015 for the base year model and October 2019 for the present year validation.

Figure 3-5 - Link connectivity for bus journeys without car access



Note: (31*) Direct access/egress from a zone centroid to bus access node (link type 31) occurs in external areas only.

Even though transit lines are a distinct link type, buses are still affected by congestion along highway links. The time taken to traverse each link is the maximum of the time coded for the service and the congested highway link time. Transit lines are effectively defined paths through the highway network along which buses travel.

At P&R sites, cyclists are also allowed to access the Bus mode. The linkages that operate at these sites for cycle access are the same as those which operate for cycle access to Rail stations as depicted in Figure 3-16. Since cyclists cannot access the Bus mode at any other stop, these linkages have not been included in Figure 3-5.

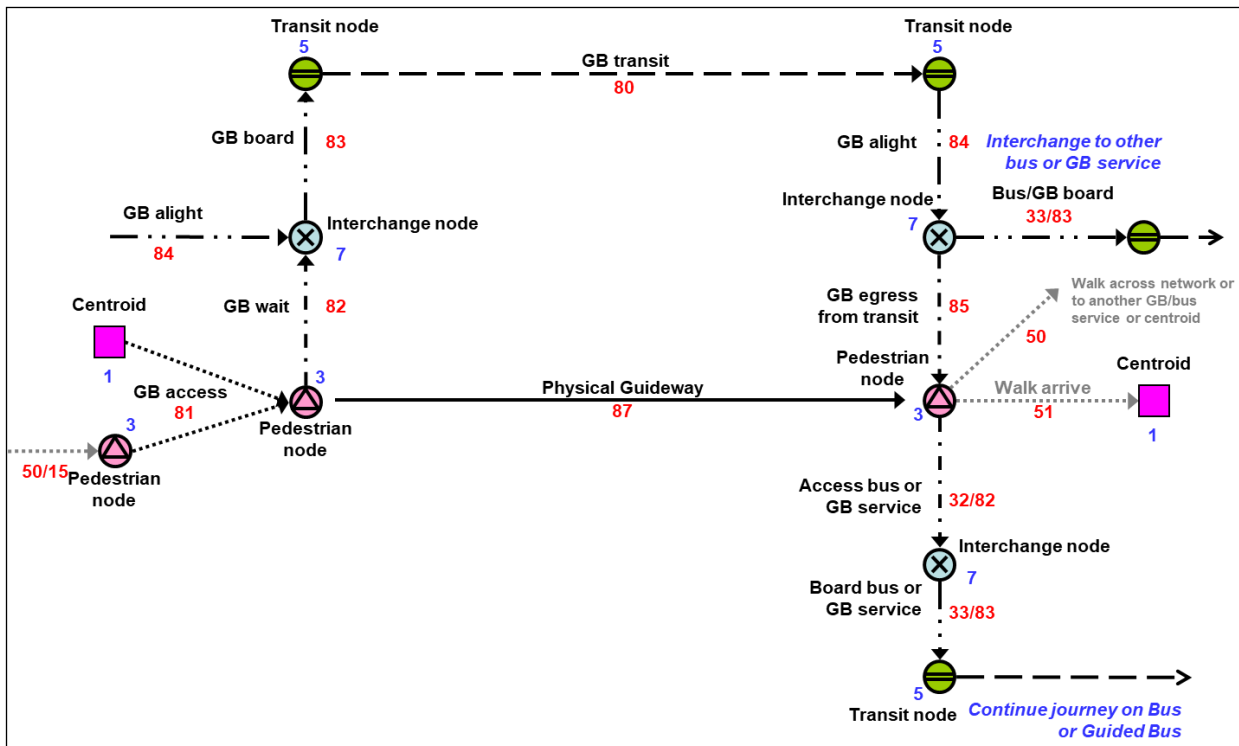
Bus trips are allowed to interconnect with other bus services only. This interchange may occur at the interchange node, accessed by the *Bus Alight* link. From the interchange link, *Bus Board* links exist for each service that may be accessed at that physical node. To alight from the network, users must *egress* to the pedestrian node.

On reaching their destination and alighting to the access node, passengers may walk along the network to either access a centroid or to pick up another bus service elsewhere.

Guided Bus (GB) works in a similar way to bus, although it makes use of both the guideway and regular highway network. Even if the guideway is not being used, a GB service remains a different mode to bus, reflecting the different levels of comfort, convenience and image that the Cambridgeshire Guided Busway services offer.

Within the GB mode, interchange to conventional bus services is allowed, since GB is above Bus in the public transport hierarchy. This takes place at the interchange node. This is allowable as GB mode can use both GB and Bus Board links. The PT node is accessed to alight the network or to use the walk network to a different location. An interchange node can be produced for multiple services at the same point, so access to other GB routes may be gained directly from the interchange node. Like Bus, the board and alight links associated with Guided Bus travel have times coded on them. For Guided Bus, the time coded on a board link is two minutes, and 20 seconds is coded on the alight links.

Figure 3-6 - Link connectivity for Guided Bus journeys without car access



It is possible for cyclists to access the GB mode at the P&R sites. The linkages that operate at these sites for cycle access are the same as those which operate for cycle access to Rail stations as depicted in Figure 3-16. Since cyclists cannot access the GB mode at any other stop, these linkages have not been included in Figure 3-6. It would be possible to allow cyclists to access the GB mode in other locations (by adding cycle park links at specific GB stops) – this functionality could be added to the model in the future if required.

Where car is used to access the GB network, it is considered to be part of the P&R mode.

3.3.1. External Bus Network

Bus services partially in the CSRM2 study area and partially in the external area are coded in the same way as internal bus services, to the edge of the physical highway network. Beyond that, bus access links representing the remainder of the bus journey have been coded separately: these have the same length as the equivalent highway zone connector, a charge calculated using the same distance-based cost function as the rest of the bus journey, and a time of 1 minute (because the full timetabled time was coded to the final highway node so no additional time is required). Figure 3-11 shows the bus services and access links coded in CSRM2.

Figure 3-7 - 2015 Base Year Bus and Guided Bus services networks – Study Area



Figure 3-8 - 2015 Base Year Bus and Guided Bus services networks – Cambridge



Figure 3-9 - 2019 Base Year Bus and Guided Bus services networks – Study Area

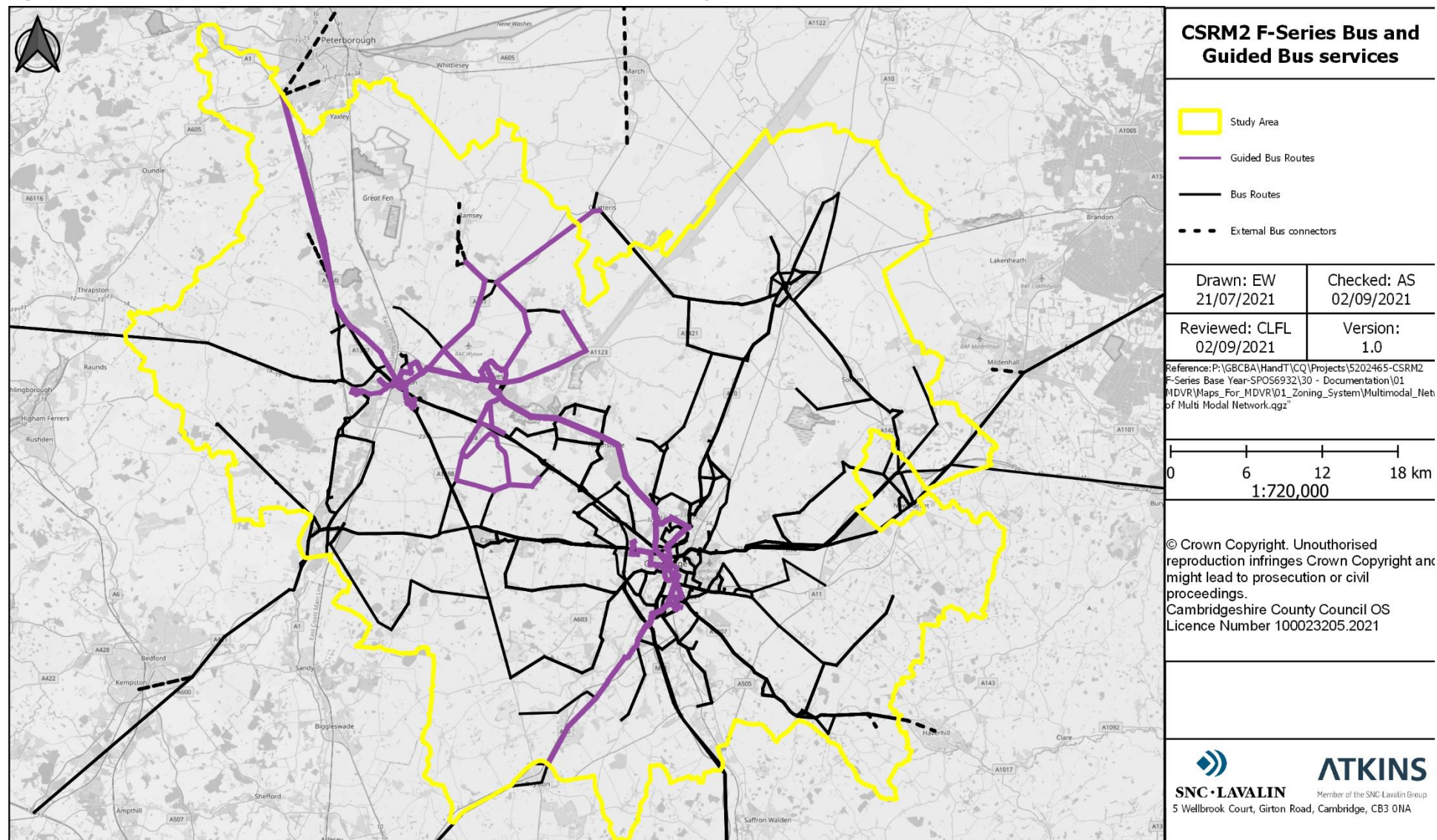


Figure 3-10 - 2019 Base Year Bus and Guided Bus services networks – Cambridge

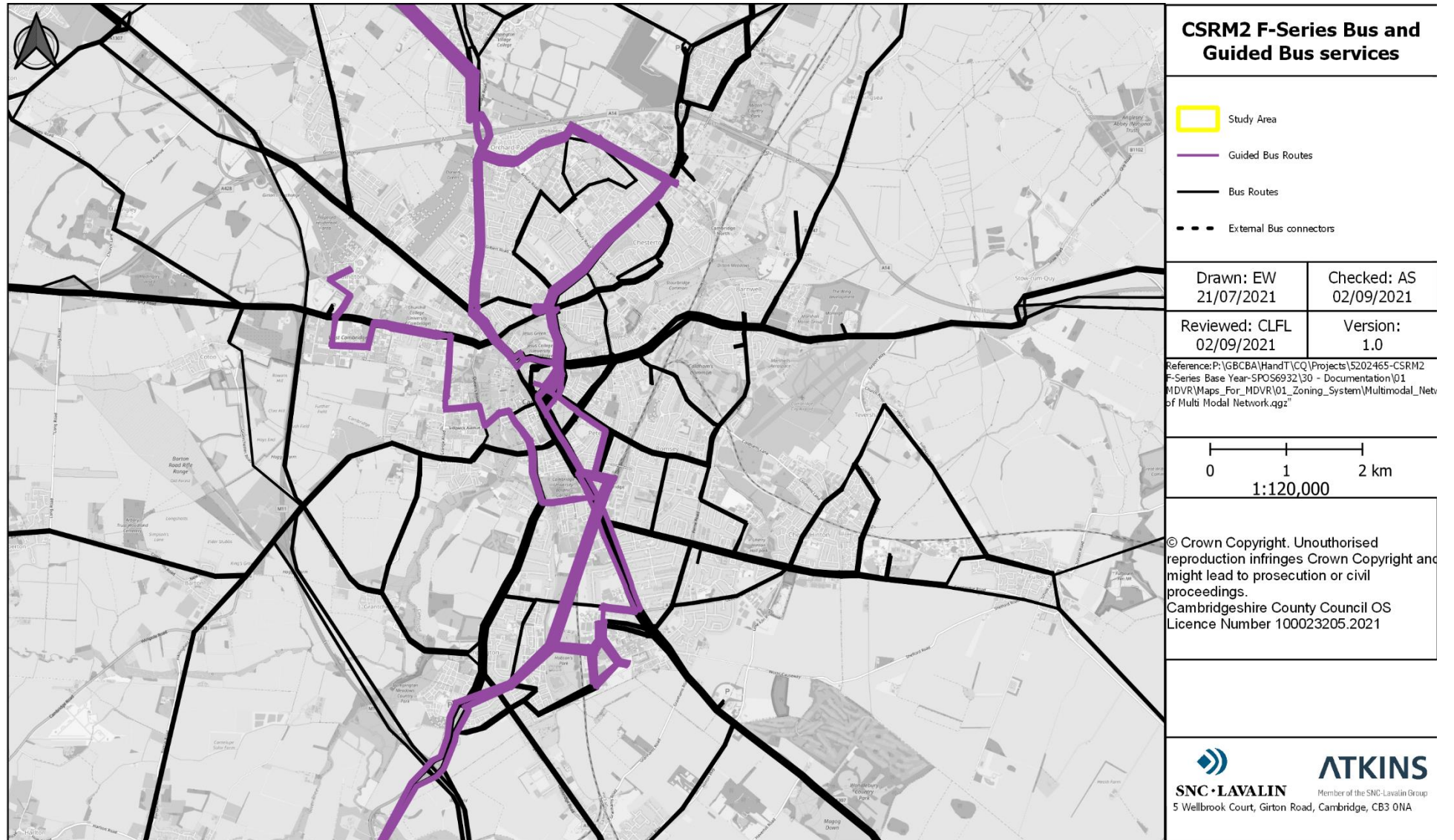
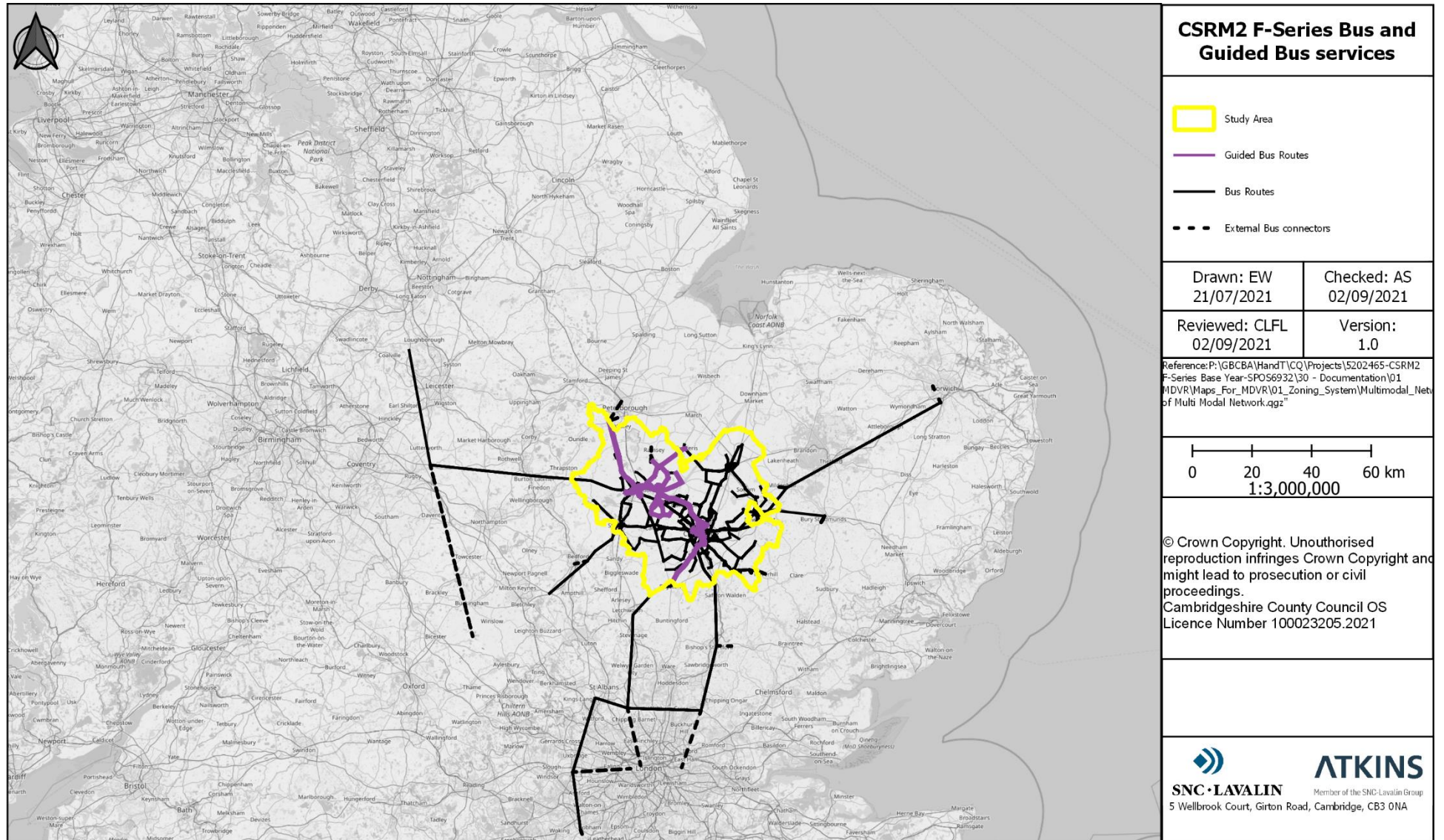


Figure 3-11 - 2015 External Bus Access Links



Figure 3-12 - 2019 External Bus Access Links



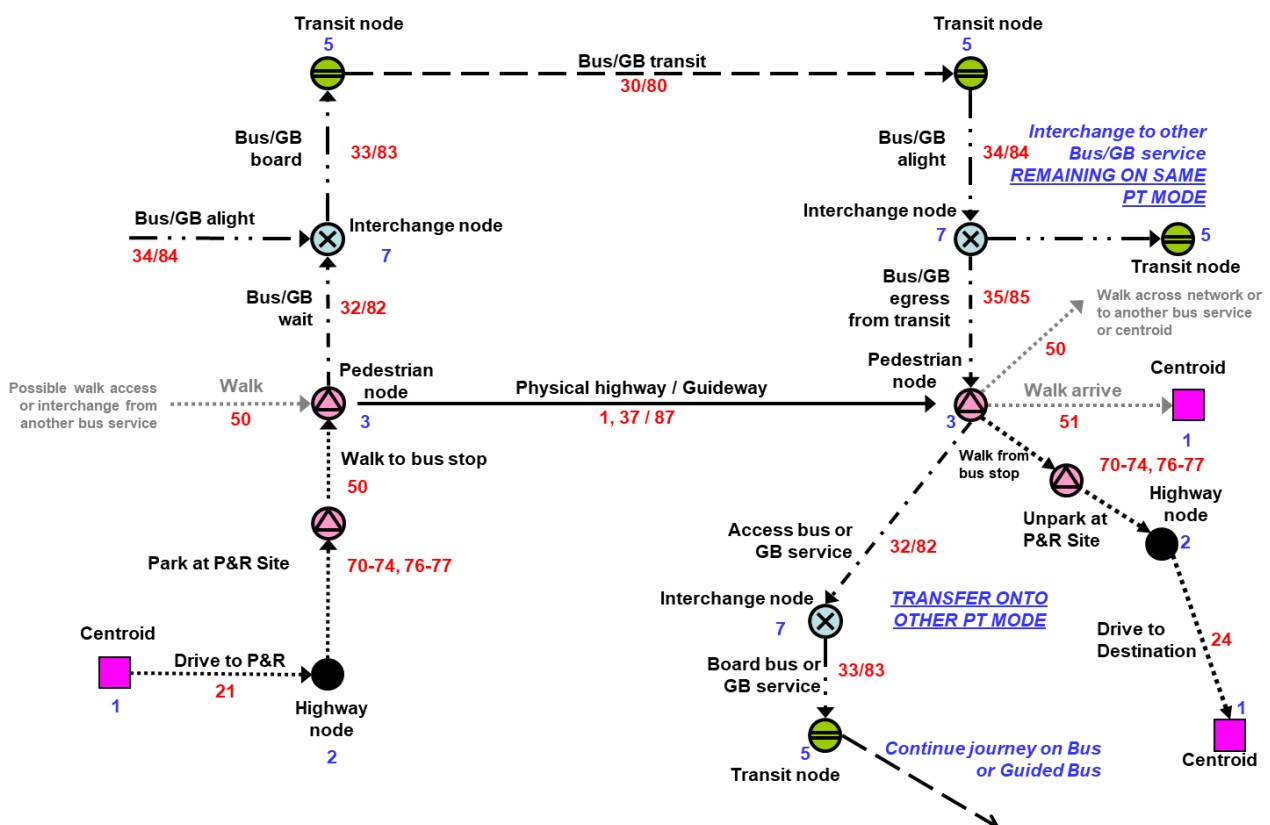
3.4. Park & Ride (Bus and Guided Bus) Network and Services

A P&R trip is a journey comprising a car drive and bus (or Guided Bus) component, but not rail. The car drive component occurs at the beginning or end of the journey not both. In order to access bus, the user must traverse an interchange parking link. This connects from the highway to the bus access node and hence bus may be taken from this point. Any combination of bus or walk can be used from this point onwards in order to reach the destination, but bus must be used for at least part of the journey to differentiate these trips from the P&A trips described in Section 3.5.

The implementation of the “drive links” (which allow trips in the public transport model to access P&R sites by car) in earlier versions of CSRM2 (and CSRM1) meant that any zone with an outgoing drive link could not be an ultimate destination for P&R trips. More precisely, in modelling terms, any zone with a drive link could not be an “attraction” zone for P&R trips. Historically, this had not been a problem since the vast majority of P&R trips were to/from the city centre, and nobody would logically drive from the city centre to a P&R site to catch a bus back into the city centre – i.e. city centre zones¹⁰ were P&R attractions and all other zones were P&R destinations. However, with the addition of P&R sites further from the city centre and new destinations served by P&R buses in tests for GCP, it became more plausible for zones to be simultaneously “production” (home) for some people and “attraction” (work / school / shopping etc.) for other people.

To enable this behaviour, in the E-series update, drive links were separated into directional “from home to the P&R site” and “from the P&R site to home” Link Types, and P&R trips were separated into directional Flow types, Network Modes and User Modes with access only to the relevant (from/to home) type of drive link.

Figure 3-13 - Link Connectivity for P&R Journeys



The car travel along the network to each P&R site is part of the route choice within the SATURN HAM. As congestion or parking cost increases, the TDM choice model allows travellers to divert to other P&R sites that provide faster and cheaper access to the city centre.

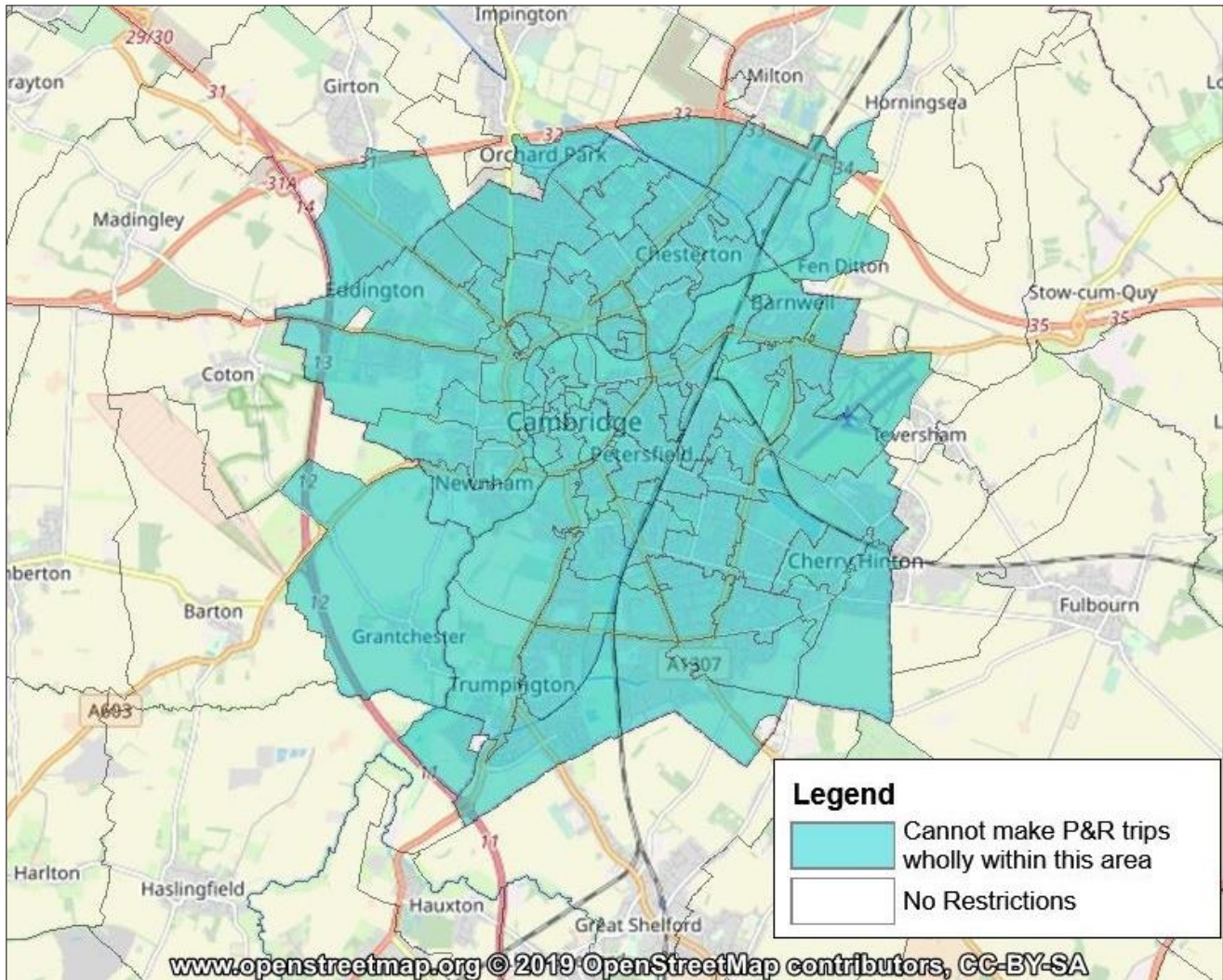
P&R trips have car links to each P&R site, which go directly from the zone centroid to the base of the parking link. These links do not determine path choice but are coded dynamically with the distance and times of the car leg which are extracted from the SATURN HAM to produce the mode and site choice characteristics.

¹⁰ This does not refer to the Cambridge City administrative area, but a specific set of model zones for which it was identified that driving to a P&R site to catch a bus would be an illogical mode choice. See Figure 3-14.

Earlier, zones were defined in Cambridge city area which cannot use bus P&R services to get to the city centre. This restriction was removed, and drive links were created between all zones and all bus P&R sites.

Following these structural changes, it was necessary to review the implementation of the discouragement factors designed to discourage P&R (and P&A) trips from occurring wholly within the group of 'city centre' zones for which P&R would be an infrequent mode choice. In the CSRM2 F-series, this has been implemented as a disutility penalty of 90 minutes for any P&R and P&A trips with both their origin and destination inside the set of zones illustrated in Figure 3-14.

Figure 3-14 - Zones in the city centre within which P&R is discouraged

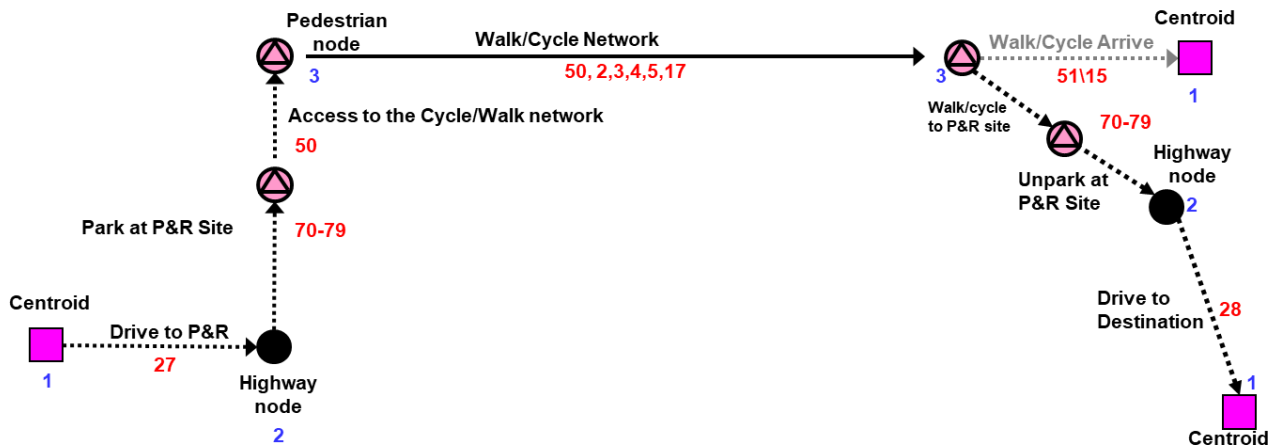


3.5. Park & Active (Walk and Cycle) Network

A P&A trip is a journey comprising a car drive to a defined P&R site and completing the journey by active modes (walk or cycle), not bus. The car drive component occurs at the beginning or end of the journey, not both. To access the walk or cycle network, the user must traverse an interchange parking link. This connects from the drive link to the walk and cycle networks from which users can reach their final destination.

Trips wholly within the city centre area shown in Figure 3-14 are discouraged from choosing P&A as set out for P&R (bus) trips in Section 3.4. For P&A, people could prefer to park their car at a P&R site and then walk or cycle to their final destination if the parking costs and the congestion are more convenient at the P&R site than driving directly to their final destination.

Figure 3-15 - Link Connectivity for P&A Journeys



3.6. Rail Network and Services

The rail mode sits at the top of the public transport hierarchy and can therefore make use of, or be accessed by, any other mode. This works in a specific way:

1. Walk, cycle, catch a bus or drive to the station;
2. Use the rail service;
3. Interchange to another rail service or alight rail entirely; and
4. Either access the centroid to end the journey or continue the journey on bus, Guided Bus or walking, with further interchanges allowed until the journey is finished.

Access to rail can be done via walking, cycling, by bus / Guided Bus or driving to the station. For travel from external zones, access is achieved directly from the centroid via the direct non-car 'Rail access' link. Town-dwellers may walk across the network and access the rail station via the 'Rail access' link that leads from the access node nearest to the station.

Drivers that access rail stations by car traverse a parking link in order to reach the rail node. Cars are blocked from using any other PT service before reaching the rail station, since they will be prohibited from using the *Bus/GB Entry* links.

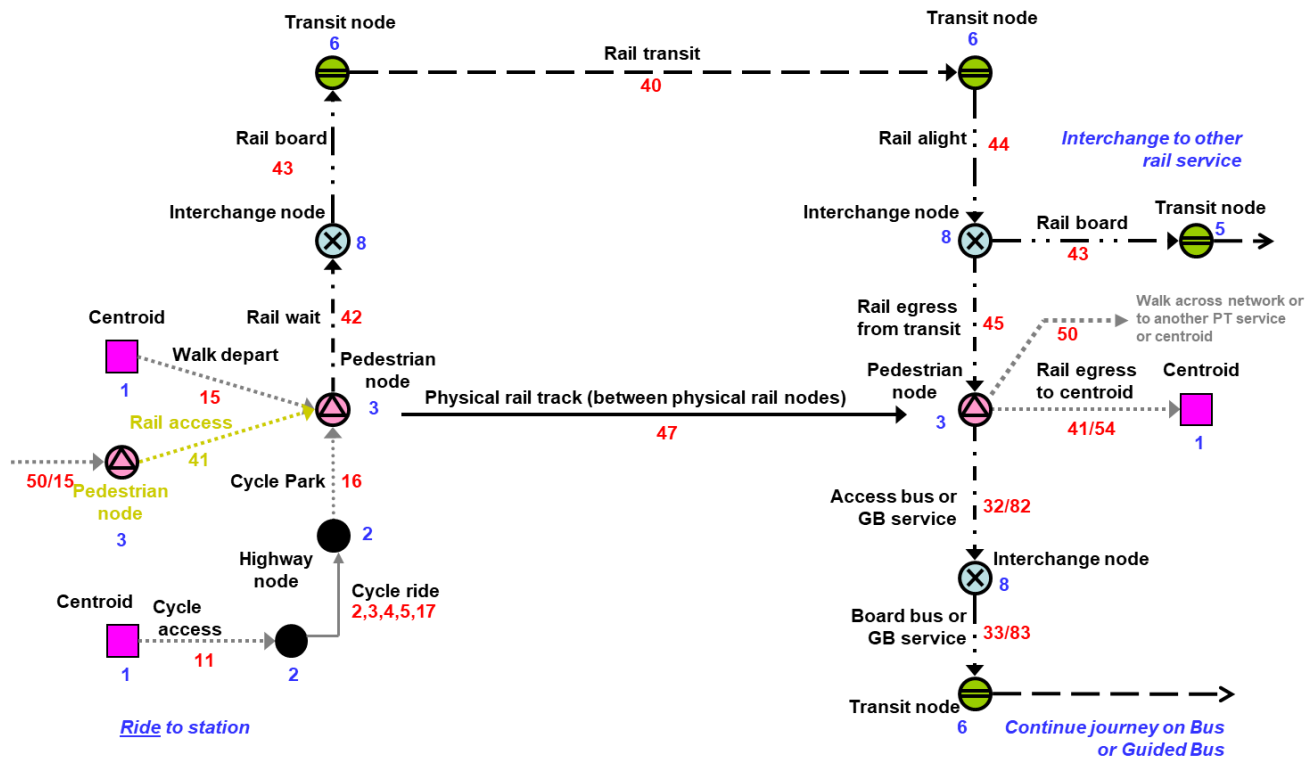
The rail transit system is accessed via *Rail access* to the interchange node and then services may be accessed via *Rail Board*.

In a similar way to bus, once a rail journey has been completed, it is possible to interchange onto another rail service directly by alighting from the service via *Rail Alight* to the interchange node and then picking up a *Rail Board* link for a connected service. The board and alight times for rail are both 1 minute.

Once the rail part of the journey is complete, the traveller reaches the access node via *Rail Egress from Transit*. From here, the centroid may be accessed directly (usually in external locations) via *Rail access* link (which is 2-way), or a bus or Guided Bus service may be accessed. This is done by accessing the bus interchange node at the rail station via *Access Bus* or *Access GB*. This is made possible since we do not prohibit rail from getting access to buses via the PT node but do from the physical network.

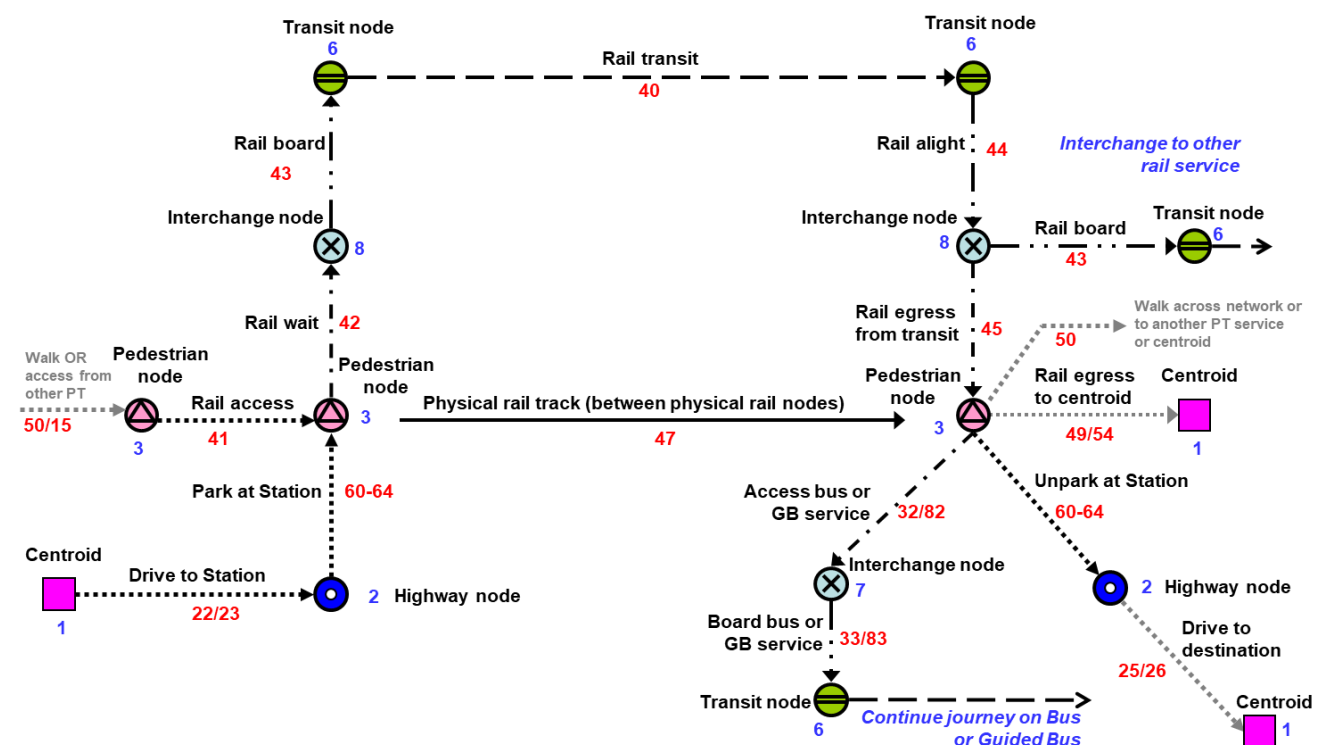
The walk network may also be accessed, allowing users to travel to nearby access nodes. From here, alternative centroids or any other PT mode may be accessed to continue the journey. This complex series of linkages can be seen diagrammatically in Figure 3-16 and Figure 3-17.

Figure 3-16 - Link Connectivity for Rail Journeys without Car Access



Note: (41*) direct access/egress from a zone centroid to rail station access node (link type 41) occurs only in external areas or internal rural areas. All zones have a car access to the internal rail network.

Figure 3-17 - Link Connectivity for Rail Journeys with Car Access



In all cases the travel demand model works with door-to-door matrices for rail. The paths for the door-to-door journey accounts for the individual travel stages for rail, such as accessing to station, waiting, boarding, alighting, as well as on-board travel in train.

Train services of different stopping patterns within a time period are coded separately, representing the frequency / headways of the services. Rail over-crowding is not included in the current version of the model but could be added at a later stage. The rail physical infrastructure is shown in Figure 3-18.

The rail sub-mode models the ability to drive to various stations and park before catching a rail service, where station parking charges are included. The network has been implemented so people can choose between their nearest 'local' rail station and one or more of six major stations in the study area: Cambridge, Ely, Huntingdon, St. Neots, Whittlesford and Royston in 2015. In addition, Cambridge North has been added in the 2019 rail network. Catchment areas were created for all major railway stations. These define to which of the main stations the zones are connected. Figure 3-19 shows the catchment area for the major rail stations for car access in 2015. The catchment areas have been expanded in 2019 to include Cambridge North as shown in Figure 3-20, as well as connections to newly activated development zones.

Local station catchment areas are based on the principle that each of the internal zones would be able to use the closest local station. Local station catchment areas are shown in Figure 3-21.

Rail services are coded in the model in terms of their headway and service patterns. The journey times between stations are derived from the 2015 and 2019 ATCO electronic timetables and only for services which serve the study area. Since the model does not include crowding or delays to rail services, the service patterns are based on the timetable times.

Figure 3-18 - 2015 and 2019 Rail Network

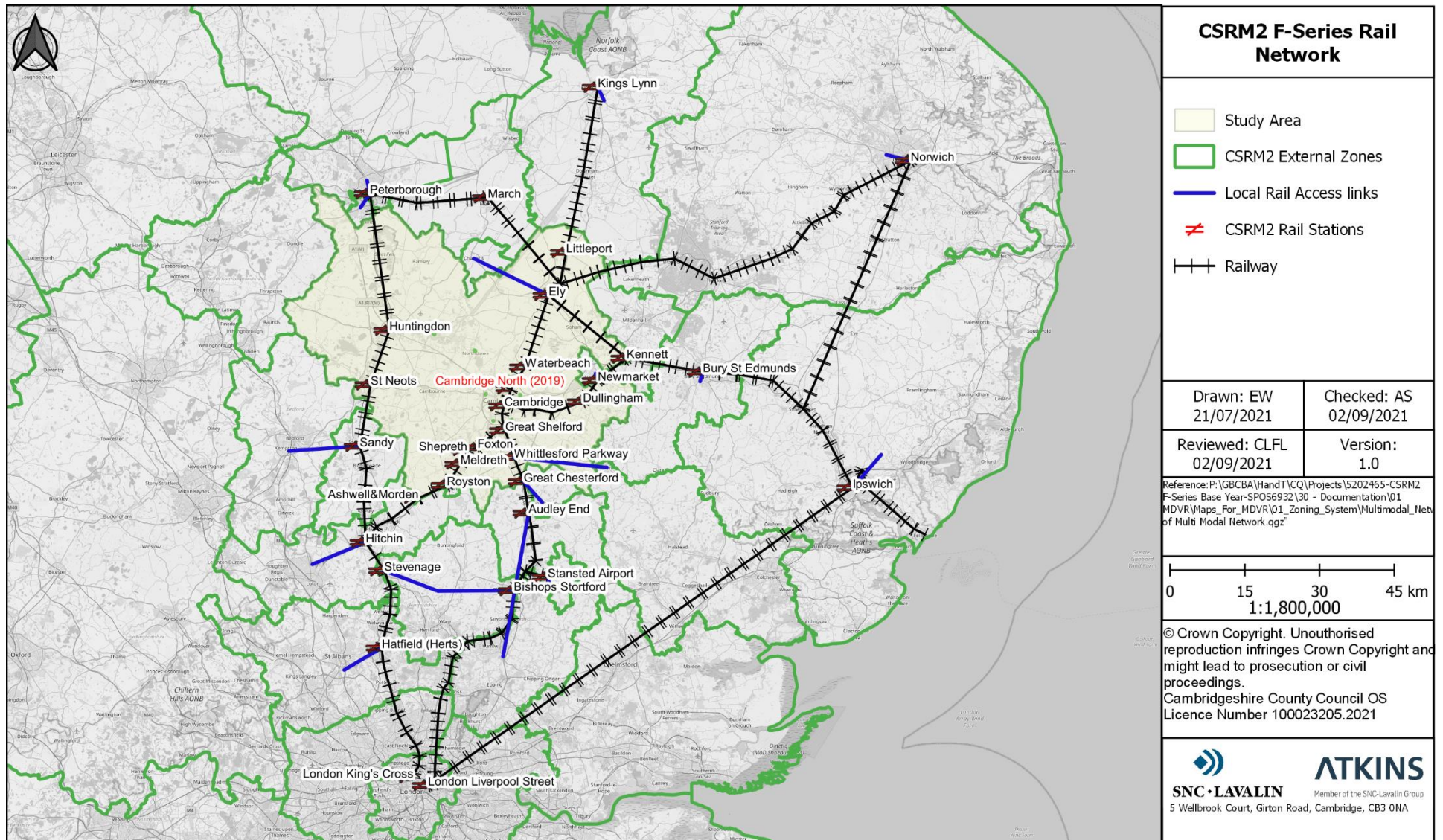


Figure 3-19 - 2015 Catchment area of major rail stations for car access

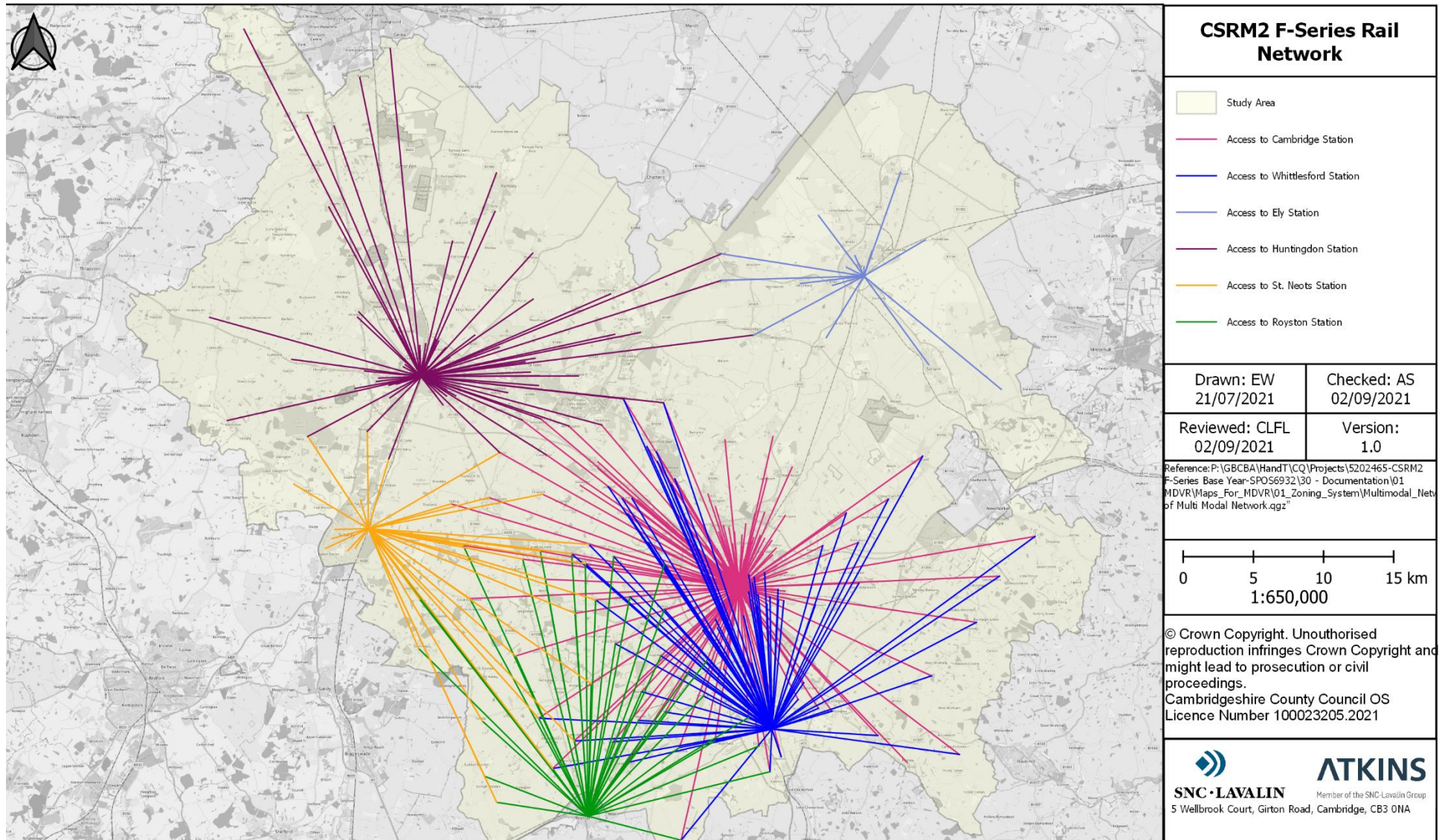


Figure 3-20 - 2019 Catchment area of major rail stations for car access

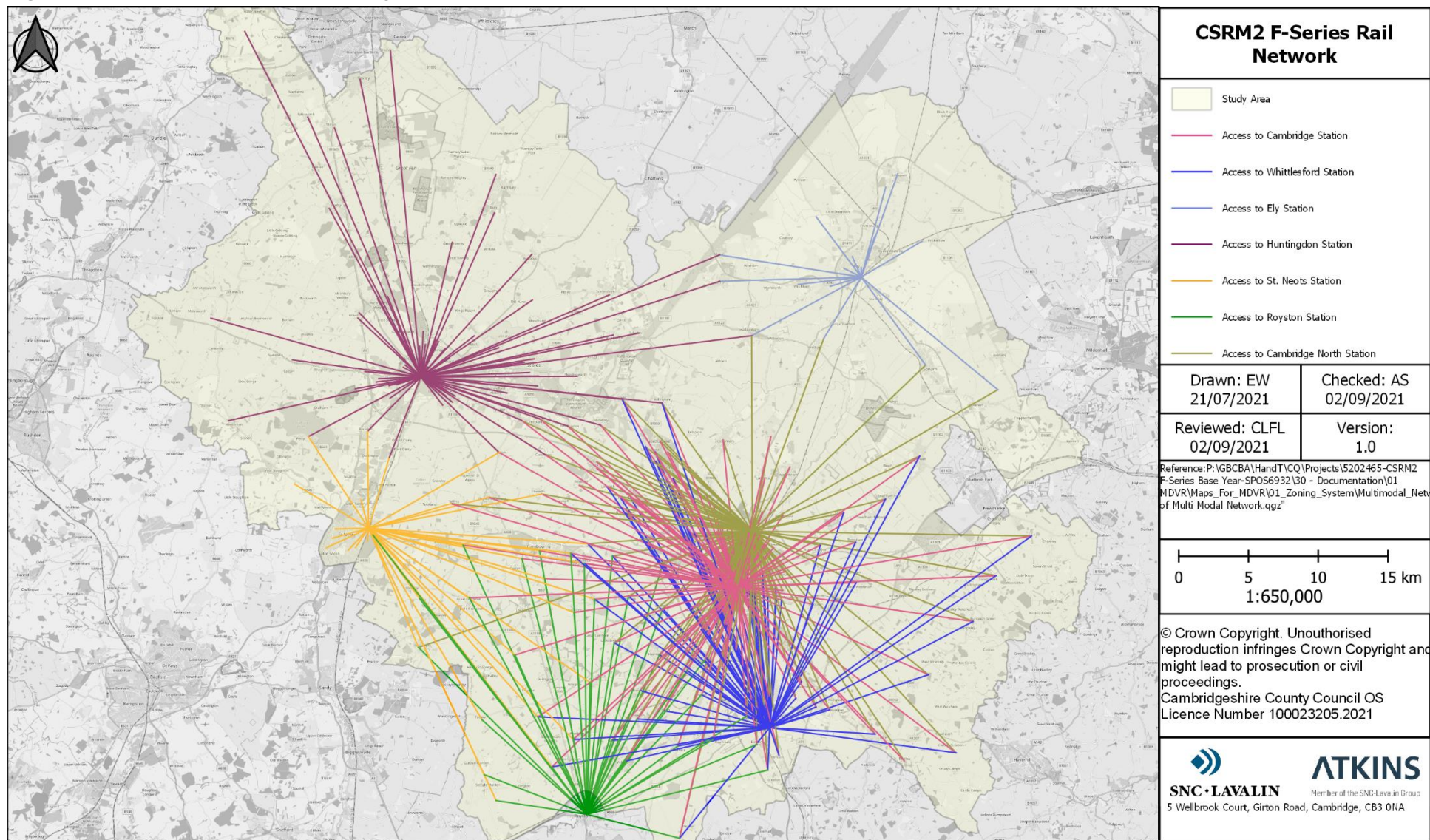
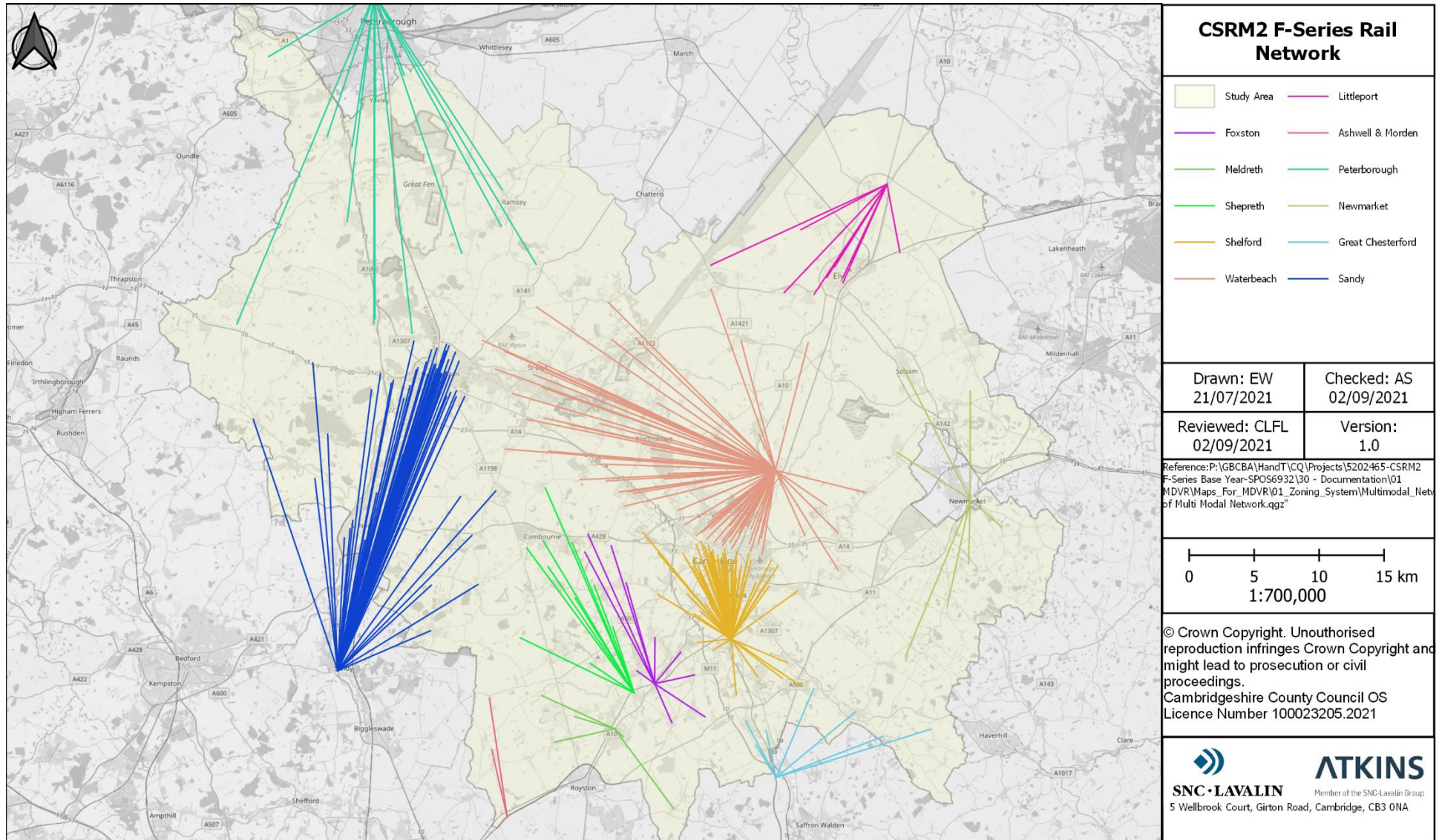


Figure 3-21 – 2015 and 2019 Catchment area of local rail stations for car access



3.6.1. External Rail Network

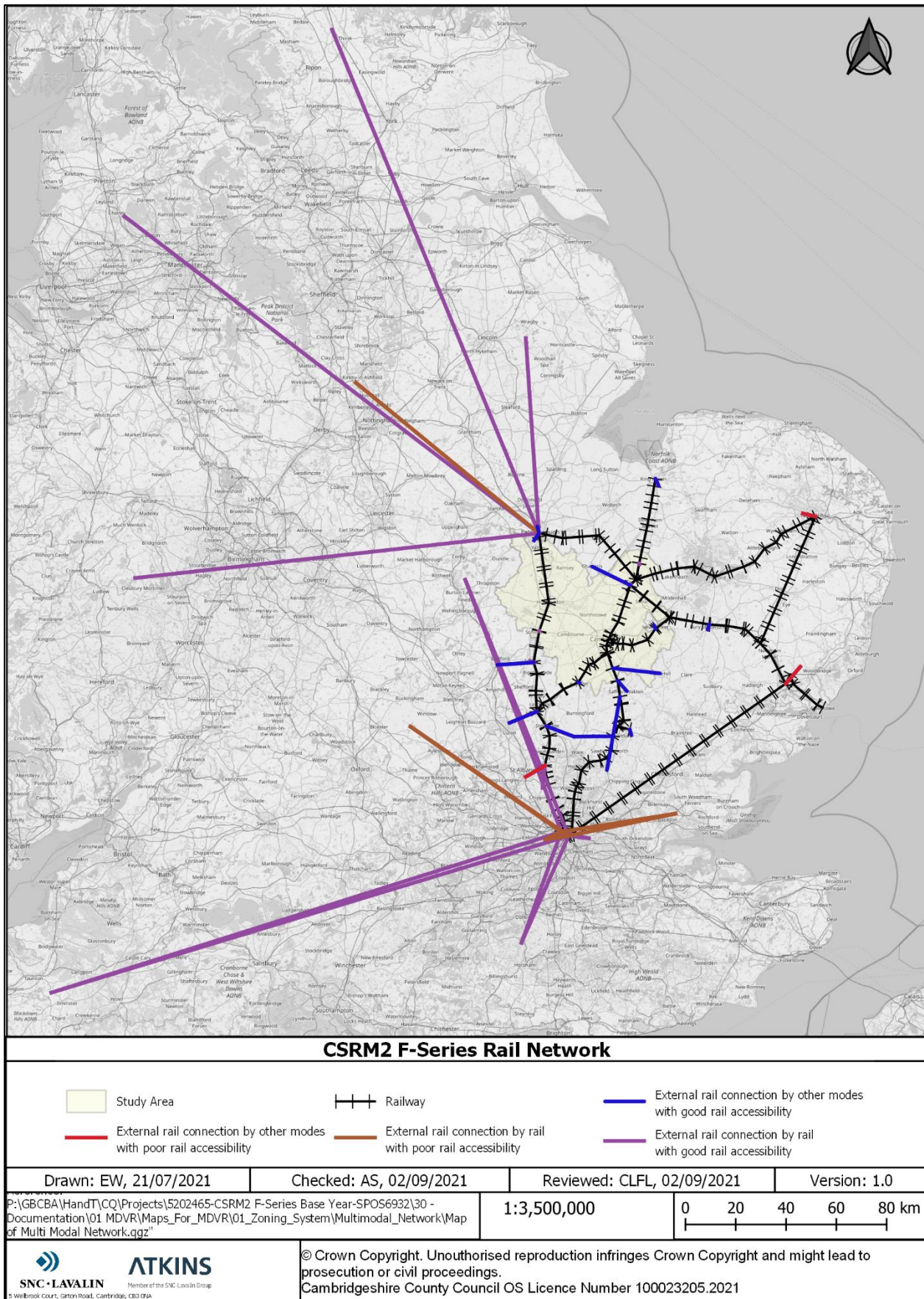
There is no detailed external rail network although the coded rail network stretches to main rail hubs such as London, Peterborough, King's Lynn, Norwich, and Felixstowe (see Figure 3-18). External zones were linked to the most likely point of access on the modelled rail network. These external connections to rail services are divided into two categories:

- Representing rail services, with an assumed distance of $1.8 \times \text{crow-fly}$, and a distance-based charge calculated using the cost function for Commuting fares:
 - For services to/from external zones with good rail accessibility, link speed calculated assuming a travel speed of 80 kph, plus a 1 hour penalty to access the external rail station; and
 - For services to/from external zones with poor rail accessibility, link speed calculated assuming a travel speed of 80 kph, plus a 1.5 hour penalty to access the external rail station.
- Representing access by other modes, coded with crow-fly distance and no charge applied:
 - For short trips (less than 1 km), link speed of 7 kph assumed (representing mainly walk access with a small proportion of faster modes);
 - For medium trips (1-4 km), link speed of 10 kph assumed (representing a lower proportion of walk, and a higher mix of cycle and car); and
 - For long trips (more than 4 km), link speed of 35 kph assumed (representing mostly car access).

Zones with poor rail accessibility have an additional access time penalty of 0.5 hours applied, while the rest have a 10-minute parking search time applied.

Figure 3-22 shows which external zones are connected by links representing rail services, and which are assumed to access the rail network by using a different mode.

Figure 3-22 - Map showing external rail connections by rail, and external rail connections by other mode



3.7. Walk and Cycle

Walking and cycling are very important in the Cambridge area and the TDM model explicitly represents these as separate main modes at the top of the choice hierarchy. This structure gives a better representation given the large number of cycle trips in Cambridge which compete as much with short distance car and bus as with walking trips.

The walking and cycling distances between zones are derived from the walk network and cycle network, which are almost exactly the same. They are both based on the road network, but with additional links both for cycle-only infrastructure and where there are one-way streets, which typically have footpaths in both directions.

The connectivity of the networks for walk and cycle travel are shown in Figure 3-23 and Figure 3-24.

Figure 3-23 - Link connectivity for Pedestrian journeys

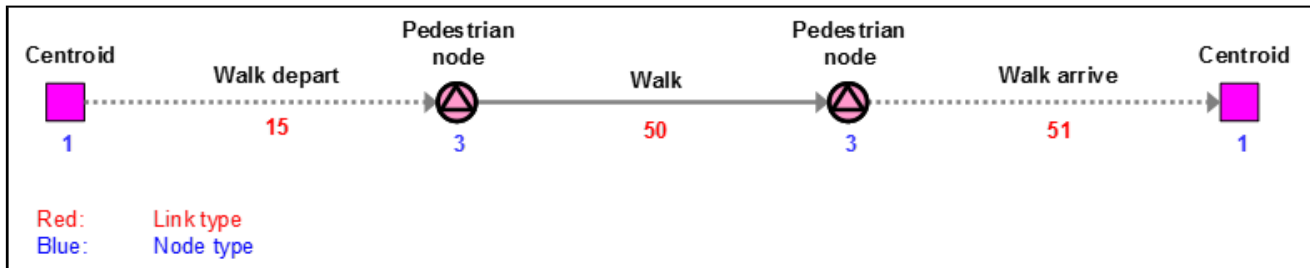
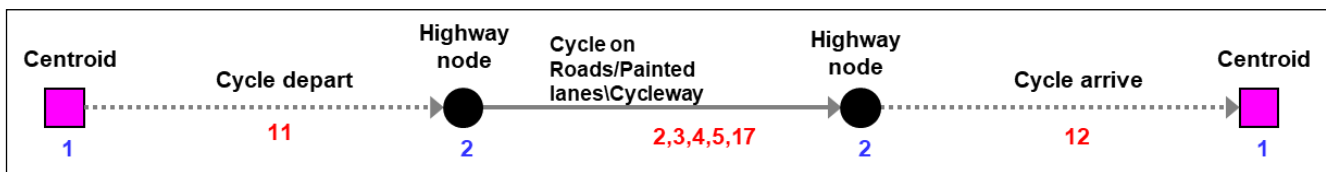


Figure 3-24 - Link connectivity for Cycle journeys



Both pedestrians and cyclists use strict minimum-distance paths in the model, as this provides the best estimate of their minimum-time path (and hence minimum generalised cost, as there is no monetary cost).

Distribution and mode split for walk and cycle are also based entirely on distance skims as described in Section 6.2. That is, the model does not assume a speed directly, but only via distance-based parameters. To generate time skims for analysis, walkers are assumed to have a speed of travel of 5 kilometres per hour (kph). There is no data available about typical cycling speeds, especially by trip purpose; CSRM2 assumes a speed of 12 kph.

As part of the F-series model update, the role of subjective variables: perception of environmental and cycling facilities and psychological indicators; has been considered to classify the different cycle infrastructure with the scope to take into account the benefits in mode shares and trip distributions when future cycle schemes are implemented which impact safety and perception but make little difference to travel distances and times. Five different types of cycle infrastructure have been identified, each one with a different impedance factor to assess the propensity of a user to cycle on the link. These are shown in Figure 3-25 and Figure 3-26 for 2015 and 2019 respectively. The classification of the type of cycle infrastructure has been developed in accordance with the Cambridge Cycle Map¹¹, OpenCycleMap¹², Google StreetView and local knowledge.

The walk and cycle networks shadow the highway network (except motorways and dual carriageways) and are used by the main walk and cycle modes as well as walk and cycle access modes to public transport and walk and cycle stages of P&A. This has several advantages including:

- Discrete assignment of walk and cycle modes on the network; and
- The walk network is removed from the highway network entirely, hence allows any degree of interchanging onto the bus or rail network.

In future years where pedestrian severance is reduced (e.g. through urban planning and design), or worsened (e.g. in the vicinity of some major new road or rail infrastructure), the walking and cycling distances can be modified to account for any such effects not captured by the nature of the infrastructure coded.

¹¹ <https://www.cambridge.gov.uk/sites/default/files/documents/cambridge-cycling-map.pdf>

¹² <https://www.opencyclemap.org>

Figure 3-25 - 2015 cycle network infrastructure

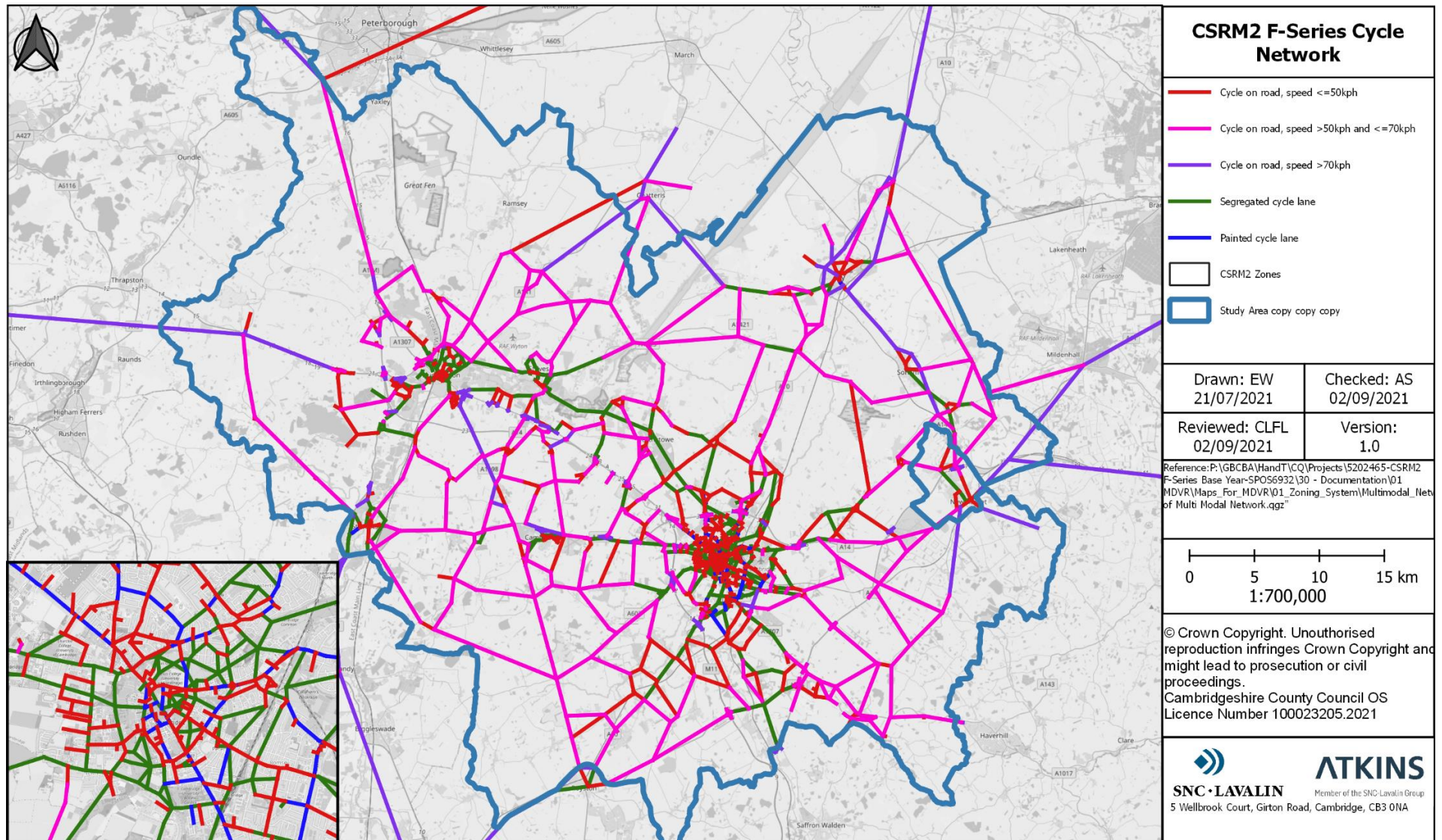
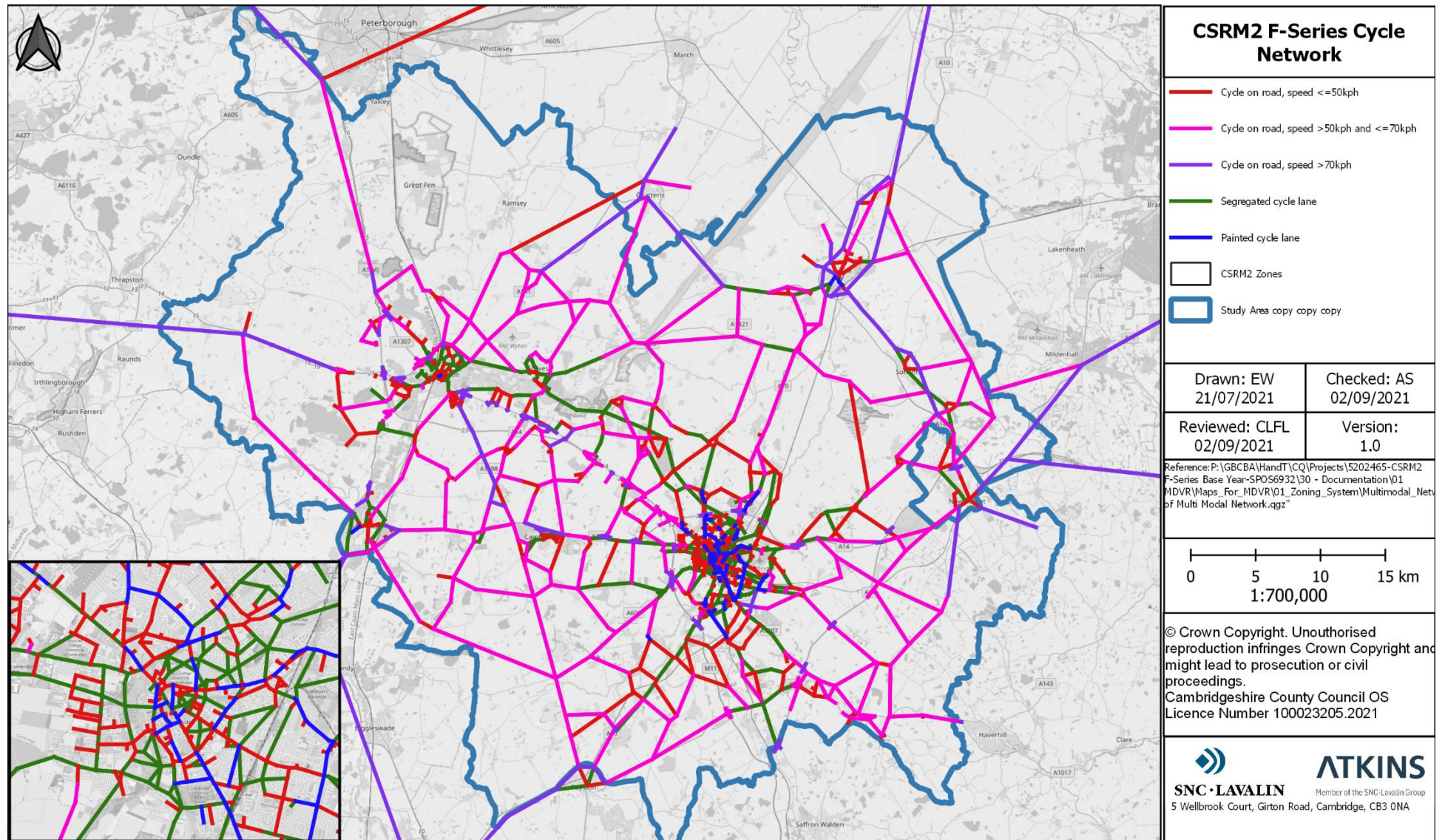


Figure 3-26 - 2019 cycle network infrastructure



3.8. Intrazonal Distances and Times

It is essential for the travel demand-forecasting side of the TDM that the distances and generalised costs of intrazonal movements are properly represented for internal model zones. For instance, if car travel becomes more expensive, some people may switch from driving to a supermarket in a nearby zone, to driving or walking to a store in the same zone. Although this is sometimes represented as a frequency-response of the car trip rate, CSRM2 represents it as a destination and/or mode shift, and it is important that the intrazonal option is present in the choice model.

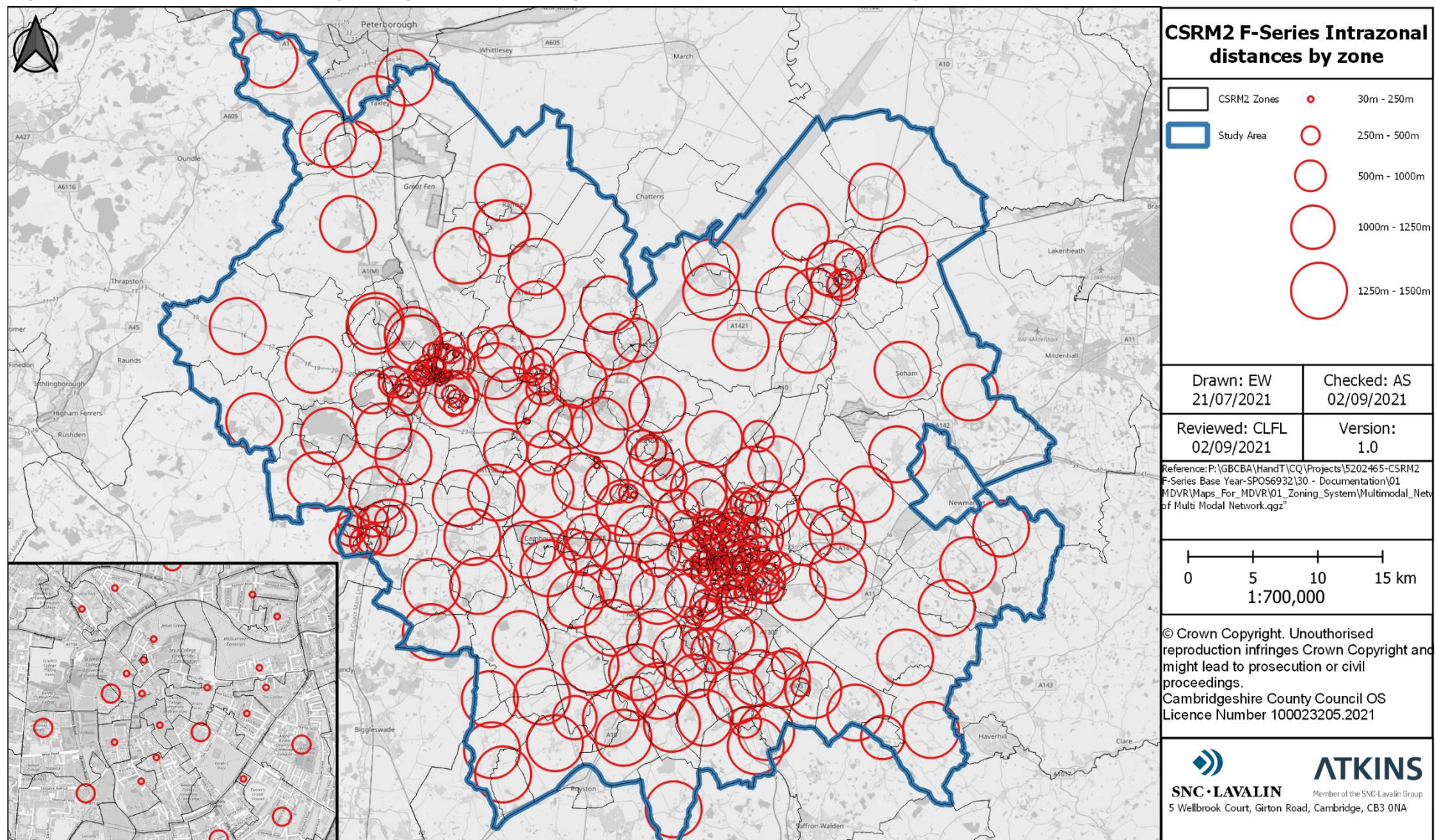
The CSRM2 model assumes that there are no bus, Guided Bus or rail intrazonal movements. No zone contains two rail stations. For bus and Guided Bus, the zones within Cambridge and Huntingdon (which are the main areas of bus use) are generally too small for a bus journey of more than one or two stops. That leaves only walk, cycle and car intrazonals.

Distance and time are the main intrazonal transport components, since walk and cycle have no monetary cost and intrazonal car costs are a linear multiple of distance in the current model. Walk and cycle generalised costs are also calculated directly from distance as described in Section 6.2.

Car time for intrazonals is based on a fixed speed of 20 km/h, plus whatever fixed time and parking costs are normally added to car trips to and from that zone for the trip purpose being undertaken. (That is, the fixed time associated with car is the same for inter-zonal and intrazonal movements.) Generalised cost is then calculated using values of time in the usual way.

The TDM takes as input an intrazonal distance for each zone. This was calculated by taking half the square root of the area of the zone, capped at a maximum distance of 1.5 km – this is a standard formulation for intrazonal distances. Figure 3-27 shows the resulting intrazonal distances for each zone in the CSRM2 study area.

Figure 3-27 - Intrazonal distances by zone (circle diameter represents relative intrazonal distance)



3.9. External Network

The representation of public transport services from external zones to the main study area has been included in a simplified form of straight links that serve as an approximation of non-car rail/bus access to the edge of the coded PT networks. These links were detailed in Sections 3.3.1 and 3.6.1, for bus and rail respectively.

Each external zone also has a possibility of car travel to the study area, or car access to the bus P&R sites of the study area. The characteristics of these journeys are modelled in the SATURN HAM.

3.10. Generalised Cost Formulations

The generalised costs of travel throughout the transport model are measured in units of time and include both the money costs and times associated with making journeys.

Adopting the TAG terminology (TAG M2.1, Section 3.1), the disutilities used in the choice modelling are the generalised costs of travel plus additional disutilities such as mode / origin / destination specific constants determined during model calibration.

The disutility of a complete journey from zone “i” to zone “j” is the sum of the disutilities of the individual stages of the journey such as accessing and waiting for public transport in addition to riding on buses, trains and the egress time at the destination. The costs and times of these different elements can be weighted to denote the relative importance when choosing the mode of travel for a journey. In addition, mode specific constants are introduced to represent the inherent attractiveness or the lack of appeal of particular modes to particular journey types.

For car trips (TAG M2.1, 3.1.6), the generalised cost is:

$$G_{car} = t_{walk} * v_{walktime} + t_{ride} + \frac{d * VOC}{(occ * VOT)} + \frac{c_{park}}{(occ * VOT)}$$

Where: t_{walk}	is the total walking time to and from the car;
$v_{walktime}$	is the weight to be applied to walking time;
t_{ride}	is the journey time spent in the car;
d	is the journey distance;
VOC	is the vehicle operating cost per km for a journey of d km, dependent on purpose;
occ	is the number of people in the car (who are assumed to share the cost);
VOT	is the appropriate value of time; and
c_{park}	is the parking cost.

For public transport, the representation of the generalised cost of a journey by mode for a given purpose, time of day and income is:

$$G_{PT} = t_{walk} * v_{walktime} + t_{wait} * v_{waittime} + t_{ride} + \frac{c_{fare}}{VOT} + c_{interchange}$$

Where: t_{walk}	is the total walking time to and from the service;
$v_{walktime}$	is the weight to be applied to walking time;
$v_{waittime}$	is the weight to be applied to time spent waiting;
t_{wait}	is the total waiting time for all services used on the journey;
t_{ride}	is the total in-vehicle time;
c_{fare}	is the fare;
VOT	is the appropriate value of time for the user segment; and,
$c_{interchange}$	is the interchange penalty if the journey involves transferring from one service to another (It is normally calculated as a time penalty multiplied by the number of interchanges.)

For P&R trips, the generalised cost is a combination of the elements shown above for the car and public transport legs respectively. For P&A trips the generalised cost is a combination of the car generalised costs and distance based walk and cycle generalised costs.

The cost and time may include terms associated with the destination (or origin) mode and purpose, such as parking charges and search times. Disutility is generalised cost plus other constants for example alternative specific constant (ASC) terms associated with particular modes, times of day and destinations.

Walk and cycle disutility is distance based and discussed in Section 6.2.

4. Travel Characteristics

4.1. Introduction

A set of characteristics are derived for input into the model, which describe the costs of travel (both monetary and non-monetary) for different journey components and allow the overall picture to be built up. These are described in more detail in the following sections:

- Vehicle Operating Costs – from DfT TAG databook;
- Vehicle Occupancies – from DfT TAG databook;
- Values of Time – from DfT TAG databook;
- Parking search times – locally derived;
- Parking charges – locally sourced;
- Public transport fares – locally sourced;
- Public transport access and wait times – locally derived; and
- Weighting of time for different journey stages – locally derived.

4.2. Vehicle Operating Cost, Vehicle Occupancies and Values of Time

Because distance and time skims are more readily available from SATURN than monetary cost skims, the vehicle operating costs (VOCs) are implemented in the TDM to reconstruct the monetary cost of car journeys for use in the choice models. The operating cost function and parameters have been implemented to be entirely consistent with those used in the SATURN HAM.

Vehicle operating costs are calculated in units of *Pence per Kilometre* (format supported by SATURN modelling software, used for highway assignment) and represent the average perceived cost to users of running a specific type of vehicle for a number of kilometres.

VOCs in CSRM2 vary by purpose, vehicle type and time of day. The DfT's guidance on vehicle operating costs indicates that travellers on business trips perceive more vehicle operating costs than just the fuel costs (TAG Unit A1.3, Sections 5.1.15-5.1.18, DfT, July 2020). The elements making up the non-fuel component of vehicle operating costs include oil, tyres, maintenance, and depreciation, and vehicle capital saving. These elements are included in total the VOC for vehicles used in working time (business journeys).

Fuel consumption is estimated using a function of the following form (DfT, July 2020, Values of Time and Operating Costs, TAG Unit A1.3, Section 5.1.4):

$$L = (a + b.v + c.v^2 + d.v^3) / v$$

Where:

- L = consumption, expressed in litres per kilometre;
- v = average speed in kilometres per hour; and
- a, b, c, d are parameters defined for each vehicle category.

The parameters needed to calculate the fuel consumption element of VOCs are given in TAG Data book unit A1.3.8 (DfT, v1.13.1 July 2020), and shown for 2015 in Table 4-1 and 2019 in Table 4-2. Note that the convention in TAG is that the equation above expresses fuel consumption, though the parameters a, b, c and d given by TAG (see Table 4-1) include fuel cost, so that what is returned is the fuel cost per km (expressed in pence per km). Information is shown for OGVs, though these are not included in the TDM, just assigned in the SATURN HAM.

Table 4-1 - Fuel Cost Equation Parameters, 2015 (in 2015 prices)

Purpose	Vehicle Type	a	b	c	d
Work (HBEB and NHBEB)	Car	44.01	7.76	-0.082	0.0006
	LGV	44.06	10.99	-0.159	0.0013
	OGV1	258.16	13.70	-0.099	0.0011
	OGV2	542.46	28.17	-0.187	0.0011
Non-Work (HBW, HBEd, HBPS, HBRV and NHBO)	Car	52.81	9.31	-0.099	0.0007
	LGV	52.88	13.19	-0.191	0.0016

Table 4-2 - Fuel Cost Equation Parameters, 2019 (in 2015 prices)

Purpose	Vehicle Type	a	b	c	d
Work (HBEB and NHBEB)	Car	41.84	7.35	-0.078	0.0006
	LGV	45.27	11.22	-0.162	0.0014
	OGV1	268.23	14.23	-0.103	0.0011
	OGV2	563.62	29.27	-0.194	0.0012
Non-Work (HBW, HBEd, HBPS, HBRV and NHBO)	Car	50.21	8.82	-0.093	0.0007
	LGV	54.33	13.46	-0.194	0.0016

The average speeds for each time period were taken from the 2015 HAM assignments (over the whole modelled network, including buffer and simulation links) and are shown in Table 4-3.

Table 4-3 - Average Network Speeds (kph), 2015 used for VOCs

	AM	IP	PM
Average speed (lights)	56	62	57
Average speed (heavies)	69	73	70

Non-fuel VOCs are only perceived during work time and are therefore only calculated for working purposes. The non-fuel element of VOC is calculated using a function of the following form (DfT, TAG Unit A1.3, paragraph 5.1.10, March 2017):

$$C = a1 + b1/v$$

Where:

- C = cost, expressed in pence per kilometre;
- v = average speed in kilometres per hour;
- a1 = a parameter for distance-related costs; and
- b1 = a parameter for vehicle capital saving.

The parameters needed to calculate this non-fuel VOC (in pence per kilometre) are given in TAG databook table A1.3.14 and A1.3.15 for an average car (DfT, June 2018), and reproduced here in Table 4-4 for 2015 and 2019. The speed term is once again taken from Table 4-3.

Table 4-4 - Non-Fuel Cost Equation Parameters, 2015 and 2019 (in 2015 prices)

Purpose	Vehicle Type	2015		2019	
		a1	b1	a1	b1
Work (HBEB and NHBEB)	Car	5.370	147.172	5.338	147.172
	LGV	7.803	51.003	7.797	51.003
	OGV1	7.268	285.602	7.268	285.602
	OGV2	14.140	550.517	14.140	550.517

Source: TAG databook v1.13.1 (July 2020), Table A1.3.14 and A1.3.15

The VOC is used in providing a monetary value to the distance received from the SATURN highway model as described in Section 6.6. Table 4-5 summarises the resulting calculated VOCs implemented in CSRM2 for each vehicle type in each time period in the 2015 base year model, in 2015 prices, while Table 4-6 shows the equivalent 2019 PYV VOCs, in 2015 prices. The variations seen are due to the variation in average speeds by time of day, and the fact that Employer's Business costs do not include VAT but do perceive non-fuel costs.

Table 4-5 - Vehicle Operating Costs in CSRM2, 2015 (pence per km, in 2015 prices)

Purpose	Vehicle Type	User Classes	AM	IP	PM
Work (HBEB and NHBEB)	Car	5	13.77	13.36	13.68
	LGV	12	15.78	15.60	15.73
	OGV ¹⁵	9, 10	41.25	40.59	41.07
Non-Work (HBW, HBEd, HBPS, HBRV and NHBO)	Car	1, 2, 3, 4, 6, 7, 8	6.92	6.73	6.88
	LGV	11	8.47	8.37	8.44

Table 4-6 - Vehicle Operating Costs in CSRM2, 2019 (pence per km, in 2015 prices)

Purpose	Vehicle Type	User Classes	AM	IP	PM
Work (HBEB and NHBEB)	Car	5	13.46	13.05	13.37
	LGV	12	15.94	15.77	15.90
	OGV ¹⁶	9, 10	42.16	41.49	41.98
Non-Work (HBW, HBEd, HBPS, HBRV and NHBO)	Car	1, 2, 3, 4, 6, 7, 8	6.58	6.40	6.54
	LGV	11	8.68	8.57	8.65

Light vehicle (car) occupancies were also calculated according to TAG A1.3.4. TAG provides the car occupancies for Commuting, Business, Other and Average car trips with no further segmentation by income level. These have been mapped to CSRM2 purposes as follows: Commuting represents HBW; Business represents EB (HB and NHB); and Other represents HBEd, HBPS, HBRV and NHBO trips. Table 4-7 shows vehicle occupancies for the base model year 2015. These are also the same for the 2019 PYV.

¹⁵ The CSRM2 HAM user classes 9 and 10 are a mix of OGV1 and OGV2, and a split of 40% OGV1 and 60% OGV2 has been assumed when calculating these values.

Table 4-7 - Vehicle Occupancies for Years 2015 and 2019

Purpose	Vehicle Occupancy (2015 and 2019)		
	AM	IP	PM
HBW	1.17	1.15	1.16
EB (HB and NHB)	1.20	1.19	1.17
HBE _d , HBPS, HBRV and NHBO	1.68	1.65	1.71

Values of time (VoTs) are used to represent the relative importance of cost versus time for different trip purpose and traveller type segments, particularly when converting time and cost into a generalised cost measure. The DfT's TAG unit A1.3 provides guidance on the use of values of time within a transport model. This suggests that three basic values of time should be used for:

- Business travel (travel in work time);
- Journeys to work (commuting); and
- Other personal travel (recreation etc.)

TAG unit A1.3 also recommends further variation by income. The TAG guidance includes a recommendation for using 3 groups of travellers based on their income (low, medium or high). Accordingly, CSRM2 uses income bands, giving values of time per person shown in Table 4-8 and Table 4-9 for 2019.

Table 4-8 - TDM Base Year (2015) Values of Time (VoT) per person (pence per minute in 2015 prices)

Income band	Commuting	Other	Business
Low (< £20,000)	7.71	4.32	15.67
Medium (£20,000 to £40,000)	13.01	7.31	21.56
High (> £40,000)	23.70	12.12	32.32

Source: TAG databook (v1.13.1) Table M2.2

Table 4-9 - TDM PYV (2019) Values of Time (VoT) per person (pence per minute in 2015 prices)

Income band	Commuting	Other	Business
Low (< £20,000)	8.02	4.49	16.29
Medium (£20,000 to £40,000)	13.53	7.60	22.41
High (> £40,000)	24.64	12.60	33.60

Source: TAG databook (v1.13.1) Table M2.2

4.3. Parking and Parking Charges

The information used in order to derive parking charges for the model was gathered from the various district council websites for the base year. In addition, parking charges at P&R sites and railway stations were derived from published sources.

4.3.1. General Car Parks

A summary of the overall method for determining parking charges is:

- From the list of the main car parks and charges in Cambridge city area, a typical short stay and long stay charge were selected;
- Parking charges for other non-Cambridge areas were sourced from district websites;
- Each transport zone has been assigned a representative charge based on proximity to a car park; and
- Each transport demand flow has been assigned a representative charge type (long stay, short stay or none)

Review of Parking Charges

For each car park in Cambridge, a cost was identified for a typical short stay. The true averages depend on the actual average length of stay, the number of people using parking 'season' tickets and the car occupancy. It has been assumed that the short stay cost is equivalent to a two-hour charge, as highlighted in bold in Table 4-10.

Table 4-10 - Car park charges in Cambridge (2015 pence)

Name	CSRM2 Zone group	Spaces	Price (pence) by no. hours						
			1 hr	2 hr	3 hr	4 hr	5 hr	>5 hr	>6 hr
Castle Hill	Cambridge Outer	112	250	250	480	480	800	800	800
Park Street Multi-Storey	Cambridge Inner	158	210	380	570	960	1700	2400	2400
Grafton West Multi-Storey	Cambridge Inner	149	210	360	560	920	1700	2400	2400
Grafton East Multi-Storey	Cambridge Inner	549	210	360	560	920	1700	2400	2400
Queen Anne Terrace Multi-Storey	Cambridge Inner 2	260	150	300	420	500	660	1000	1330
Grand Arcade Multi-Storey	Cambridge Inner	280	230	460	690	1020	1950	2500	2500
Gwydir Street	Cambridge Outer	38	180	360	n/a	n/a	n/a	n/a	n/a
Adam and Eve Street	Cambridge Inner	40	140	420	n/a	n/a	n/a	n/a	n/a

Source: <https://www.cambridge.gov.uk/parking> (retrieved 04/04/2016)

Similarly, for each car park in Huntingdonshire, "short stay" (up to 2 hours) and "long stay" (up to 10 hours) were obtained: these are summarised in Table 4-11.

Table 4-11 - Car parking charges in Huntingdonshire (2015 pence)

Car Park	Town	Short stay charge	Long stay charge
Riverside	Huntingdon	60	200
Hinchingbrooke Country Park	Huntingdon	100	200
Sainsbury's (Chequers Court)	Huntingdon	120	N/A
Princes Street	Huntingdon	120	N/A
Mill Common	Huntingdon	120	300
Great Northern Street	Huntingdon	120	300
Ingram Street	Huntingdon	120	300
St. Germain Street	Huntingdon	120	N/A
Cattle Market	St. Ives	120	300
Darwoods Pond	St. Ives	120	300
Globe Place	St. Ives	120	300
Cattle Market, Waitrose	St. Ives	120	N/A
Riverside	St. Neots	60	200
Priory Lane	St. Neots	120	N/A
Brook Street	St. Neots	120	N/A
Tan Yard	St. Neots	120	N/A
The Priory	St. Neots	120	300
Tebbutts Road	St. Neots	120	300
Waitrose	St. Neots	120	N/A

Source: <http://www.huntingdonshire.gov.uk/streets-parking-transport/parking/locations-charges-and-information> (retrieved 04/04/2016)

Parking Charges in CSRM2

The modelled parking charge varies for different trip types as follows:

- Commuters pay a flat £3 charge, except in Ely (where all parking is free) and Central London (as described below);
- Education trips incur no parking charge (as education trips are generally dropping off or picking up children from school and will not involve paying for parking); and
- Discretionary and business trips pay the short stay charge.

The £3 charge for commuters is based on the assumption that many commuters in Cambridge have access to private non-residential parking (which is generally provided without a charge), while others would have to pay the much higher long-stay parking charges. The Central London charge includes the Congestion Charge, as well as reflecting the high parking charges and very limited availability of private non-residential parking in this area.

The resulting TDM charge level assumptions are summarised in Table 4-12. No charges are applied in other villages or rural areas.

Table 4-12 - Parking charges by geographical area in CSRM2 (2015 pence)

Zone Group	Short stay charge	Commuters' charge
Cambridge Inner	360	300
Cambridge Inner 2	300	300
Cambridge Outer	250	300
Huntingdon Central, St. Ives, St. Neots	120	300
Huntingdon Outer	60	300
Ely	0	0
Central London	1000	1500
Rest of London	1000	300

The composition of each “zone group” detailed in Table 4-12 is shown geographically in Figure 4-1. The groups of Cambridge zones reflect that parking in the historic city centre is more expensive than parking on the edge of the centre, as well as accounting for travellers’ parking locations relative to their final destination. In CSRM2, car parking is not modelled in detail, and travellers cannot park in one zone and then walk to their destination. Therefore, the parking charge is applied to groups of zones that are the destinations for travellers who might be parking elsewhere, such as the multi-storey car parks.

Parking at stations and at P&R sites has been treated differently, and parking charges for these places are independent of the zone in which the site is to be found

Parking Search Times

The inconvenience time associated with finding a parking space (termed “parking search times”) are shown in Table 4-13 and Figure 4-2. In each case, the time for EB and discretionary purposes is 1.5 times the time for commuting and education: the former category are less likely to have an allocated or ‘usual’ parking space and may not be familiar with the area in which they are parking. These values have been calibrated during the model development process, to provide the best match to observed data regarding the apparent attractiveness of car travel to different areas.

Table 4-13 - Parking Searching Time (minutes) by area

Area	Commuting and education	EB and discretionary
Inner core of Cambridge City	10.0	15.0
Rest of Cambridge City	15.0	22.5
South Cambridgeshire ring around Cambridge City	15.0	22.5
Rest of internal area (including Huntingdon, St. Ives, St. Neots and Ely)	8.0	12.0
London	15.0	22.5
Rest of external area	2.0	3.0

Parking at stations and at P&R sites has been treated differently, and parking times for these places are independent of the zone in which the site is to be found.

Figure 4-1 - Zones / areas with car parking charges

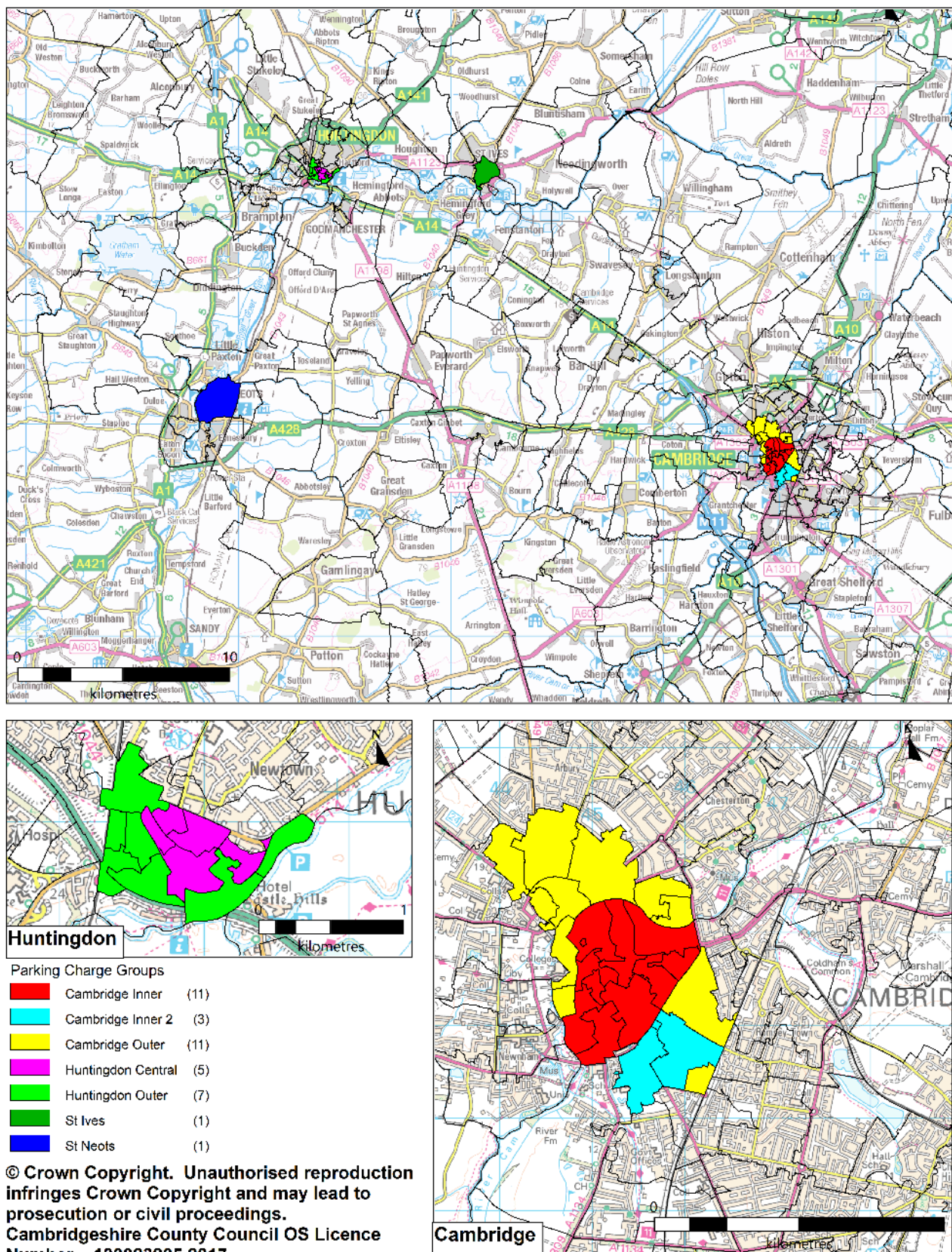
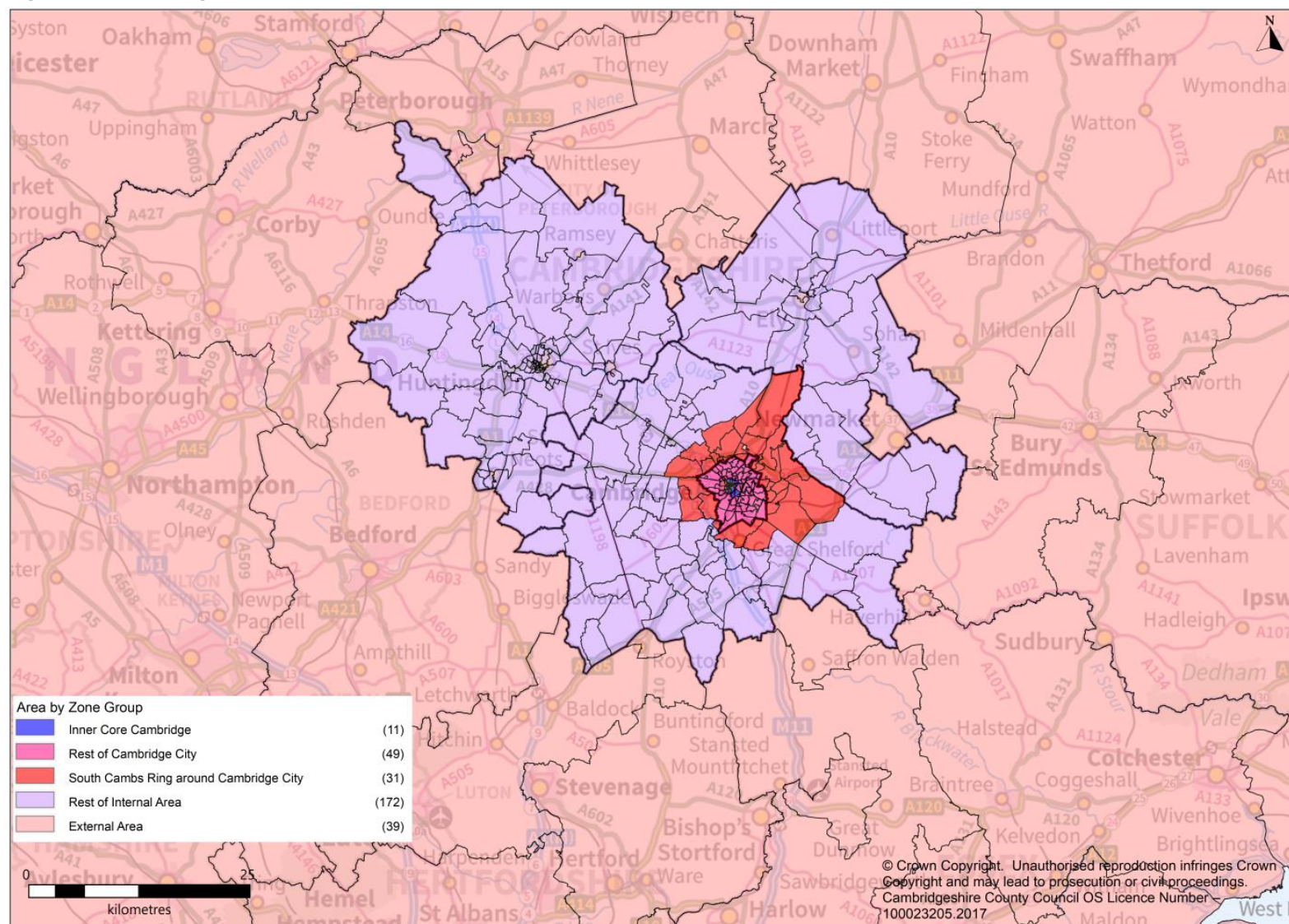


Figure 4-2 - Parking search time areas



4.3.2. Parking at Park & Ride / Park & Active Sites

The assumed search time at a P&R site is 6 minutes for all purposes (including parking the car and walking to the bus stop). In the 2015 base year the parking charge is £1 at every P&R site¹⁷. These times and charges are coded on the parking and unparking links, rather than being applied at a zonal level, with half the charge/time penalty applied to each parking and unparking link. In 2019, the parking charges at the P&R sites were already removed and therefore they haven't been included in the model.

4.3.3. Parking at Rail Stations

The assumed parking inconvenience times for different rail stations are shown in Table 4-14. These times are applied both for parking and for unparking, reflecting not only the time taken to search for a parking space and pay for it, but also potentially the queue to exit the station when a large number of passengers disembark from one train.

Searching for a parking space at local rail stations is assumed to take longer as there is a shortage of places at these stations. For some local stations, the parking search time was increased further during calibration, to reflect the inability of parking at these stations and reduce car access. In order to dissuade parking at a station in the PM Peak period, and unparking in the AM Peak period, the parking inconvenience time for both parking and unparking during these periods is set to 25 minutes, for all stations. These times can be considered part of the calibration, not that the time to park would be longer than in other time periods.

Table 4-14 - Parking search times at rail stations (minutes)

Rail station	Time penalty
Local stations with little / no parking (Great Shelford, Shepreth, Newmarket)	30.0
Local stations with limited parking (Waterbeach)	22.5
Local stations (all others)	15.0
Cambridge and Ely stations, and Cambridge North (2019 onwards)	12.0
Other main stations (Huntingdon, St. Neots, Royston, Whittlesford)	7.0

Parking charges have been implemented in the model for the local and major stations within the Study Area, as shown in Table 4-15. These charges have been implemented on the links associated with parking/unparking at the stations concerned, with half the charge applied to each parking and unparking link.

¹⁷ This charge is removed in the forecast years as the parking fees ceased in April 2018, but is retained in the base model as the fees were in force at all sites throughout 2015.

Table 4-15 - Car park charges at rail stations (2015 pence)

Station	Spaces	Daily charge before 10AM	Daily charge Off Peak
Main Stations			
Cambridge	372	920	600
Cambridge North (2019 onwards)	450	474	474
Huntingdon	824	580	330
Ely	141	540	460
St. Neots	349	790	330
Royston	341	760	330
Whittlesford	383	700	400
Local Stations			
Ashwell and Morden	26	480	330
Baldock	44	540	330
Bishop's Stortford	477	780	460
Foxton	0	0	0
Great Chesterford	0	0	0
Great Shelford	0	0	0
Hatfield	742	680	330
Littleport	40	180	180
Meldreth	46	150	150
Newmarket	12	0	0
Peterborough	731	1350	700
Sandy	142	530	330
Shepreth	11	0	0
Waterbeach	40	310	310

Source: http://www.nationalrail.co.uk/stations_destinations/ Date retrieved: 26/10/2016

4.4. Public Transport Fares

4.4.1. Price conversion from 2016 to 2015

As presented in the following sections, both rail and bus fares have been derived and calibrated in 2016 prices. A scale factor of 0.98, derived from the Retail Prices Index (RPI), has been applied to scale the 2016 prices back to 2015 prices in the model for the 2015 base.

4.4.2. Rail fares

Rail fares data was gathered on thirty different trips (zone pairs) across a range of distances, from the National Rail website in September 2016. For each trip, the fares collected were *Weekly*, *Monthly*, *Annual* season ticket price, *Regulated return* (typically 'cheap day return'), *Unregulated return* (typically 'standard day return'), and *Standard first class return* fare. A single journey charge (SJC) was then calculated for each type of ticket.

Rail fares are categorised into commuting, business and leisure fares for each of the TDM travelling purposes. The fares data was graphed and a polynomial distance decay function was fitted through the points. It was found necessary to increase the constant part of the fare paid for trips to/from London, as these are often more

expensive than other journeys. The six data sets (London / non-London and commuting / business / leisure) and the resulting functions are shown in Figure 4-3.

The form of the fares function is:

$$\text{Fare} = \text{Constant} + (\text{DistPar} \times \text{Distance}^{(1-\text{ExpPar})})$$

Where *Constant* is a fixed cost per trip

DistPar is the cost per kilometre travelled

Distance is the distance travelled by rail

ExpPar is the parameter to convert the function from linear to a distance decay function (ExpPar=0 when linear)

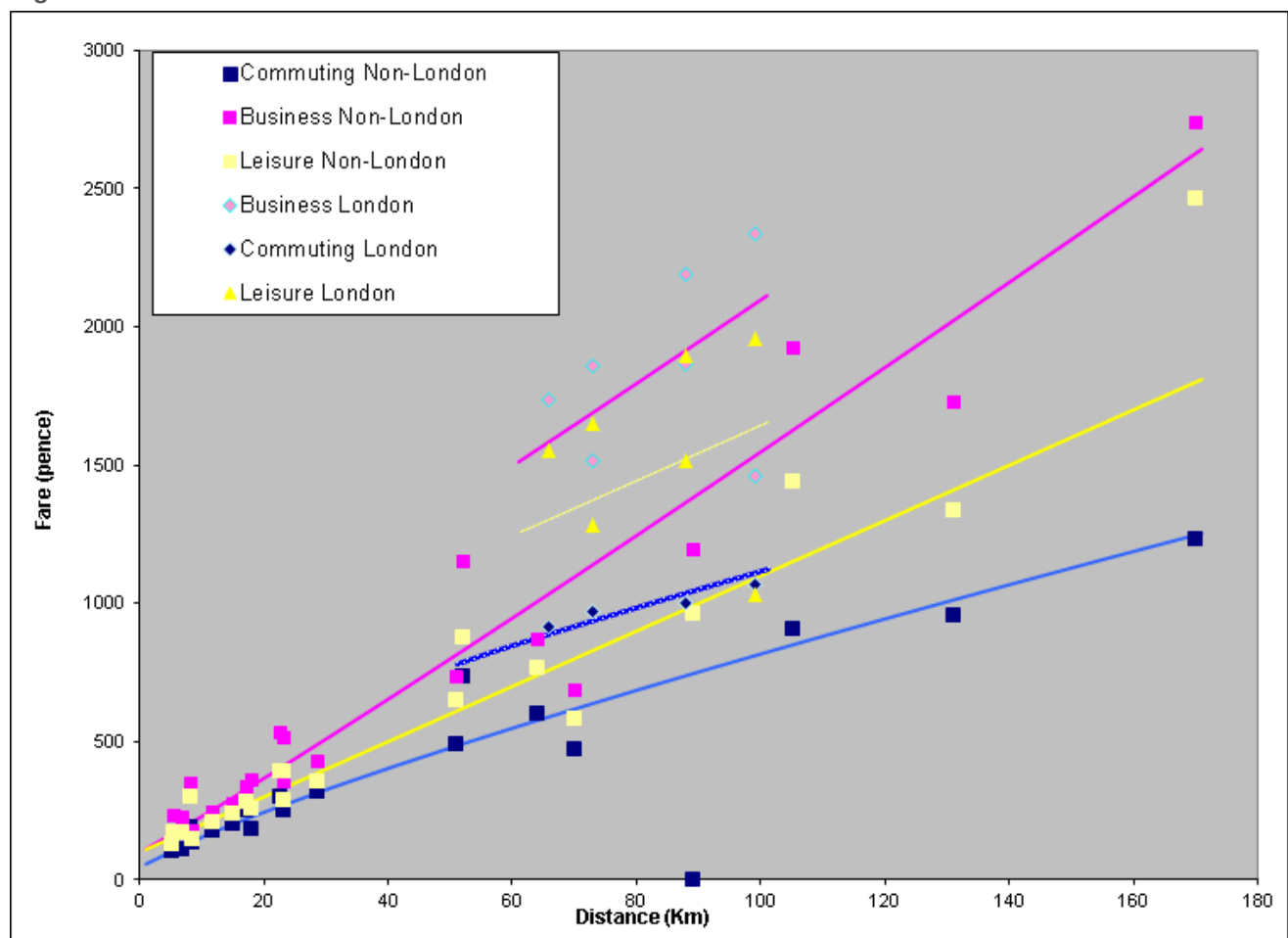
The values of these parameters are defined for each purpose in Table 4-16.

Table 4-16 - Estimated single journey (one-way) rail fares non-London (2016)

	Business	Leisure	Commuting
Constant (pence)	100	100	40
DistPar (pence per km)	11.5	10	17
ExpPar	-0.05	0	0.17
London additional constant (pence)	550	550	300

Note: 2016 data used and adjusted to 2015 price systematically

Figure 4-3 - Rail Fare Functions



Special season tickets including a fifty per cent discount are available to school children (via inquiry at Cambridge rail station). Therefore, for education trips, the assumed fare is half of the commuting function noted above.

A proportion of young persons (under 26) and retired people are also likely to use railcards. However, the main obstacle of representing this in the model is that the number of eligible people who choose to purchase railcards is not currently known. For this version of the model, railcards on leisure tickets have not been represented.

Fares are coded for each trip modelled, thus the single journey cost is coded for each leg of the journey and the complete tour will pay the sum of the two legs (from and to home).

4.4.3. Bus/Guided Bus fares

Bus fares in CSRM2 are split into three types. Zone-based charges apply to bus fares covered by the Stagecoach “Day/Mega Rider” areas, according to the origin and destination of the trip. Fixed bus fares apply to P&R bus services, based on the return P&R fare to Cambridge. Distance-based charges apply to other journeys whose fares are not covered by the previous rules (for example, National Express long-distance buses).

Fares are coded for each trip modelled, thus the single journey cost is coded for each leg of the journey and the complete tour will pay the sum of the two legs (from and to home).

In all cases, each bus fare was factored down by an appropriate amount for each traveller purpose, representing the proportion of passengers in that category who would pay the full fare. Table 4-17 gives these factors, and shows that education trips are the most heavily discounted, as would be expected since the majority of these travellers are school children, while the majority of business users pay the full fare. These factors were derived from historic NTS data for CSRM1 and it has not been possible to calculate more recent values as the equivalent data is no longer published. The Inter Peak factors are also applied to the PM Peak.

Table 4-17 - Estimated Fare Fraction Paid by Traveller Category

Travelling category	% paid AM Peak	% paid Inter Peak
Commuting	72%	76%
Education	64%	61%
Other	73%	73%
Business	94%	94%

In order to determine the zone-based bus fares :

- Data on the adult day return fare was collected for Stagecoach bus services both inside and outside of Cambridge in 2016 (Stagecoach, 2016);
- The data was divided into four bus fare zones based on fares and location (see Figure 4-4):
 - Stagecoach Day Rider Cambridge;
 - Stagecoach Day Rider Peterborough;
 - Stagecoach Day Rider PLUS Cambridgeshire; and
 - Stagecoach Day Rider GOLD East¹⁸; and
- The Day Rider cost was halved to provide a “per journey” cost. Table 4-18 shows these fares, and Table 4-19 shows which movements paid which fare.

Table 4-18 - Day Rider Fares (Stagecoach, 2016)

Ticket	Ticket Price	Price per Trip
Day Rider (within Cambridge or within Peterborough)	£4.10	£2.05
Day Rider Plus (within Cambridgeshire plus Peterborough)	£6.40	£3.20
Day Rider Gold (within the Eastern region)	£13.50	£6.75

Note: 2016 data used and adjusted to 2015 price systematically

Source: <https://www.stagecoachbus.com/tickets/all-tickets>, retrieved in October 2016

¹⁸ Although the “GOLD East” ticket covers Norfolk, CSRM2 does not include any local (Stagecoach) buses to/from that zone. Therefore, the zone groupings shown in Figure 4-4 exclude Norfolk from the GOLD East area.

Table 4-19 - Rider Fares Applied to Movements

		To			
		Cambridge	Peterborough	Cambs + Pboro	Eastern Region
From	Cambridge	Day Rider Cambridge	Day Rider PLUS Cambridgeshire	Day Rider PLUS Cambridgeshire	Day Rider GOLD East
	Peterborough	Day Rider PLUS Cambridgeshire	Day Rider Peterborough	Day Rider PLUS Cambridgeshire	Day Rider GOLD East
	Cambridgeshire + Peterborough	Day Rider PLUS Cambridgeshire	Day Rider PLUS Cambridgeshire	Day Rider PLUS Cambridgeshire	Day Rider GOLD East
	Eastern Region	Day Rider GOLD East	Day Rider GOLD East	Day Rider GOLD East	Day Rider GOLD East

P&R bus fares vary according to whether the P&R site is urban (Newmarket Road, Babraham Road, Trumpington, Madingley Road and Milton) or rural (the St Ives and Longstanton sites on the Guided Busway), as well as where the P&R trips end.

As part of the decision-making process around assumptions for the new GCP P&R sites, a review of the P&R bus fares structure was undertaken and it was noted that the coding allowed people to drive (for example) from Cambridge city centre to Trumpington P&R and catch a bus to London, but only pay the fare of a bus trip from Cambridge city centre to Trumpington P&R. In practice, nobody in the model was making this movement (in spite of the apparently low fare) – but the potential for anomalies of this nature to occur would increase when more P&R sites serving more destinations are added to the model.

In the E-series, having made the changes to separate the “from home” and “to home” legs of P&R trips, the P&R bus fares have been refined so that they depend on the direction of travel (from or to home) as well as the location of the P&R site – because the bus portion of the P&R journey should always be the part furthest from home (i.e. the second leg of a “from home” journey or the first leg of a “to home” journey).

The P&R bus fares are presented in Table 4-20 below.

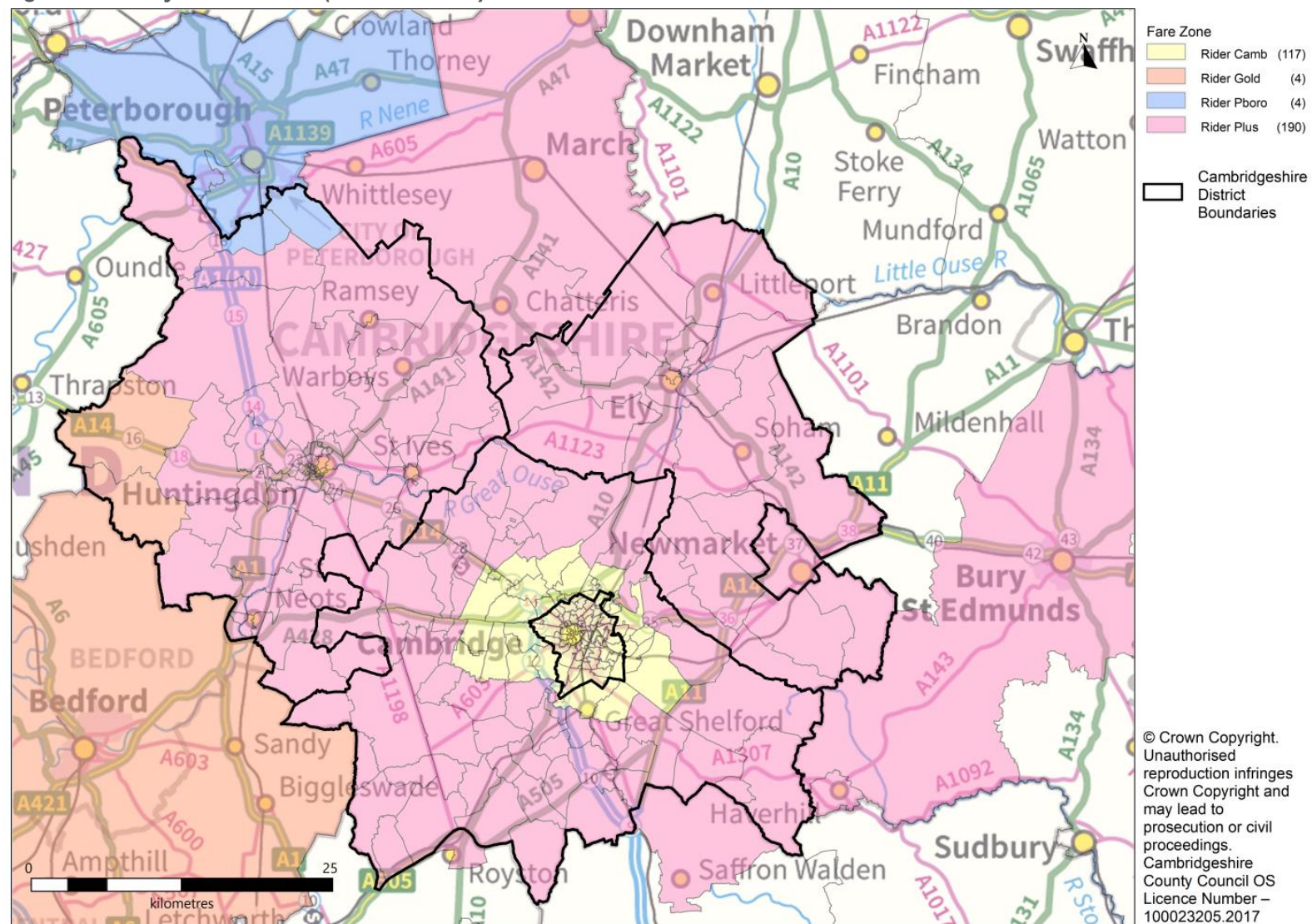
Table 4-20 - P&R Bus Fares (Stagecoach, 2016)

P&R Site Location	Ultimate Bus Destination	Return Ticket Price	Price per Trip
Urban sites (Milton, Newmarket Road, Babraham Road, Trumpington or Maddingley Road)	Within Cambridge City	£2.70	£1.35
Urban sites (Milton, Newmarket Road, Babraham Road, Trumpington or Maddingley Road)	Outside of Cambridge City but within Day Rider Cambridge	£4.10	£2.05
Urban sites (Milton, Newmarket Road, Babraham Road, Trumpington or Maddingley Road)	Outside of Day Rider Cambridge but within Day Rider Plus (within Cambridgeshire plus Peterborough)	£6.40	£3.20
Urban sites (Milton, Newmarket Road, Babraham Road, Trumpington or Maddingley Road)	Outside of Day Rider Plus but within Day Rider Gold	£13.50	£6.75
Urban sites (Milton, Newmarket Road, Babraham Road, Trumpington or Maddingley Road)	Outside of Day Rider Gold – rest of the country	Distance-based bus fare used	
Rural (Longstanton or St Ives)	Within Day Rider Plus (within Cambridgeshire plus Peterborough)	£6.40	£3.20
Rural (Longstanton or St Ives)	Outside of Day Rider Plus but within Day Rider Gold	£13.50	£6.75
Rural (Longstanton or St Ives)	Outside of Day Rider Gold – rest of the country	Distance-based bus fare used	

Note: 2016 data used and adjusted to 2015 price systematically

Source: <https://www.stagecoachbus.com/tickets/all-tickets>, retrieved in October 2016

Figure 4-4 - 'Day Rider' Zones (2016 Estimate)



In order to determine the remaining, distance-based, bus fares, data on the adult single fares for services outside of the Stagecoach Day Rider zones was collected in 2016 from National Express¹⁹. The data was graphed, and a polynomial distance decay function was fitted through the points in order to obtain the price of an adult one-way fare as a function of distance (see Figure 4-5). The formula for this curve is as follows:

$$\text{Fare} = \text{Constant} + (\text{DistPar} \times \text{Distance}^{(1-\text{ExpPar})})$$

- where
- Constant* is a fixed cost per trip
 - DistPar* is the cost per kilometre travelled
 - Distance* is the distance travelled by bus
 - ExpPar* is the parameter to convert the function from linear to a distance decay function (ExpPar=0 when linear)

The values of these parameters are defined in Table 4-21.

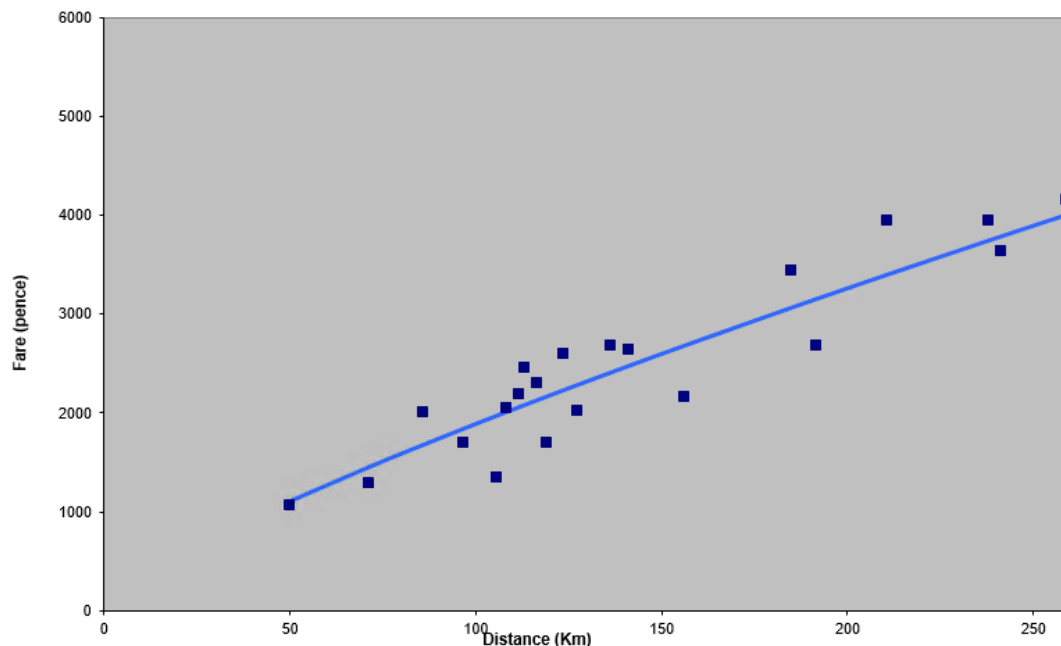
Table 4-21 - Estimated single journey (one-way) distance-based bus fares (2016)

Parameter	Value
Constant (Pence)	72
DistPar (Pence per km)	43.63
ExpPar	0.19

Note: 2016 data used and adjusted to 2015 price systematically

These fares only apply for journeys not covered in the in the Stagecoach Dayrider area and therefore they are used for long distance journeys. The equation and its parameters fit well to the 2015 sampled bus fares as shown in Figure 4-5.

Figure 4-5 - 2016 Bus fares by distance (2016 prices)



Note: 2016 data used and adjusted to 2015 price systematically

4.4.4. Growth of PT fares

The default growth assumptions for PT fares when CSRM2 is used in forecasting mode are:

- RPI + 2% per annum for bus fares; and
- RPI + 0% per annum for rail fares up to 2020, RPI +1% per annum from 2021 onwards.

¹⁹ <http://www.nationalexpress.com/home.aspx>, retrieved October 2016

These are calculated in relation to the 2015 base. Further information is provided in the CSRM2 Forecasting Report.

The same assumptions are used when backcasting from 2015 to 2011, i.e. the bus fares are reduced to 92.2% of the 2015 levels, and rail fares are reduced to 96.0% of 2015 levels. The bus fares assumption was checked against observed PT fares growth between 2007 (CSRM1 observed values) and 2015, and found to be reasonable.

For 2019 PYV, checks were made on the actual fares changes from 2015 to ensure that the growth was correctly reflecting the value of the fares in 2019. This analysis found that, contrary to the default growth assumptions, there had been no real increase in bus fares between 2015 and 2019. Thus all fares in 2019 are assumed to be the same (in real terms) as in 2015.

4.5. PT Access and Wait Times

For walk access to and egress from PT services a fixed speed of 5 km/h is assumed. Cycle access, where possible, assumes 12 km/h plus a default “cycle parking” penalty term of eight minutes, coded on the cycle parking link, to encourage short access journeys to use walk access. The cycle parking times were then adjusted during calibration with the resulting times shown in Table 4-22.

Table 4-22 - Cycle parking times

Location	Cycle parking time
Longstanton P&R site	3
St Ives P&R site	4
Cambridge and Ely rail stations	5
Whittlesford rail station	20
All other cycle parking locations (default) – including Cambridge North (2019 onwards)	8

The walk and cycle main modes use different parameters based on distance to calculate the generalised cost, see Section 6.2. Both pedestrians and cyclists use minimum-distance paths in the model to access PT services.

Rail access from external or rural zones with no detailed highway network were linked to the most likely point of access on the modelled rail network by rail access links, as described in Section 3.9.

The times (speeds) of car legs (car access) in P&R and rail movements are skimmed from the HAM's congested SATURN assignment.

The PT wait times are dependent on the headway²⁰ of the bus, Guided Bus or rail service being accessed. These wait times or wait ‘penalties’ are added onto the automatically-generated boarding links of a PT journey (link type 33 for bus boarding, 83 for Guided Bus boarding and 43 for rail boarding).

The wait time function is the same for bus, Guided Bus and rail modes in all time periods, although the headway itself may vary between services and periods. For headways of up to 10 minutes it is assumed that the traveller has a random wait, with average time being half the headway. As the headway grows longer, the average wait time increases but more slowly because at least some of the travellers will use timetable information to arrive closer to the expected time.

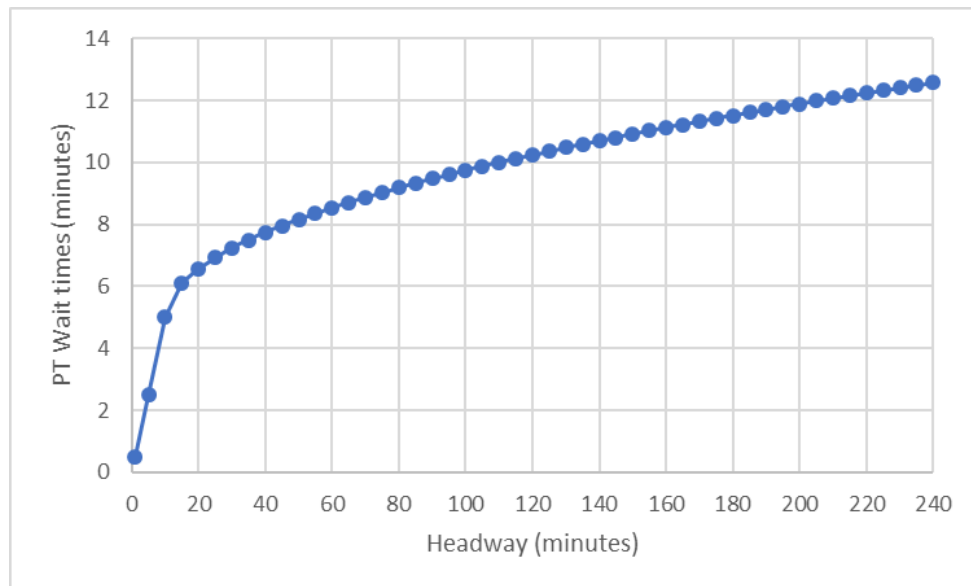
The function is:

$$\text{wait time} = \begin{cases} \frac{\text{headway}}{2} & \text{if headway} \leq 10\text{min} \\ \frac{10 + \sqrt{\text{headway} - 10}}{2} & \text{headway} > 10\text{min} \end{cases}$$

This wait function is plotted in Figure 4-6. An hourly service will induce approximately an eight-minute wait and a four-hourly service will induce a twelve-minute wait.

²⁰ The headway of a public transport service is defined as the elapsed time between services in a modelled time period, normally calculated as an average. For example, a bus service which operates 3 times in the morning peak (07:00-10:00) has a 60-minute headway. Headway is used to calculate wait times for PT services.

Figure 4-6 - Relationship between PT wait time and service frequency



In addition to wait times, board and alight times are added to PT journeys as described in Sections 3.3 (bus / Guided Bus) and 3.6 (rail).

TAG Unit M3.2 (DfT, January, 2016) suggests that crowding on public transport should only be modelled where it is likely to have a significant effect on traveller behaviour or where an effect on crowding is one of the objectives of the scheme. It is widely acknowledged that PT crowding is problematic to represent within a strategic model. Bus operators will routinely alleviate crowding by increasing service frequencies or running double-deck buses, a variation usually best represented by assuming that changes in crowding are not a significant factor for bus passengers over the long-term. Crowding can be a more permanent feature on rail services and constrain demand. Though lack of seats is an issue for services between London and Cambridge, this is not currently considered to constrain overall numbers travelling though may impact times of travel. It is also noted that rail services to the north of Cambridge are also crowded, particularly on the Ely to Cambridge leg, though this is often related to train length and student travel. The volume to capacity ratios should be monitored when forecasting to determine whether crowding will become a problem in the future and will recommend further policy runs if this is the case.

4.6. Weighting of Time

Weightings of time are used to distinguish the time spent accessing and waiting for public transport from the other journey stages when constructing the generalised cost of travel on which the travellers' choices are based. They also represent the general reluctance of people to walk long distances or wait for a public transport due to the perceived time required that may not be the same as actual time.

The weights used within the model are shown in Table 4-23. (Network modes are defined in Section 3.2).

Table 4-23 - Weighting of time components in generalised cost

Stage of travel	Network Mode	Path assignment	Mode and Dest choice
In Vehicle Time	Bus Ride	1.00	1.00
	GB Ride	0.90	0.90
	Rail Ride	0.85	0.85
Wait Time (this is IVT weight above, multiplied by 2.5)	Bus wait	2.50	2.50
	GB wait	2.25	2.25
	Rail wait	2.13	2.13
Access to PT	Walk access	3.00	2.00
	Cycle access	3.00	2.00
	Car access	0.80	1.00
Interchange to P&R (bus or rail)	Cycle park	2.00	2.00
	Car park ²¹	2.00	2.00

Walk and cycle generalised costs are based on distance as described in Section 6.2, so any weighted time for access is added based on assumed fixed walk or cycle speed. This is equivalent to a time weighting of 3 or 2 as shown above for the different choice stages. A higher value of 3 is used in path assignment to ensure the walk stages on PT trips are not excessively long or frequent. The rail time weighting of 0.85 reflects the greater comfort and ability to use time productively on rail services.

The Guided Bus time weighting of 0.9 reflects the high quality and comfort (e.g. leather seats and wireless internet access), and the fact that the ride quality on guided sections is superior to normal bus services. The Guided Bus time weighting has been chosen to be between that for bus and rail. This is in line with TAG Unit M3.2 (DfT, January 2014) which confirms that *“in some instances, factors may be applied to the in-vehicle times that reflect people’s preferences for the various modes. This is most likely to be relevant where the influence of fare on the choice of routes and services is likely to be quite weak and, as a result, the fare term may be excluded from the generalised cost formulation used at the assignment stage. These in-vehicle time factors may be interpreted as mode-specific values of in-vehicle time. Thus, instead of an in-vehicle value of time of unity being used, as might be used in models for multimode transport studies, non-unity values of in-vehicle time are used to represent the inherent, relative attractiveness of the various modes”*.

There is some literature support for this, see for instance Whelan et al. (2008)²² who conducted a Stated Preference experiment in the north of England into Bus Rapid Transit (BRT) which found that the public’s perceived time weighting for BRT was 92% of the time weighting for conventional bus. Light Rail was discovered to have a perceived time weighting 78% of the same. Guided Bus ridership in CSRM1 was compared with surveyed GB usage in 2012, and found to correspond reasonably well, with the additional attraction factor producing reasonable results. It was also found during CSRM2 calibration that using this weighting produces plausible ridership results in comparison to other bus services.

During the calibration of CSRM1, an adjustment was made to the time weighting for car interchange to local rail stations in the Inter Peak period: instead of the standard 2.0 (given in Table 4-23 and applied in all other cases), a weighting of 2.5 is applied in this instance. This represents the additional difficulty of finding a parking space at local (small) stations – making it less attractive to park in the Inter Peak than the parking charge alone might suggest. This calibration factor has been carried into CSRM2.

²¹ Except at local stations in the Inter Peak, when a weighting of 2.5 is applied instead of 2.0.

²² G Whelan, J Crockett, L Hunt and C Sinclair, “Willingness to pay for bus rapid transit: an examination of the influence of psychographics on choice”, in *Proceedings of the European Transport Conference 2008*. <http://etcproceedings.org/paper/willingness-to-pay-for-bus-rapid-transit-an-examination-of-the-influence-of-ps>

5. Travel Demand Input

5.1. Introduction

CSRM2 differs from CSRM1 in that no separate Land Use model is used to derive trip ends. This does not affect the structure or working of the main Transport Demand Model (TDM) or supply-demand iterations. Instead it simply implies that the production and attraction locations which were previously derived in the base year and future years from the Land Use model are now derived outside the CSRM2 model itself.

This chapter outlines the general structure of the Trip Ends input to the model, including both the trip productions and attractions, and how these are derived from land use data. The process by which the land use data for 2011, 2015 and 2019 was derived is also described.

For each model zone, the number of HB trip productions are derived by applying trip rates based on the population of the zone. To facilitate this, a population for each zone has been derived with the segmentation required for the demand model, and then trip rates are applied individually to each population segment. The population data is first prepared for 2011, making use of 2011 Census of Population data, and then updated to the 2015 base year and 2019 present year using local data and ONS mid-year population estimates.

The process of deriving the HB trip productions and attractions can therefore be divided as follows:

- Derivation of segmented population in 2011 from Census data;
- Derivation of trip attractions in 2011;
- Update of the population and attraction data from 2011 to 2015 and 2019; and
- Derivation and application of trip rates.

5.2. Segmented 2011 Population

The CSRM2 zones have been defined such that all zones are made up of one or more Census Output Areas (OA). This allows the overall resident population of each zone to be calculated directly from Output Area data. The usual resident population in 2011 Census table QS103EW has been used for this purpose.

All zones either nest within Census Middle Super Output Areas (MSOAs) or are defined as groups of MSOAs. This has the advantage that, where the segmentation required for the model is not available directly from Output Area Level Census tables, an MSA level table can be used to derive a percentage segmentation, and this applied across zones within the MSA.

Table 5-1 below summarises the Census tables which have been used in deriving 2011 population data. The Census of Population is supplemented with data on incomes from the National Travel Survey (NTS). Table 5-2 shows the segmentation of the trip ends input to the model for each HB purpose, alongside more detail of the derivation of the 2011 population relevant to this segmentation.

Table 5-1 - Tables used for 2011 Population

Source	Table	Table Fields	Dimensions used in CSRM	Spatial level	Unit
2011 Census	QS103EW	Usual residents by age	Total population, and school age	OA	All usual residents (in both household and communal establishment)
	DC6606EW	NS-SeC and Economic Activity	GSeC, FT/PT work, student, non-employed or retired status	MSOA	All usual residents aged 16 and over
	LC4609EW	Economic Activity and #Cars/vans in Household	Combined with DC1401EW to estimate car availability	OA	All usual residents in household aged 16 and over
	DC1401EW	Household composition by #Cars/vans	Combined with LC4609EW to estimate car availability	MSOA	Households
	LC4109EW	#cars/vans by age	Number of cars in household (children)	OA	All usual residents in household
	DC1109EW	Household composition by age	Number of adults in household (children)	MSOA	All usual residents in household
NTS	n/a	Income by economic activity, age and #cars/vans	Applying income segmentation	National, excl. London and metropolitan areas	Trips

Table 5-2 - Home-based trip production segments and derivation of 2011 populations

Trip Purpose	Transport Demand Model (TDM) dimensions	Derivation
Commuting (HBW)	4 * GSeC for employed adults 2 * PT/FT 3 * Car Availability (24 HBW segments)	Total Employed Residents by zone derived from MSOA level data, table DC6606EW providing NS-SeC and FT/PT employment status. Additional segmentation by car availability added using: Census LC4609EW (economic activity and number of cars in household), DC1401EW (number of adults and cars in household), and NTS data (NS-Sec, FT/PT work and number of cars for HBW trips)
Education (HBEd)	3 * Car Availability 3 * Income 4 * Age (education stage) (36 HBEd segments)	Education stages are identified from population by age (Census table QS103EW), as follows: Pre-school (excluded): 0-4 years Primary school: 5-11 years Secondary school: 12-16 years Sixth-form/FE: 17-18 years The number of higher education students by zone is derived from DC6606 economic activity table, with sixth form/FE students then removed. Car availability is estimated using information on number of cars and adults in households with dependent children (DC1401), further refined using tables DC1109EW and LC4109EW. Income segmentation is derived from NTS data. The 17-18 year olds are then re-scaled at study area level to match the total number of sixth form and FE college places available, as not all people of this age will attend full-time.
Employer's business (HBEB)	3 * Car Availability 3 * Income (9 HBEB segments)	Trip rates applied to Employed Resident data, as described for HBW above. GSeC and FT/PT groups are converted to income bands using NTS data relating NS-SeC and working status to income.
Discretionary trips (HBPB and HBRV)	3 * Car Availability 3 * Income (9 HBPS segments and 9 HBRV segments)	Trip rates are applied separately to each population segment, including Employed Residents, children and students, and additionally non-employed and the retired. The latter two categories are derived from Census table DC6606 on Economic Activity together with QS103EW and LC4609EW. The non-employed are defined as economically active unemployed, plus the economically inactive who are long-term sick or disabled, or looking after home or family. Car availability is derived as for Employed Residents above. All non-employed and retired are assumed to be low income for trip-making purposes.

All trip ends are segmented by three levels of car availability, which are defined in Table 5-3 below.

Table 5-3 - Car availability definitions in CSRM2

TDM car availability	Definition
No car availability	1 adult 0 car 2+ adults 0 car
Partial car availability	2+ adults 1 car
Full car availability	1 adult 1+ cars 2+ adults 2+ cars

5.3. Derivation of Trip Attractions

Table 5-4 summarises the trip attraction weights used in the model and the sources of these. HBW (commuting) and HBEd (for primary, secondary and sixth form/further education, but not tertiary/higher education) are doubly-constrained. For these doubly-constrained purposes, the attractions are input as absolute figures, and are scaled (for each trip attraction segment shown below) to match the number of trip productions across the whole model.

The other purposes are singly constrained, and therefore trip attractions act only as unitless weightings of attraction to each zone.

Table 5-4 - Source of trip attraction weights

Trip purpose	Attraction weight	Segmentation	Source	Notes
HBW	Employment	GSeC and FT/PT	Census 2011 tables WP601EW: FT/PT by workplace zone (WPZ), and WP607EW: GSeC by WPZ	Doubly-constrained at this segmentation level
HBEB and NHBEb	Employment	Income	From above, with GSeC mapped to income band using NTS data	
HBEd (Primary, Secondary and Sixth/FE)	School places	Education stage	DfE school census ²³ and performance tables ²⁴	Doubly-constrained by education stage
HBEd (Tertiary/Higher)	Tertiary/higher education pupils at place of study	None	Analysis of floorspace for CSRM1	Only approximate distribution of University education facilities
HBPS, NHBO	Employment in retail, accommodation, food services and health services (SIC G, I and Q)	None	Census WP605EW (WPZ)	SIC = Standard Industrial Classification
HBRV	Employment in arts, entertainment and recreation (SIC R and S), plus population	None		Recreation employment and population given equal weighting ²⁵

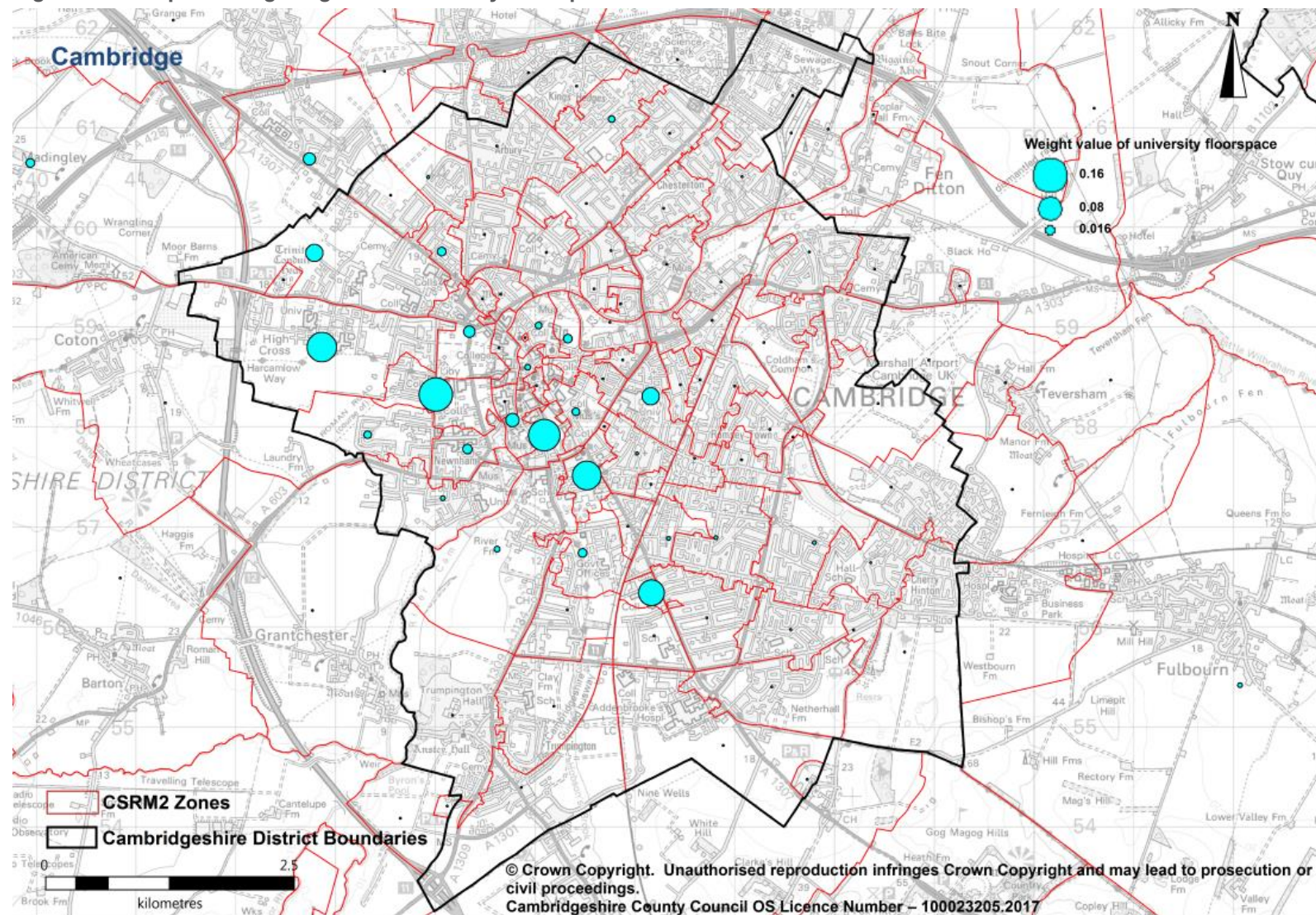
During the update of CSRM2, it was not possible to obtain updated university/higher education floor space for the 2015 base year, and these weightings have therefore been carried over from CSRM1. A sense-check has been carried out, and Figure 5-1 shows the distribution of the weights that have been retained in the CSRM2 base.

²³ <https://www.gov.uk/government/statistics/schools-pupils-and-their-characteristics-january-2016>

²⁴ <https://www.compare-school-performance.service.gov.uk>

²⁵ Recreation and visiting friends are combined in a single trip purpose with a single attractor. NTS trip rates suggest that the individual trip rates are very similar. Therefore, recreation, employment and population are given equal weightings in the attraction. This is achieved by calculating the attractor as an index across all zones for each sub-purpose in turn, and then averaging the result.

Figure 5-1 - Map showing weights of university floorspace attractions



5.4. Growth from 2011 to 2015 to 2019

Data for trip productions and attractions which was sourced from 2011 Census has been scaled to represent growth from 2011 to 2015 and 2019. The approaches taken are outlined below. The CSRM2 Forecasting Report contains more information and land use changes through time. Many of the methods and data are common to the 2011-2015-2019 period. Therefore, the Forecasting Report should be consulted to gain a fuller understanding of this.

Population Growth

Population growth has been considered using two separate approaches: delivery of additional dwellings to identify the zonal growth patterns, and ONS population estimates to control the overall totals at Output Area level.

The additional dwellings completed between 2011, 2015 and 2019 were first determined at a zonal level using dwelling completion data provided by CCC, for internal zones only. ONS population estimates for 2015 and 2019 were then obtained from the NOMIS website²⁶ at Output Area (OA) level for Cambridgeshire and at MSOA level nationally, and again mapped to zones using the mapping derived from 2011 data. The resulting population per dwelling ratios for internal zones were calculated and inspected, and some adjustments were made to the mapping of OA population to model zones to account for new developments where the population growth from 2011 had not been uniform across the OA.

The approach of applying zonal growth based on dwellings means that local demography is preserved and will influence overall patterns (i.e. population by categories are growing at the same speed without variation). The NTEM v7.2 dataset from DfT forecasts number of households segmented by number of cars owned, which suggests a continuous trend (see Table 5-5) of decreased proportion of household without car and increased proportion of household with 2 or more cars. Therefore, the adjustments on proportions of household by car availability have been applied based on NTEM data by NTEM zones (MSOA). All CSRM2 zones residing in the same MSOA will have the same adjustments.

Table 5-5 - CSRM2 study area households (Hhs) composition by number of cars

Year	Hhs with No Car	Hhs with 1 Car	Hhs with 2 Cars	Hhs with 3+ Cars
2011	17%	42%	31%	10%
2015	17%	42%	31%	11%
2019	16%	42%	31%	11%

Source: NTEM v7.2

No other estimates for change by population segment were available which were considered reliable or significant for 2011-2015-2019 (e.g. household size, age, economic activity) and therefore no specific adjustments were made.

Job Growth

Job growth in the internal study area was sourced at the MSOA level from the East of England Forecasting Model (EEFM), which provides estimates of employment by MSOA. EEFM is maintained by CCC Research Group, and data was reviewed with CCC in February 2021. For the majority of cases, the change from 2011 to 2015/2019 was assumed to be uniform across all zones within an MSOA. However, where information from CCC or the Local Authority Districts indicated that changes were concentrated within a specific zone, a specific adjustment at the zonal level was applied.

No separate estimates were available for jobs growth by segment (e.g. GSeC, FT or PT, or industry). Therefore, all segmentation of job attractions (including retail and recreation jobs for HBPS and HBRV trips) was assumed fixed within zones, but as with population variations in growth patterns between zones will naturally vary the overall segmentation.

²⁶ www.nomisweb.co.uk, tables SAPE20DT10h (2015) and SAPE22DT10h (2019), data accessed 15 January 2021

5.5. Trip Generation

5.5.1. Trip Rates

TAG Unit M2.1 Section 4.6 states that in a model where walk and cycle are explicitly included, there should be no need to model trip frequency responses. Total trip rates vary relatively little between areas with quite different costs of travel, once significant differences between “person types” are allowed for, and provided that all trips (including relatively short walk trips) are included. However, trip lengths and mode choices (and thus the total travel by each mode) vary significantly according to the characteristics of the travel choices available.

A good simplification in multi-modal forecasting is to treat the total number of trips as being constant within each planning scenario, but – at least in principle – to model changes in mode and destination choices in response to changes in generalised cost which arise both from congestion and the impact of policy action.

In CSRM2 this is achieved by calculating the segmented land use information (population, employment, school places) as described above, and allowing the TDM to determine the response (in terms of trip length, mode and time of day) based on changes in generalised costs.

The conversion of land use activities into the demand for travel is carried out using trip generation rates derived from the National Travel Survey (NTS) for a detailed person and trip purpose segmentation.

The NTS is a continuous household survey on personal travel. It provides the DfT with data to answer a variety of policy and transport research questions. The survey has been running on an ad hoc basis since 1965 and continuously since 1988. NTS data used in CSRM2 was collected between 2004 and 2014.

The HB and NHB trips are generated slightly differently within the model. This section explains how HB trip rates were calculated.

The NTS dataset used to calculate trip rates includes records from 2004-2014 inclusive for the whole of Great Britain (excluding London and other metropolitan areas) to meet the requirements of sample size. The trip rate comes from the ratio of the number of trips by segment to the associated number of individuals in the NTS for the same segment. The trip rates required for the TDM are the trip production or tour rates – i.e. for HB trips the number of from home trips made for that trip purpose.

As set out previously in Table 2-15, the CSRM2 TDM models 24-hour average weekday trips for HBW and HBEB trips but 12-hour average weekday trips for discretionary (HBPS and HBRV) trips, and 12-hour term-time weekday trips for HBEd. The 24-hour/12-hour variation takes place at the stage of TOD split where proportion of trips for 12-hour period over 24-hour total have been used for discretionary trips. At this trip productions stage, where population is converted to trips, 24-hour average weekday trip rates by purpose are required, although for HBEd 12-hour term-time weekday trip rates (as effectively no education trips are generated in Off Peak time from NTS) are needed after scaling average weekday to term-time weekday.

The resulting trip rates are shown in Table 5-6 to Table 5-8 below. The education rates shown in Table 5-7 include escort education trips. Where sample sizes in NTS were too small to support variation in trip rates, an identical overall rate has been applied for each segment, and the individual rates are greyed out.

Table 5-6 - HBW and HBEB Trip Rates: 24-hour weekday From Home trips/employed resident

Purpose	Work Time	GSeC	Trip Rate by Car Availability			
			No Car	Part Car	Full Car	Overall
HBW	Full Time	1	0.703	0.700	0.616	0.636
		2	0.668	0.682	0.624	0.639
		3	0.656	0.667	0.581	0.608
		4	0.672	0.750	0.703	0.715
		all	0.669	0.699	0.622	0.645
	Part Time ²⁷	1	0.324	0.324	0.324	0.324
		2	0.369	0.369	0.369	0.369
		3	0.378	0.378	0.378	0.378
		4	0.526	0.526	0.526	0.526
		all	0.435	0.435	0.435	0.435
HBW Average			0.615	0.645	0.574	0.596
HBEB ²⁸	Full Time	1	0.102	0.102	0.102	0.102
		2	0.079	0.079	0.079	0.079
		3	0.076	0.076	0.076	0.076
		4	0.043	0.043	0.043	0.043
		all	0.074	0.074	0.074	0.074
	Part Time	1	0.074	0.074	0.074	0.074
		2	0.074	0.074	0.074	0.074
		3	0.057	0.057	0.057	0.057
		4	0.046	0.046	0.046	0.046
		all	0.057	0.057	0.057	0.057
HBEB Average			0.070	0.070	0.070	0.070

Source: calculated from NTS data, 2004-2014

Table 5-7 - Education Trip Rates: 12-hour weekday From Home trips/person in education

Age (school stage)	Car Availability			
	No Car	Part Car	Full Car	Overall
5 to 11 (primary school)	1.361	1.741	1.655	1.646
12 to 15 (secondary school)	1.160	1.298	1.199	1.222
16 to 18 (6 th form / further education)	1.030	1.050	1.061	1.055
19+ (higher education)	0.584	0.438	0.323	0.411
Total	0.815	1.021	0.954	0.956

Source: calculated from NTS data, 2004-2014

²⁷ The HBW Part Time trip rate does not vary by car availability as the sample sizes from NTS were too small.

²⁸ The HBEB trip rate does not vary by car availability as the sample sizes from NTS were too small.

Table 5-8 - HBPS and HBRV Trip Rates: 24-hour weekday purposes/person

Purpose	Population category		Car Availability/Household Income			Overall
HBPS	Adults		No Car	Part Car	Full Car	
	Employed		0.266	0.285	0.261	0.268
	Non-employed		0.506	0.542	0.538	0.529
	Retired		0.492	0.670	0.647	0.616
	Children and Students		High Income	Medium Income	Low Income	Overall
	Age bands	0 to 4	0.518	0.385	0.559	0.484
		5 to 11	0.152	0.137	0.181	0.155
		12 to 15	0.128	0.107	0.149	0.127
		16 to 18 ²⁹	0.163	0.163	0.163	0.163
		19+	0.240	0.314	0.218	0.256
HBRV	Adults		No car	Part Car	Full Car	Overall
	Employed		0.191	0.285	0.326	0.306
	Non-employed		0.260	0.403	0.519	0.403
	Retired ³⁰		0.260	0.403	0.519	0.403
	Children and Students		High Income	Medium Income	Low Income	Overall
	Age bands	0 - 4	0.363	0.246	0.403	0.335
		5 to 11	0.349	0.209	0.361	0.304
		12 to 15	0.323	0.232	0.388	0.311
		16 to 18	0.327	0.243	0.410	0.321
		19+	0.296	0.298	0.279	0.291

Source: calculated from NTS data, 2004-2014

Once the trips have been generated from the population, the 24-hour trips (except education which is 12-hour trips) then are converted into four periods (AM Peak, Inter Peak, PM Peak and Off Peak) for both HBW and HBEB trips, and three periods (AM Peak, Inter Peak and PM Peak) for discretionary trips. The factors in Table 5-9 are the default TOD split ratios assumed by the choice model for each purpose. Therefore, the sum of the split ratio by periods for HBW and HBEB is one whilst for discretionary trips is less than one as Off Peak trips are not included.

²⁹ The HBPS trip rate for children/students aged 16 to 18 does not vary by income group as the sample sizes from NTS were too small.

³⁰ The HBRV trip rate does not vary between Non-Employed and Retired adults as the sample sizes from NTS were too small.

Table 5-9 - Time of Day Split Input to the Model

Purpose	Time of Day	Car ³¹	PT	Walk	Cycle
HBW	AM	0.71	0.70	0.70	0.70
	IP	0.12	0.16	0.16	0.16
	PM	0.06	0.03	0.03	0.03
	OP	0.11	0.11	0.11	0.11
	Total	1.00	1.00	1.00	1.00
HBEB	AM	0.56	0.54	0.54	0.54
	IP	0.28	0.37	0.37	0.37
	PM	0.07	0.05	0.05	0.05
	OP	0.09	0.04	0.04	0.04
	Total	1.00	1.00	1.00	1.00
HBPS	AM	0.27	0.19	0.19	0.19
	IP	0.59	0.71	0.71	0.71
	PM	0.13	0.07	0.07	0.07
	Total	0.99	0.98	0.98	0.98
HBRV	AM	0.16	0.14	0.14	0.14
	IP	0.42	0.50	0.50	0.50
	PM	0.30	0.21	0.21	0.21
	Total	0.88	0.86	0.86	0.86

Source: calculated from NTS data, 2004-2014

Within the TDM it is necessary to convert the HB tours into trips from and to home. This step is carried out before the trips are assigned in the network models by which stage the tours have been disaggregated by mode and time period. The conversion process therefore requires data for each trip purpose on the number of trips to-home by mode and time period for each from-home mode and time period. These figures were also derived from NTS data and have been shown previously in Table 2-17.

5.5.2. Exceptions

The first exception to the above is education trips, which do not have any time of day choice, thus 12-hour tour matrices by mode are created. As with the above trip rates, these parameters have been calculated from 2004-2014 NTS data. Primary, secondary and 6th form were combined to form “school”, while higher education was treated separately. The proportions used in the model by mode are shown in Table 5-10.

³¹ The red-highlighted values for car time of day splits have been calibrated, supported by other sources of highway data available across Cambridgeshire (county screenline traffic counts, and 2013 RSI data in Cambridge).

Table 5-10 - Education travel proportions: 12 hour trips split by time of day and direction

Mode	Time Period	HBEd from home (per 12-hour from-home trip)		HBEd to home (per 12-hour from-home trip)	
		School	Higher	School	Higher
Car	07:00-09:59	0.912	0.670	0.038	0.131
	10:00-15:59	0.078	0.305	0.523	0.329
	16:00-18:59	0.010	0.024	0.235	0.333
	Grand Total	1.000	1.000	0.795	0.794
PT	07:00-09:59	0.943	0.670	0.005	0.000
	10:00-15:59	0.056	0.305	0.420	0.317
	16:00-18:59	0.001	0.024	0.568	0.532
	Grand Total	1.000	1.000	0.993	0.849
Walk and Cycle	07:00-09:59	0.900	0.527	0.053	0.057
	10:00-15:59	0.093	0.464	0.786	0.439
	16:00-18:59	0.007	0.009	0.153	0.358
	Grand Total	1.000	1.000	0.992	0.854

Source: calculated from NTS data, 2004-2014

The second exception is the HBW trips, which must be converted from the eight GSeC Full/Part Time categories to three income segments using income split coefficients which are shown in Table 5-11. Therefore, each HBW car or public transport tour generates up to 3 categories of from-home trips (some in each income range), and three income categories of to-home trips in that and subsequent time periods, for as many as nine associated to-home flows. Because walk and cycle do not have income-segmented flows, each HBW walk or cycle trade generates only one from-home flow in one period, and one to-home flow in the same and subsequent periods.

Table 5-11 - Income split by GseC for commuters

Full / Part Time	GseC	% high	% medium	% low
Full Time	1	77.8%	19.2%	2.99%
	2	67.2%	26.9%	5.93%
	3	52.9%	35.1%	11.97%
	4	42.5%	40.1%	17.43%
Part Time	1	73.8%	18.1%	8.14%
	2	52.7%	33.5%	13.82%
	3	41.9%	33.7%	24.37%
	4	29.1%	36.8%	34.09%

Source: calculated from NTS data, 2004-2014

5.5.3. Non-home-based trips

NHB trips are generated from HB trip attractions (e.g. persons arriving at work). All HB trip attractions can generate NHBO trips; only HBEB and HBW generate NHBE. No NHB trips are generated in Off Peak.

As is standard practice in this type of model, non-home-based (NHB) trips (e.g. from work to the shops) are modelled as single-leg trips with no knowledge of the return portion. This is because they might be stop-offs on the way to/from home, and not necessarily a return trip between the same two points. In this sense, NHB trips are inherently asymmetric. However, with the increased uptake of P&R in the GCP tests, it became apparent that many NHB trips were travelling into the city centre using P&R but travelling out of the city centre by car

(because the two trips are not linked, and because the parking charges associated with taking a car into the city centre (making P&R more attractive in this direction) do not apply on the outward leg). This caused a noticeable imbalance of modelled trips at P&R sites, with cars being parked there but never being retrieved.

In reality, it is expected that only a very small number of NHB trips would use P&R. A further review of the Department for Transport's guidance confirmed that it is entirely acceptable for the P&R mode to be unavailable for NHB trips and so this approach has now been taken in the CSRM2 E-series onwards: NHB trips are no longer able to use P&R.

The NHB trip rate per HB trip attraction (Gamma values, listed in Appendix D in detail) are calculated from NTS data (2004-2014), based on the method used in the National Trip End Model version 7.2 (NTEM7.2). The idea is that workers arriving in a given period only generate trips in that and the subsequent period. Those arriving in cars can use cars or other modes, with a conditional probability spread, while those not arriving in cars use a probability spread conditional on not arriving in a car, which generally gives much lower car use.

NHB walk and cycle trips are not generated in external zones, nor can they be attracted to external zones, as the model does not include weights for these modes to such zones. This is unlikely to be a problem as such trips are usually short and the study area boundary does not pass through any urban areas. For car and public transport trips, NHB trips are attracted to external zones, but not produced there.

6. Implementation of the Transport Demand Model

6.1. Discrete Choice Model and Parameters

This section documents the key parameters used in the nested logit discrete choice models which are the core of the Demand Model. The mathematical form of these models is as described in TAG unit M2.1 Section 4.3 (DfT May 2020), especially appendix E, and the notation used here is consistent with the notation defined in that appendix. The “TAG illustrative” parameter values given below are from Table 5.1 of that report.

The hierarchy used is the TAG default hierarchy for all purposes, as discussed in Chapter 2, with three main levels as shown previously in Figure 2-7: main mode choice, macro time of day choice, then distribution.

The lambda (λ) parameters shown in Table 6-1 are the calibrated sensitivity parameters used in tour distribution for car and public transport. For any tour production zone i , attraction zone j , main mode m , time of day t and demand segment p , the trip distribution probability is:

$$T_{ijmtp} = \frac{T_{imtp} B_j \exp(-\lambda_{dest,m,t,p} G_{ijmtp})}{\sum_k B_k \exp(-\lambda_{dest,m,t,p} G_{ikmtp})} \quad (\text{TAG M2.1, Section E.5.4})$$

where B_j are zonal attraction (size) terms for zone j defined in Section 5.3 above.

G_{ijmtp} is the generalised cost of travel from zone i to zone j by mode m and time period t , for trip purpose/segment p from the assignment models after sub-mode choice

$\lambda_{dest,m,t,p}$ is the distribution parameter referred to above; and

T_{imtp} is the number of trips from zone i by the mode m and time period t after the main mode choice step.

The composite disutility at a production zone that is passed up to the TOD and mode choice nests is:

$$U_{imtp} = \ln \sum_j B_j \exp(-\lambda_{dest,m,t,p} G_{ijmtp}) - \ln \sum_j B_j \quad (\text{TAG M2.1, Section E.4.1})$$

Note that λ is for a two-way (out+return) cost for HB purposes and a one-way trip cost for NHB purposes. (See Section 2.9 and Table 2-13). The illustrative destination choice parameter values in TAG M2.1 Table 5.1 are understood to be for a one-way trip cost, and have been halved as appropriate for comparison with the HB purposes in Table 6-1. Also, note that they are quoted as positive in this notation.

Table 6-1 - Distribution parameters for Car and Public Transport, with TAG default values

Purpose	Mode	CSRM lambda	TAG M2.1 Table 5.1 illustrative values				% diff from Median	Cost units
			For purpose	Min	Median	Max		
Home-Based								
HBW	Car	.0358	HBW	.0270	.0325	.0565	+10%	2-way
	PT	.0206	HBW	.0115	.0165	.0215	+25%	2-way
HBEB	Car	.0419	HBEB	.0190	.0335	.0530	+25%	2-way
	PT	.0225	HBEB	.0150	.0180	.0220	+25%	2-way
HBPS	Car	.0450	HB Other	.0370	.0450	.0800	0%	2-way
	PT	.0225	HB Other	.0165	.0180	.0310	+25%	2-way
HBRV	Car	.0450	HB Other	.0370	.0450	.0800	0%	2-way
	PT	.0225	HB Other	.0165	.0180	.0310	+25%	2-way
HBEd	Car	.0495	HB Other	.0370	.0450	.0800	+10%	2-way
	PT	.0225	HB Other	.0165	.0180	.0310	+25%	2-way
Non-Home-Based								
NHBEB	Car	.1013	NHBEB	.0690	.0810	.1070	+25%	1-way
	PT	.0525	NHBEB	.0380	.0420	.0450	+25%	1-way
NHBO	Car	.0770	NHB Other	.0730	.0770	.1050	0%	1-way
	PT	.0413	NHB Other	.0320	.0330	.0350	+25%	1-way

Source: TAG M2.1 Table 5.1 May 2020

TAG guidance states that lambda values should be within $\pm 25\%$ of the TAG median lambdas, as the minimum and maximum values are based on a small sample of models. All parameters in CSRM2 are within those 25% bounds. (Specifically, the car values for HBPS, HBRV and NHBO match the TAG median values; the HBW and HBEd values are 10% higher; the EB values (both HB and NHB) are 25% higher; and the PT values are all 25% higher than the median).

These values have been calibrated to improve the elasticity responses of the model, whilst maintaining good trip length distributions.

6.2. Walk and Cycle Parameters

Because of the local importance of cycling in the Cambridge area, the CSRM2 travel demand model includes both walking and cycling as distinct modes with separate trip distribution models. This means that the model requires distribution parameters for walk and cycle by travel purpose.

6.2.1. Path Choice

As described in paragraph 3.7, the distance-based generalised costs for cycling are further modified by impedance factors which vary by cycle infrastructure link type and take into account the different quality and safety conditions on the cycle infrastructure. The “perceived” distance for each link is therefore an indication of how likely or unlikely a user would be to cycle on a particular link type, and it becomes:

$$d_l^* = \theta_L d_l \text{ where } l \in L$$

where θ_L is a parameter by link type L which has been estimated through the use of the Strava Metro dataset and d_l is the link distance.

Strava Metro provides data on the patterns of people cycling on the network to provide impactful, data-driven decisions, whether planning and building new infrastructure or measuring the impact and behaviour change after a project is complete.

As with any mobility data source, Strava Metro data does not cover the entire population. However, since the service was launched in 2014, Strava has worked extensively with partners and research institutions on ways to use and adjust Metro data to create a representative sample that enables powerful analyses of the overall population.

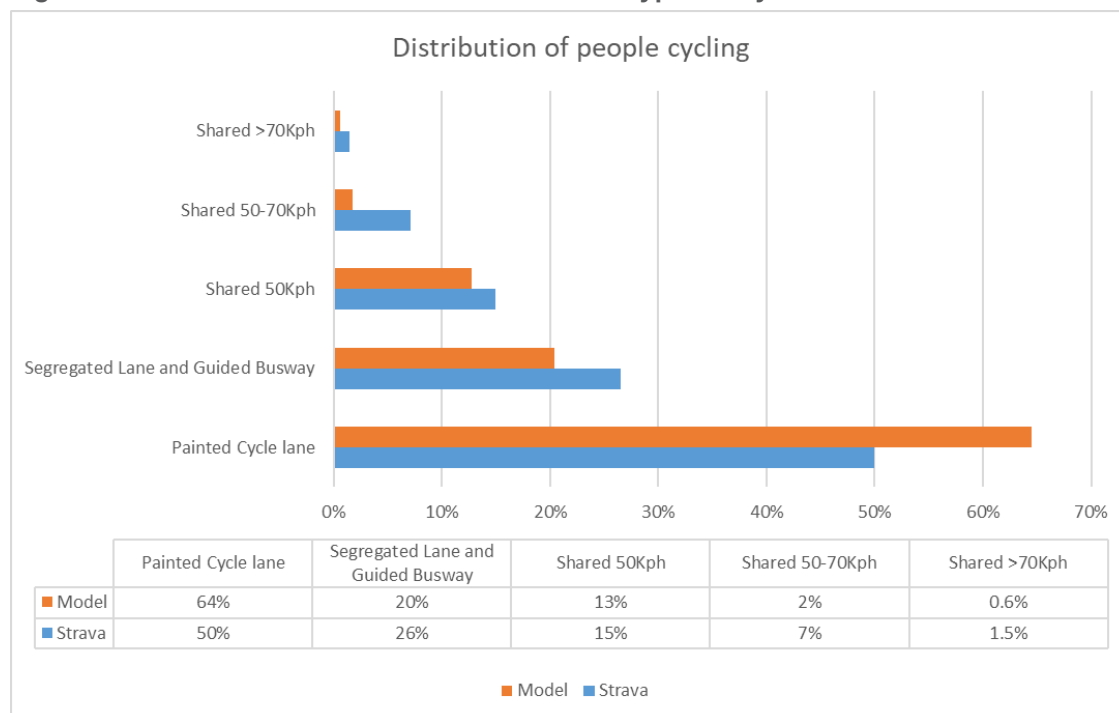
Several independent academic studies have analysed the relationship between Metro data and data recorded by electronic or human bike counters and found robust correlations between the two. This shows that Strava members' travel patterns are representative of the overall population and also means that Metro partners who have collected additional count data from even a small number of fixed locations have the opportunity to combine the two data sources, generate adjustment factors, and produce very robust insights about the entire network. Moreover, route choice by Strava members bears a close relationship to what might be expected from the overall population. As a result, the infrastructure needs and opportunities that one might infer from Metro data are consistent with the overall population of an area. An analysis conducted in New Hampshire showed that Strava users will generally chose streets with bicycle infrastructure when available.

Since the Strava Metro dataset provides a sample of the entire population, a normalised unit of the kilometres of cycle infrastructure travelled by the users has been calculated for both the Strava Metro data and the model outputs. The propensity to cycle coefficients for the different link types have then been calibrated to match the Strava distribution on the different link types.

The analysis of the Strava Metro data showed that users prefer to travel on painted or segregated cycle infrastructure, which are safer than links where the cyclists and motorised users share the carriageway. Moreover, the distribution pattern showed that the attractiveness of the destination also plays an important role in route choice: most of the painted cycle lanes are located in Cambridge where people generally find cycling safe.

Figure 6-1 shows the distribution on the different types of cycle infrastructure for both the Strava data and CSRM2 and Table 6-2 shows the calibrated theta coefficients.

Figure 6-1 - Distribution of users on the different types of cycle infrastructure



Note: This graph contains aggregated and de-identified data from Strava Metro.

Table 6-2 - Calibrated impedance factors for cycle infrastructure

Link type	Link description	θ
2	Painted cycle lane	0.85
3	Shared ≤ 50 kph	1.20
4	Shared > 50 and ≤ 70 kph	1.80
5	Shared > 70 kph	3.00
17	Segregated cycle lane	0.70
50	Walk	1.00

The composite path for a generic origin (i) destination (j) is the sum of the perceived distance of the links which occur in the path and it therefore takes into account the propensity to cycle on the different infrastructure types.

$$d_{ijmp}^* = \sum_{l \in path} d_l^*$$

6.2.2. Distribution

A local distribution parameter estimation for walk and cycle was not possible within the CSRM2 project, and TAG guidance regarding these modes remains limited. During the development of CSRM1 (in 2008), RAND Europe were commissioned to provide a short note about walk and cycle distribution parameters derived in model estimations they have developed, both in the UK and overseas³². This suggested a minimum, maximum and average of parameters from comparable models for each of walk and cycle modes by purpose. These ranges and the parameters adopted by CSRM2 are listed in Table 6-3.

A difficulty that arises when statistically estimating walk and cycle models is that the speed and lambda are highly collinear and it is therefore difficult to estimate both. Instead, the parameter used is a β distance term, with the generalised cost term being a function of distance. The trip distribution probability becomes:

$$T_{ijmp} = \frac{T_{imp} B_j \exp(\beta_{distance,m,p} d_{ijmp}^*)}{\sum_k B_k \exp(\beta_{distance,m,p} d_{ikmp}^*)}$$

where d_{ijmp}^* is the distance by mode m (walk or cycle) and purpose

$\beta_{distance,m,p}$ is the distribution parameter by mode and purpose

and similarly, the disutility passed up for mode choice is:

$$U_{imp} = \ln \sum_j B_j \exp(\beta_{distance,m,p} d_{ijmp}^*) - \ln \sum_j B_j$$

³² James Fox, 28 May 2008. "Cycle and Walk Parameters", RAND Europe. Technical note reference 08093.

Table 6-3 - Distribution parameters for Walk and Cycle, with illustrative values (sourced by RAND Europe for CSRM1)

Purpose	Mode	β distance (per km)	Nominal lambda*	RAND Europe illustrative β distance values (per km)				Cost units
				For purpose	Min	Median	Max	
Home-Based								
HBW	Walk	0.4620	0.0385	HBW	0.3560	0.4620	0.8360	2-way
	Cycle	0.1770	0.0354	HBW	0.1420	0.1770	0.2290	2-way
HBEB	Walk	1.2500	0.1042	EB	0.1740	1.2500	1.2500	2-way
	Cycle	0.2770	0.0554	EB	0.1340	0.2770	0.5800	2-way
HBPS	Walk	0.5520	0.0460	Shopping	0.3830	0.5520	0.6740	2-way
	Cycle	0.2450	0.0490	Shopping	0.2210	0.2450	0.7010	2-way
HBRV	Walk	0.3960	0.0330	Other	0.3960	0.4850	0.8360	2-way
	Cycle	0.1160	0.0232	Other	0.1160	0.2990	0.4280	2-way
HBEd	Walk	0.6220	0.0518	Education	0.4720	0.5930	0.6220	2-way
	Cycle	0.3130	0.0626	Education	0.0830	0.3130	0.3270	2-way
Non-Home-Based								
NHBEb	Walk	2.5000	0.2083	EB	0.3480	2.5000	2.5000	1-way
	Cycle	0.5540	0.1108	EB	0.2680	0.5540	1.1600	1-way
NHBO	Walk	0.9700	0.0808	Other	0.7920	0.9700	1.6720	1-way
	Cycle	0.5980	0.1196	Other	0.2320	0.5980	0.8560	1-way

Bold indicates the number used where applicable

* The “nominal” lambda is the equivalent lambda per generalised minute if the walk speed is assumed to be 5 kph and the cycle speed 12 kph. These speed assumptions are not used directly in the model, but these values are presented to facilitate comparison with the car and PT parameters.

In most segments the median of RAND Europe illustrative values has been used. In the case of HBRV, it is expected that the trips will be longer (based on the NTS) so the minimum beta (β) values have been used.

For education walk trips, the maximum beta has been adopted to better match the trip lengths of students who walked in the National Pupil Database³³. These walk and cycle parameters were carried over from CSRM1 without requiring further calibration.

6.3. Time of Day and Mode Choice Parameters

The theta parameters (θ) denote relative sensitivities of different levels of the choice tree, in particular:

- $\theta[\text{tod/distribution}]$ is the sensitivity of macro time of day choice relative to distribution; and
- $\theta[\text{mode/tod}]$ is the sensitivity of main mode choice compared to time of day choice.

NHB purposes do not have time of day or mode choice in CSRM2, though their mode split is partially determined by the mode of the HB trip from which they are derived.

HB Education has no time of day choice, so there is only a parameter for $\theta[\text{mode/distribution}]$.

For Home-Base purposes other than education, the relative sensitivity of mode to distribution is:

$$\theta[\text{mode/distribution}] = \theta[\text{mode/tod}] \cdot \theta[\text{tod/distribution}]$$

³³ 2007 National Pupil Database, supplied for the CSRM1 study area by the Department for Children, Families and Schools (DCFS) in 2008.

The theta parameters adopted in CSRM2 are shown in Table 6-4. As seen in the table, it is assumed that mode and time of day have the same sensitivity, that is, $\theta[\text{mode/tod}] = 1$ for all purposes. Thus

$$\theta[\text{mode/distribution}] = \theta[\text{tod/distribution}].$$

In most cases, the TAG default median values have been adopted (see Table 6-5), except for HBEB where the maximum value has been used and for HBW where the value of 14% above the default maximum value had been adopted in order to obtain better elasticity responses from the model for this purpose.

Table 6-4 - Relative sensitivity of main mode, time of day (TOD) and distribution choice

Purpose	θ [mode/TOD]	θ [TOD/distribution]	θ [mode/distribution]
HBW	1.00	0.9500	0.9500
HBEB	1.00	0.6500	0.6500
HBPS	1.00	0.5830	0.5830
HBRV	1.00	0.5830	0.5830
HBEd	n/a	n/a	0.5830

Table 6-5 - Relative sensitivity of main mode and distribution, with TAG default values

Purpose	θ mode/distribution	TAG default values			
		For purpose	Min	Median	Max
HBW	0.9500	HBW	0.5000	0.6800	0.8300
HBEB	0.6500	HBEB	0.2600	0.4500	0.6500
HBPS	0.5830	HB Other	0.2700	0.5300	1.0000
HBRV	0.5830	HB Other	0.2700	0.5300	1.0000
HBEd	0.5830	HB Other	0.2700	0.5300	1.0000

Default values source: TAG M2.1 May 2020 Table 5.2

6.4. Sub-Mode Choice

Sub-mode choice nests under distribution choice as described in Section 2.9. During the calibration of the E-series base model, it was possible to reduce the site choice lambda values for P&R sites and rail stations without detrimentally affecting the overall validation – this leads to a more stable model with improved convergence and has been retained for the F-series. The sub-mode choice parameters are shown in Table 6-6 below.

Table 6-6 - Sub-mode choice parameters

Choice	Lambda	Cost units
Car vs P&R	0.045	2-way
P&R site choice	0.130	2-way
P&R vs P&A	0.100	1-way
Bus vs Rail/GB	0.060	2-way
Rail versus GB	0.060	2-way
Rail station choice, Rail: car access versus non-car access	0.130	2-way

The lambda values listed above used for sub-mode split are related to HB trips and this value is doubled when it applied to NHB trips as they are single trips. The higher values for P&R site choice and rail station choice make these site choices relatively more sensitive than the choice to use that mode as a whole.

6.5. Cost Damping

In most models, using the generalised cost directly in mode split and distribution results in the model's elastic response to fuel price or car time changes being dominated by very long trips in a way that does not seem to accord with actual experience. Other Value of Time experiments have shown, simultaneously, that the marginal influence of both cost and time seems to decrease for very long trips. It is therefore recommended in the demand modelling guidance (TAG unit M2.1, Section 3.3) that some form of cost damping to long trips may be required in order to reduce the elasticity of response and improve model realism.

CSRM2 applies a damping function to all purposes with the exception of education – which tends to have short trip lengths and the issues do not arise to the same degree. The functional form is a power function of utility (TAG unit M2.1, Section 3.3.16):

$$G_{ij}'' = \mu G_{ij}^{\beta}$$

where: G_{ij}'' is the damped generalised cost of travel between an origin zone and a destination zone;
 G_{ij} is the original generalised cost of travel between an origin zone and a destination zone; and
 μ and β are coefficient and power parameters (respectively), set depending on trip purpose as shown in for car and for public transport.

Table 6-7 - Car generalised cost damping parameters by trip purpose

Purpose	Power β	Coefficient μ	Intersection $G''=G$
HBW	0.95	1.2523	90.0
HBEB	0.95	1.2523	90.0
NHBEB	0.95	1.2097	45.0
HBRV	0.85	1.8481	60.0
HBPS	0.85	1.8481	60.0
HBE _d	no damping		
NHBO	0.85	1.6656	30.0

Table 6-8 - PT cost damping parameters by trip purpose

Purpose	Power β	Coefficient μ	Intersection $G''=G$
HBW	0.90	1.5060	60.0
HBEB	0.90	1.5060	60.0
NHBEB	0.90	1.4051	30.0
HBRV	0.90	1.5060	60.0
HBPS	0.90	1.5060	60.0
HBE _d	no damping		
NHBO	0.90	1.4051	30.0

The values in Table 6-7 and Table 6-8 were derived during the calibration process, to achieve a balance between model elasticities and trip lengths.

Guidance recommends that cost damping should be applied consistently across modes and purposes with minimal variations introduced if needed for model responsiveness.

- For car travel a damping power between 0.85 and 0.95 has been applied to all purposes where damping is applied, with higher values (less damping) for business purposes which are more sensitive to generalised cost, and lower values for discretionary purposes whose long trips are less sensitive to generalised cost. The discretionary purposes are known to have a “heavy tail” of long trips compared to other trip distributions, perhaps reflecting sub-segments such as visiting relatives whose distribution is less affected by cost.
- For PT travel the damping has been set at $\beta=0.9$ for all purposes where damping is applied.

- For other modes (walk and cycle) no damping is applied since these trips are relatively short.

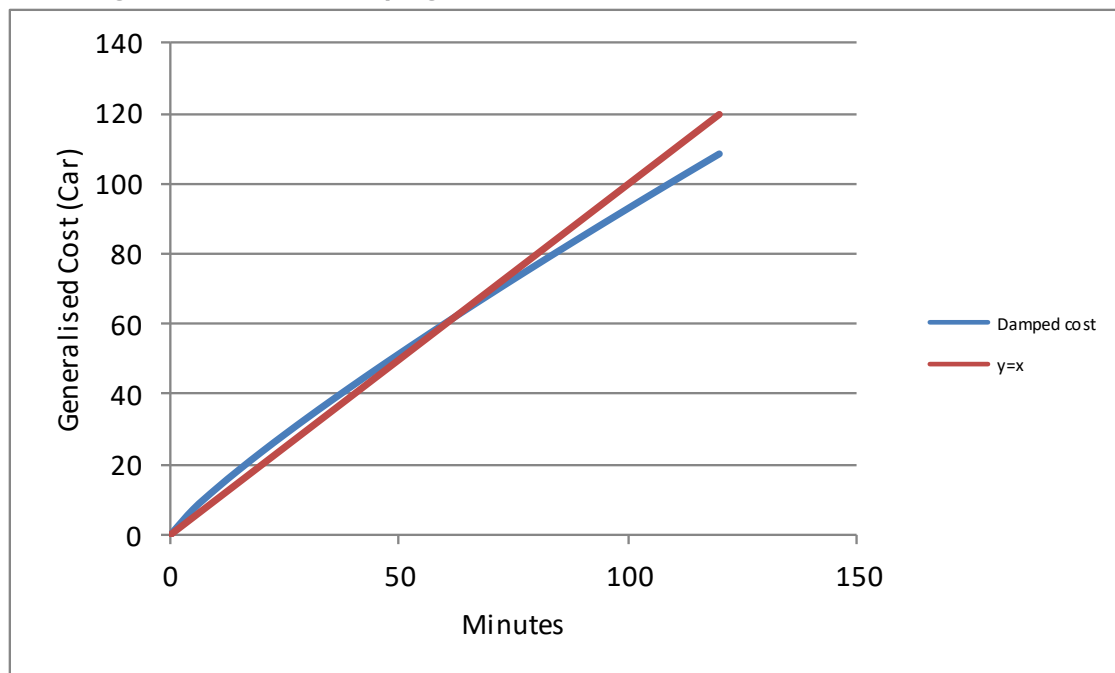
The functional form can be seen as a form of Box-Cox transformation applied to the whole generalised cost function. The coefficient μ is calculated so as to make $G''=G$ at a specific point, which varies by purpose (shown in Table 6-7 and Table 6-8). So, for example, when $G=60$ generalised minutes of two-way cost (as in HBPS or HBRV):

$$\mu = 60^{1-\beta}$$

This means the damping function is nearly linear for trips shorter than that and so has little impact on the shorter distance trips.

Figure 6-2 illustrates the car cost damping function being used for HBPS and HBRV trips, showing original linear cost, the damped cost calculated by the above function, and the intersection ($G''=G$) which has been set to 60 generalised minutes in this case.

Figure 6-2 - Car generalised cost damping function for HBPS and HBRV



6.6. TDM to SATURN Linkage

There is a two-way flow of information between the MEPLAN software implementing the TDM and PT, walk and cycle assignment models and the SATURN software implementing the HAM.

From the SATURN assignment model to the Demand model:

- HAM matrices of congested journey distances and times by user class for the three assigned one-hour periods are read directly into the transport demand model. The TDM constructs cost matrices for car based on the distance matrices from SATURN and pence per kilometre values representing vehicle operating costs;
- Generalised costs of travel are constructed from these cost and time matrices by the demand model for the different traveller types using appropriate Values of Time;
- Congested link travel times are also fed from the highway model into the TDM for links without bus lanes, so that bus speeds are affected by highway congestion as appropriate; and
- Congested travel times to / from each P&R site and rail station are fed into the TDM for zones accessing these facilities.

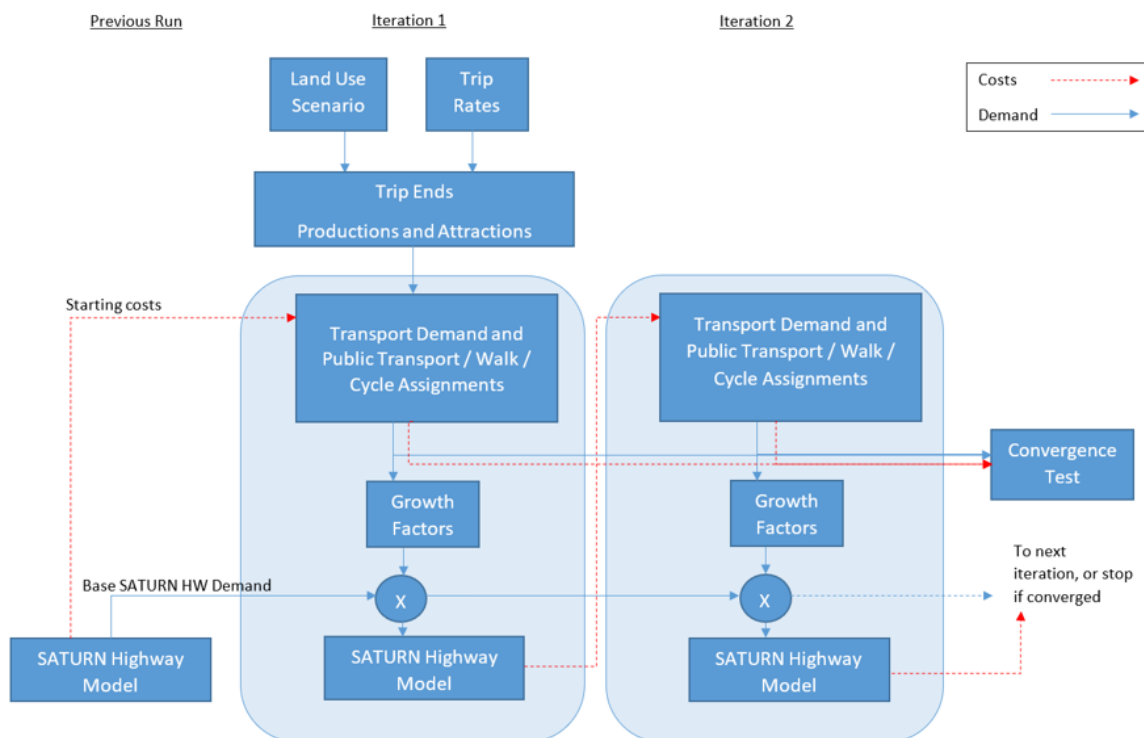
From the Demand Model to SATURN assignment model (in forecasting mode only, also used for realism testing):

- Final synthetic highway vehicle matrices in O-D format are output from the demand model for each user class for modelled periods: 3-hour AM and PM Peak periods and 6-hour Inter Peak period; and
- The ratio of the forecast TDM matrix to the base TDM matrix for a given period is used to scale the base highway O-D vehicle matrices.

These steps are iterated as shown in Figure 6-3 starting with highway assignment, then using the costs in the demand model. The demand outputs are used to pivot the SATURN matrices (this step is marked 'X') and assigned, and the process then repeats.

The next few sections describe some of the details of these linkages.

Figure 6-3 - Model structure, showing relationship between the Transport Demand Model and the SATURN Local Highway Model



6.7. Obtaining Highway Distance, Cost and Time Skims

SATURN skims are obtained using the standard utility SKIM_ALL. This extracts average generalised cost paths for each inter-zonal zone pair through the network resulting from a SATURN assignment, and outputs the distance in metres and congested time in seconds. The results consist of 24 distance matrices and 24 time matrices for each of the 8 light vehicle user classes and 3 time periods.

The Demand model distances are then built up from these in a straightforward way:

$$\text{TDM distance} = \text{skimmed distance} / 1000 \text{ metres per km}$$

$$\text{TDM cost} = (\text{TDM distance} * \text{PPK}[\text{user class, time of day}]) / \text{Occupancy}[\text{segment}] + \text{terminal costs (parking)}$$

where PPK = Pence Per Km is an input to the model to represent vehicle operating costs

$$\text{TDM time} = \text{skimmed time} / 60 \text{ seconds per minute} + \text{terminal times}$$

$$\text{TDM generalised cost} = \text{TDM cost} / \text{Value of Time}[\text{segment}] + \text{TDM time}$$

Terminal costs and times are additional costs and times per zone for the origin and destination representing the time and expense required for parking, as discussed below.

The car legs of P&R trips are represented in the PT, walk and cycle network as links from various zones to the P&R sites. The distances and times of these links are updated based on the SATURN skims to and from the dedicated P&R zones in the HAM. Car legs to rail stations are treated in an analogous way.

A few other terms are added to the skims obtained from SATURN before they are used in the demand model:

- Intrazonal matrix entries are added as described in Section 3.8;
- In zones where SATURN centroid connectors are coded as simulation centroid connectors (SATURN Software Manual, Section 5.1.8), the vehicles are assumed to appear on a chosen link with no additional distance between the centroid and link. Therefore, some additional distance, cost and time are added for this leg; and
- Parking charges and additional times related to parking and unparking the car are added depending on the zone at the non-home end of the trip or the destination for NHB trips. These vary from 2 minutes to 20 minutes depending on the destination zone. The higher search times are intended to represent the shortage of available parking spaces in these areas. Including this time is essential if the competition between car, P&R and other modes is to be modelled successfully.

6.8. Converting Person Trip Matrices by Time Period to Peak Hour Highway Matrices

This section describes how a synthetic light vehicle trip matrix (or *synthetic highway matrix*) is extracted from the multi-modal demand model matrices. There are three parts:

- Conversion of person trip matrices to vehicles, including only trips with a private car leg;
- Conversion of 3- or 6-hour demand to peak hour demand for the one-hour periods modelled by the HAM; and
- Extraction of car legs from end-to-end P&R/P&A and rail trips with a car access leg (“Park & Ride” for rail).

The model assumes car trips have a fixed occupancy by purpose and time period as shown in Table 4-7 and the same occupancies are assumed for the car legs of P&R trips etc. so the vehicle demand is just the person trip demand divided by these constants.

Fixed ratios are also used to convert 3-hour to 1-hour in the peak periods, and 6-hour to 1-hour in the Inter Peak. The values used are shown in Table 6-9. For the Inter Peak period, which is an average Inter Peak hour, the 10:00-16:00 period is simply divided by six; for the AM and PM Peak periods, the values are derived from the RSI data collected in 2006 and 2013.

The car leg extraction involves moving either the origin or destination of a P&R/P&A trip or Rail P&R trip to the relevant zone, which will be one of the HAM's P&R zones (see Appendix B) or the zone containing the relevant Rail Station.

This “synthetic highway matrix” is the form of the synthetic matrix used for pivoting the SATURN Base matrix when running CSRM2 in forecasting mode (and for realism tests).

Table 6-9 - N-hour to 1-hour vehicle trip ratios, by purpose

Purpose	AM: 07:00-10:00 to 08:00-09:00	IP: 10:00-16:00 to average hour	PM: 16:00-19:00 to 17:00-18:00
HBW	0.40	0.17	0.43
EB	0.34	0.17	0.35
Education	0.59	0.17	0.37
Other	0.27	0.17	0.34

6.9. Pivoting the Highway Matrix

The TDM incorporated within CSRM2 produces synthetic trip matrices in an absolute form (that is, the absolute number of trips is forecast in each year, rather than being expressed as a change from the previous year), for all modes, including highway trips.

Because the synthetic matrices are not suitable for direct assignment within SATURN, a matrix adjustment process has been developed whereby the base year (2015) SATURN matrices are scaled in line with the

growth in the synthetic growth forecast by CSRM. This is referred to as the ‘pivoting’ process within CSRM, although TAG describes the methodology as “absolute models applied incrementally” (TAG M2.1 4.3.5).

The basic method of scaling to derive future year demand uses the following four matrices:

- B: the 2015 base year (validated) SATURN matrix;
- Sb: the equivalent synthetic highway demand matrix (aggregated to SATURN user classes and converted to vehicle trips) for the 2015 base year;
- Sf: the future year forecast synthetic matrix (aggregated to SATURN user classes and converted to vehicle trips); and
- F: the forecast SATURN matrix, which is derived as:
 - $F[o,d,uc] = B[o,d,uc] * (Sf[o,d,uc] / Sb[o,d,uc])$,
 where [o, d, uc] denotes a matrix cell by origin, destination and assignment user class.

There are however some special cases which apply to this process at the cell level as follows:

- Where Sb is zero, the value of B is used (including if B is zero);
- Where B is zero, no growth is applied (i.e. the cell remains zero), unless it is a designated ‘growth zone’ (see below); or
- Where Sf/Sb is a large value, this may be caused by a very small base year value of Sb being compared with a more significant future figure. If the B matrix value is non-zero, this can cause infeasibly large values for F. Therefore, a cap is applied, with a maximum growth rate for any cell value of 10.0 in forecast years (or 2.0 in 2019 PYV).

This produces a forecast SATURN highway matrix where the growth rate in each cell is equivalent to the growth rate forecast by CSRM2.

Adjustments are made to this matrix in special cases:

- The scaling process is constrained so that district level scalings are maintained (i.e. the scalings for zone pairs within a district-district pair are adjusted so that the district-district scaling is always consistent with that forecast by the TDM); and
- Exogenous adjustments are added to account for external-external trips and goods vehicle trips not dealt with by CSRM2.

Where transport or land use developments in future years will radically alter demand for specific zones, the zone can be specified as a ‘growth zone’, which causes the future year assignment values to be taken directly from the synthetic (i.e. $F = Sf$). This forecasting facility is described in more detail in the next section.

6.10. Growth Zones

The term ‘growth zone’ applies to any zone for which land use development is expected to transform trip-making rather than being incremental from existing patterns. This relates to whether the growth in vehicle trips in the HAM for future years will be determined by:

- scaling the 2015 base year according to synthetic trip growth (incremental modelling) – this is done in non-growth zones; or
- using the synthetic vehicle trips directly in the highway model (absolute modelling) – this is done in growth zones.

The application of growth zones is through a number of files applied in each model run. To assist with the production of these files, a spreadsheet has been developed to export the files in the correct format for a given set of growth zones. Note that there are no growth zones active in the base year realism tests (Section 7.6), as there are no land use changes in these tests. Growth zones are identified for several reasons:

- Where large changes in land use are predicted. Such changes are normally made in “development zones”, which are growth zones by definition, but in certain circumstances it can be more appropriate to use an existing zone;
- Where B and Sb are sufficiently different that applying the synthetic growth rate results in an inappropriate growth in highway trips. This can occur for a variety of reasons (such as: trips being evident in the highway matrix but generated by a land use that is not captured in the trip generation process (Section 5). As part of

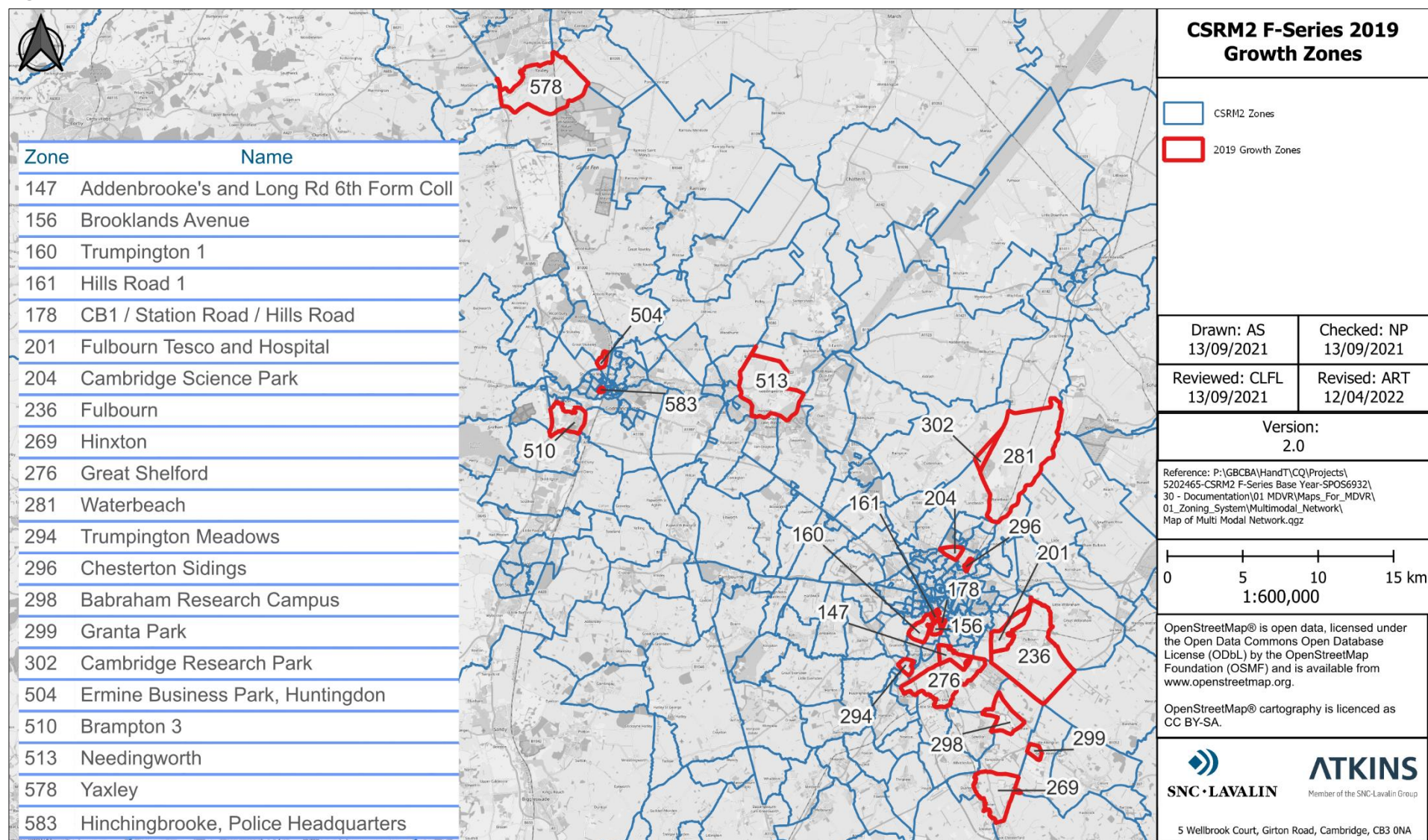
the 2019 PYV, 21 such zones have been identified³⁴ during the model build and are shown in Figure 6-4 below; and

- Where the synthetic matrix S_f has trips, but one or both of the base matrices (B or S_b) do not. This is automatically detected in the pivoting process.

In the first two cases above, the growth zones are also excluded from the district scaling process.

³⁴ A zone is designated as a growth zone of this type if the difference in row or column totals between the base highway and synthetic car matrices is greater than 30% in any time period.

Figure 6-4 - 2019 Growth Zones



6.11. Smoothing

To increase the speed in which the Integrated Transport Model reaches convergence, the highway demand matrix is 'smoothed' across iterations. This process takes a proportion of the matrix from the previous iteration and combines it with a proportion of the matrix produced by the pivoting process described above. The proportions used are:

- Iterations 2 and 3: 50% current matrix, 50% previous matrix; and
- Iteration 4+: 20% current matrix, 80% previous matrix.

From iteration 3 onwards, the previous matrix will itself have been smoothed and so although the output from all iterations is used, the relative contribution of earlier iterations to the final matrix will decrease with the number of iterations.

6.12. Goods Vehicles and External-External Demand

There are two key traffic types for which trip patterns and numbers are not derived within the Transport Demand Model:

- Goods vehicle trips: Heavy Goods Vehicles (HGVs) and Light Goods Vehicles (LGVs) used for goods transport are not modelled in the demand model; and
- External-external ('through trips'): Trips which cross the study area but do not have either end within the study area are not modelled, for any vehicle type or trip purpose.

For the base year, these trips have been derived entirely within the SATURN HAM validation process, and the derivation is therefore laid out within the Local Model Validation Report (LMVR). In CSRM2 base year runs, there is no need to consider these trips, as their impact on the transport system is entirely within the HAM. During realism testing (outlined in Section 7.6) the volumes of LGV, HGV and external-external trips are held constant, though the HAM allows routing responses to be considered.

For future years, growth factors are applied to LGV, HGV and external-external trips in the HAM using DfT Road Traffic Forecasts.

7. Demand Model Calibration and Validation

7.1. Introduction

7.1.1. Approach to Calibration and Validation

This section contains CSRM2 Transport Demand Model calibration and validation results. Public Transport calibration is presented separately in Chapter 8. The calibration and validation exercises have been carried out in line with TAG unit M2.1 Section 5 (Demand Model Calibration) and Section 6.4 (Realism Testing). Section 5 advises that ideally local data should be used to calibrate the parameter values within the Variable Demand Model, in order to produce a model which replicates observed base year data. However, no firm criteria are set for this, and it is noted that this is less of an issue for incremental or pivot-point models such as CSRM2. The guidance also advises that effort should be proportionate to the quality and relevance of available data. Therefore, for both the TDM and PT/active mode calibration, the aim has been to calibrate model parameters to produce a reasonable match against observed local data, whilst also ensuring that the model responses in realism tests meet the advised standards.

The approach that has been taken in the development of CSRM2 is an iterative process of reviewing the model outputs against observed data and using judgement to adjust model parameters to produce a better fit. All of the data presented below and in Chapter 8 is 'independent' in the sense that it has not been used directly in the modelling (e.g. for the statistical estimation of model parameters), but has been used to inform judgement when calibrating the model parameters presented previously.

Presented here are the results most relevant to the overall patterns of demand within the model. This covers comparison of the demand model results against available comparators including National Travel Survey, 2011 Census Journey to Work data and the SATURN Highway Model base year matrix. Realism (elasticity) tests to demonstrate the appropriate sensitivities of response, as required by TAG, are also presented.

The transport demand and assignment model has been run with base years of both 2011 and 2015, along with 2019 PYV, to allow for the most accurate comparisons with available data. 2015 has been the main focus (especially for the highway model and walk/cycle/public transport network flows), but 2011 has been used for comparison against the Census (which was surveyed in 2011) and the National Travel Survey (where data from 2012 to 2014 has been used).

Mode shares and trip length distributions have been compared against both Census and NTS data. Origin-Destination distributions for HBW have been compared against the Census for all modes, and car trips for all purposes have been compared against the validated HAM demand matrix. These comparisons all show that the model is performing broadly as expected.

Realism tests have been carried out to check the elasticities of the model, and these results have all met the criteria specified in TAG.

7.1.2. Calibration adjustments to model

The adjustments undertaken during the calibration process include changes to:

- sensitivity parameters used in the VDM (see Sections 6.1 and 6.2);
- alternative specific constants (ASCs), principally related to modes and sub-modes of the model (see Section 3.10); and
- assumed proportion of car trips taking place in the AM Peak (see Table 5-9).

Various aspects of the coded transport infrastructure and services were reviewed and improved based on observations during calibration, including access times and interchange penalties. In addition, the selection of NTS data used to calculate trip rates (see Section 5.5.1) was informed to some extent by calibration, as well as by the need to maintain large enough sample sizes.

7.1.3. Chapter Overview

This chapter of the report demonstrates that the demand model has been appropriately calibrated and validates in line with current modelling and appraisal guidance.

Modelled results are compared against available data sources to check mode shares and trip length distributions, as well as checking the overall shape and size of the output synthetic car matrices against the validated highway matrices and finally carrying out standard realism tests. Section 7.2 describes the available data for comparison.

In Section 7.3, mode shares for each purpose are compared against NTS data, with good results. As would be expected for a national dataset, the NTS does not have such a high cycle mode share as the model – but the data from the Census (which does represent the local area rather than a national average) has a much higher cycle mode share and the model agrees closely with this. At a detailed sector level, some discrepancies can be seen: particularly for rail vs car trips to/from the External Other sector.

The trip length distributions presented in Section 7.4 are generally a good match to the Census for HBW trips. Comparisons for other purposes have been made against NTS data, with the majority of discrepancies being attributable to the national nature of the dataset.

Section 7.5 presents a comparison between the TDM synthetic car matrices and the validated highway matrices, to provide an indication of any issues that might arise during forecasting. The overall matrix sizes and trip-making patterns are very similar, although there are some differences on closer inspection of the purposes and for individual sector-to-sector movements. At the zone pair level, there is a good correlation between the two matrices, with R^2 values in the range 0.85-0.9.

The realism testing methodology and terminology is explained in Section 7.6. Section 7.7 gives the results for each realism test in turn. The model is slightly below the lower end of the range of acceptable elasticity values for the car fuel cost test, and the patterns within these results (for different purposes, and for different income groups) are as expected. The low elasticities are likely to be due to the high levels of congestion within the Cambridge area, and the higher-than-average income of residents. The PT fares and car own-time responses both fall well within the recommended bounds.

In summary, the model compares well against Census data for mode shares and trip length distributions; the mechanics of the pivoting process have been shown to work; and the realism test results show that the model is responsive to changes in fuel costs, PT fares and journey times. There are some discrepancies between the TDM synthetic car matrix and the validated highway matrix, which should be kept in mind when using the model to forecast trips between those areas.

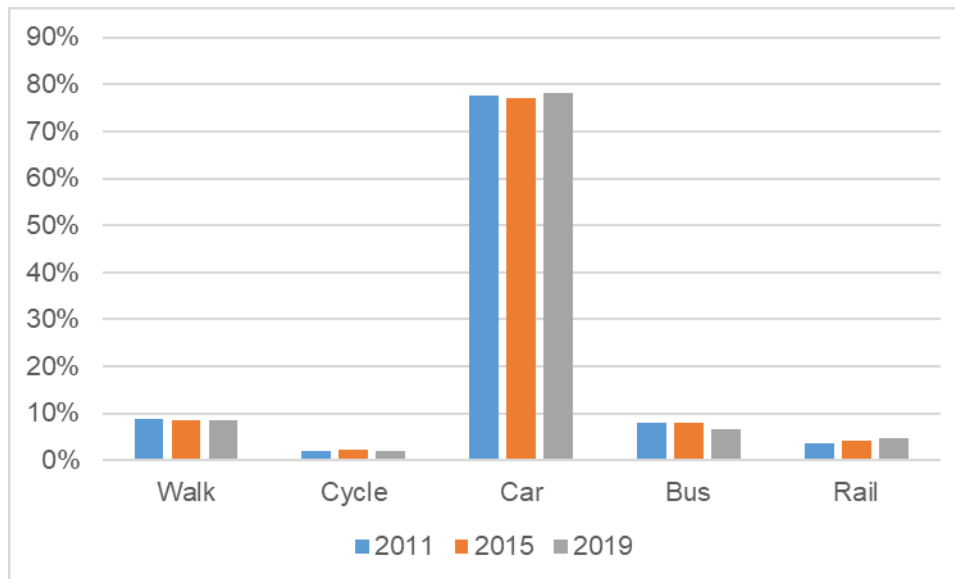
7.2. Data Availability

As described in Chapter 6, many of the data sets available have been used to implement and calibrate the TDM. The remaining data available for comparison against the transport demand model results is as follows:

- Readily available Journey to Work (JTW) tables from the 2011 Census of Population were used to check the output mode shares and trip length distributions for commuting trips; and
- Data from the National Travel Survey (NTS) 2012-2014, excluding London and other metropolitan areas, were used to validate the output mode shares by purpose, and the trip length distributions for all purposes. (The trip length distributions for commuting trips were compared against the locally-focussed Census data, to provide a baseline for interpreting the other purposes against this national dataset).

A comparison made between the 2010/2011, 2014/2015 and 2018/2019 NTS data shows a constant trend in mode shares across the years, particularly if bus and rail are considered as a combined public transport mode. Therefore, it is still plausible to assume valid a comparison between the 2012-2014 NTS and the 2019 PYV mode shares. Figure 7-1 shows the NTS trend between 2011, 2015 and 2019.

Figure 7-1 - 2011, 2015 and 2019 NTS trend in mode shares



The SATURN Highway Model (HAM) is validated against observed vehicle flows and TrafficMaster journey time data as reported separately in the Local Model Validation Report. The HAM demand matrices are segmented by AM Peak, Inter Peak and PM Peak hours, and into 12 user classes (8 of which represent cars/motorcycles and are comparable with the car mode of the TDM). It is important that these matrices are sufficiently similar to the synthetic demand model in order for the full model to forecast highway demand in a consistent way. Therefore, comparisons against the validated HAM matrices are also presented in this Chapter.

7.3. Mode Shares

As set out above, mode share information is available both from the NTS (2012-2014) and the Census (2011). Table 7-1 below shows the comparison between NTS mode shares and trip production level mode shares from CSRM2 (2011 model run), by purpose for HB purposes across the whole model. Due to the national nature of NTS, we would expect the cycle mode shares in CSRM2 to be higher: this is counteracted by lower results for car and public transport, particularly for the HB purposes. Table 7-2 shows the same NTS data, compared against the 2015 CSRM2 run, while Table 7-3 compares against the 2019 PYV – the trend is a small increase towards car between CSRM2 2011, 2015 and 2019, but the values still compare well with NTS (See Section 2.8 for mode definitions). Table 7-4 provides the CSRM2 2011 HBW values again, alongside the Census equivalent – again, these values are all day productions/attractions across the whole model.

The proportion of people using active modes and PT versus car slightly declines following the vehicle operating costs reduction over time which makes car cheaper.

Table 7-1 - Mode Shares (CSRM2 2011 vs NTS) by Purpose

Purpose	CSRM2 (2011)				NTS (2012-2014)			
	Car	PT	Walk	Cycle	Car	PT	Walk	Cycle
HBW	71%	7%	9%	13%	78%	8%	10%	4%
HBEB	80%	7%	5%	8%	87%	8%	4%	1%
HBEd	38%	9%	46%	6%	51%	9%	39%	2%
HBPS	68%	5%	25%	2%	73%	7%	19%	1%
HBRV	62%	2%	27%	9%	69%	4%	25%	2%
NHBEB	84%	4%	11%	1%	83%	4%	11%	1%
NHBO	71%	3%	24%	2%	74%	4%	20%	1%
Total	65%	6%	23%	6%	71%	6%	21%	2%

Table 7-2 - Mode Shares (CSRM2 2015 vs NTS) by Purpose

Purpose	CSRM2 (2015)				NTS (2012-2014)			
	Car	PT	Walk	Cycle	Car	PT	Walk	Cycle
HBW	74%	7%	8%	12%	78%	8%	10%	4%
HBEB	80%	7%	5%	8%	87%	8%	4%	1%
HBEd	40%	10%	45%	6%	51%	9%	39%	2%
HBPS	71%	5%	22%	2%	73%	7%	19%	1%
HBRV	65%	2%	24%	8%	69%	4%	25%	2%
NHBEB	85%	4%	10%	1%	83%	4%	11%	1%
NHBO	72%	3%	24%	2%	74%	4%	20%	1%
Total	68%	5%	21%	5%	71%	6%	21%	2%

Table 7-3 - Mode Shares (CSRM2 2019 vs NTS) by Purpose

Purpose	CSRM2 (2019)				NTS (2012-2014)			
	Car	PT	Walk	Cycle	Car	PT	Walk	Cycle
HBW	75%	6%	8%	11%	78%	8%	10%	4%
HBEB	82%	7%	4%	7%	87%	8%	4%	1%
HBEd	39%	10%	45%	6%	51%	9%	39%	2%
HBPS	71%	5%	22%	2%	73%	7%	19%	1%
HBRV	66%	2%	24%	8%	69%	4%	25%	2%
NHBEB	85%	4%	10%	1%	83%	4%	11%	1%
NHBO	72%	3%	23%	2%	74%	4%	20%	1%
Total	69%	5%	21%	5%	71%	6%	21%	2%

Table 7-4 - Mode Shares (CSRM2 2011 vs Census), HBW

Source	Car	PT	Walk	Cycle
CSRM2 2011	71%	7%	9%	13%
Census 2011	74%	9%	7%	10%

Note: these values sum to 100% except for rounding errors.

Table 7-4 confirms that the model achieves a good match to locally observed mode shares for commuting, at the 24-hour production/attraction level.

Table 7-5 compares HBW mode share in the morning peak from the 2011 model run at origin/destination level with statistics from the 2011 Census by origin district, and Table 7-6 by destination district. For this comparison, Census JTW home locations are assumed to be origins and Census JTW work locations are assumed to be destinations. These results are shown at the origin/destination level rather than the production/attraction level in order to give the breakdown for bus and rail separately, which is not available at the earlier production/attraction stage of the model. The AM movements are presented as an approximation for the home to work commuting patterns.

Table 7-5 - HBW Mode Shares (CSRM2 2011 vs Census) by Origin/Home District, AM

District	Car		Bus		Rail		Cycle		Walk	
	CSRM	Census	CSRM	Census	CSRM	Census	CSRM	Census	CSRM	Census
Cambridge City	38%	37%	4%	7%	5%	5%	34%	33%	18%	16%
South Cambs	78%	76%	2%	5%	5%	4%	11%	9%	4%	6%
East Cambs	80%	83%	1%	2%	8%	7%	3%	3%	7%	6%
Huntingdonshire	81%	81%	2%	3%	6%	4%	4%	4%	7%	8%
External	83%	90%	5%	3%	11%	6%	0%	0%	0%	0%
Total	72%	74%	3%	4%	7%	5%	11%	10%	7%	7%

Table 7-6 - HBW Mode Shares (CSRM2 2011 vs Census) by Destination/Work District, AM

District	Car		Bus		Rail		Cycle		Walk	
	CSRM	Census	CSRM	Census	CSRM	Census	CSRM	Census	CSRM	Census
Cambridge City	50%	56%	6%	9%	6%	5%	25%	21%	12%	9%
South Cambs	81%	83%	2%	3%	2%	1%	10%	7%	4%	6%
East Cambs	84%	84%	1%	2%	2%	1%	4%	5%	10%	9%
Huntingdonshire	84%	83%	1%	2%	1%	1%	5%	4%	9%	10%
External	72%	80%	2%	2%	25%	18%	0%	0%	0%	0%
Total	72%	74%	3%	4%	7%	5%	11%	10%	7%	7%

Further analysis at a more detailed sector level was carried out to consider the implied excess or shortfall of HBW trips by mode in the AM Peak, shown in Table 7-7 for origins and Table 7-8 for destinations. Although the Census does not give numbers of trips (as it has no information about the frequency of journeys to work; only the home and work locations), the implied excess or shortfall is calculated by considering the differences in mode shares, and applying these to the modelled numbers of trips in the AM Peak (2011), which are also shown in the tables to give some context to the scale of the numbers. In these tables, positive figures imply the CSRM2 mode share is higher than the Census. Figure 7-2 is a map showing the locations of these sectors.

Although the overall mode shares from CSRM2 compare well with NTS and Census, Table 7-7 and Table 7-8 show some differences at a more detailed level. In particular, the car mode share to destinations in Central Cambridge within CSRM2 is low compared to the Census but to South Cambs Outer is high: these are balanced by discrepancies in shares for the other modes to those sectors. Across the majority of origin and destination sectors, the rail mode share within CSRM2 is high compared to Census, while in the majority of cases bus is too low. The rail share is particularly high for trips to and from the External Other sector, balanced by a deficit in car trips to/from this sector. Due to the strategic level of the model, it should not be expected that the mode shares at a detailed sector level would match perfectly, but it is helpful in interpreting model results to understand the areas in which the model might be less accurate.

Figure 7-2 - Core 13 Sector System

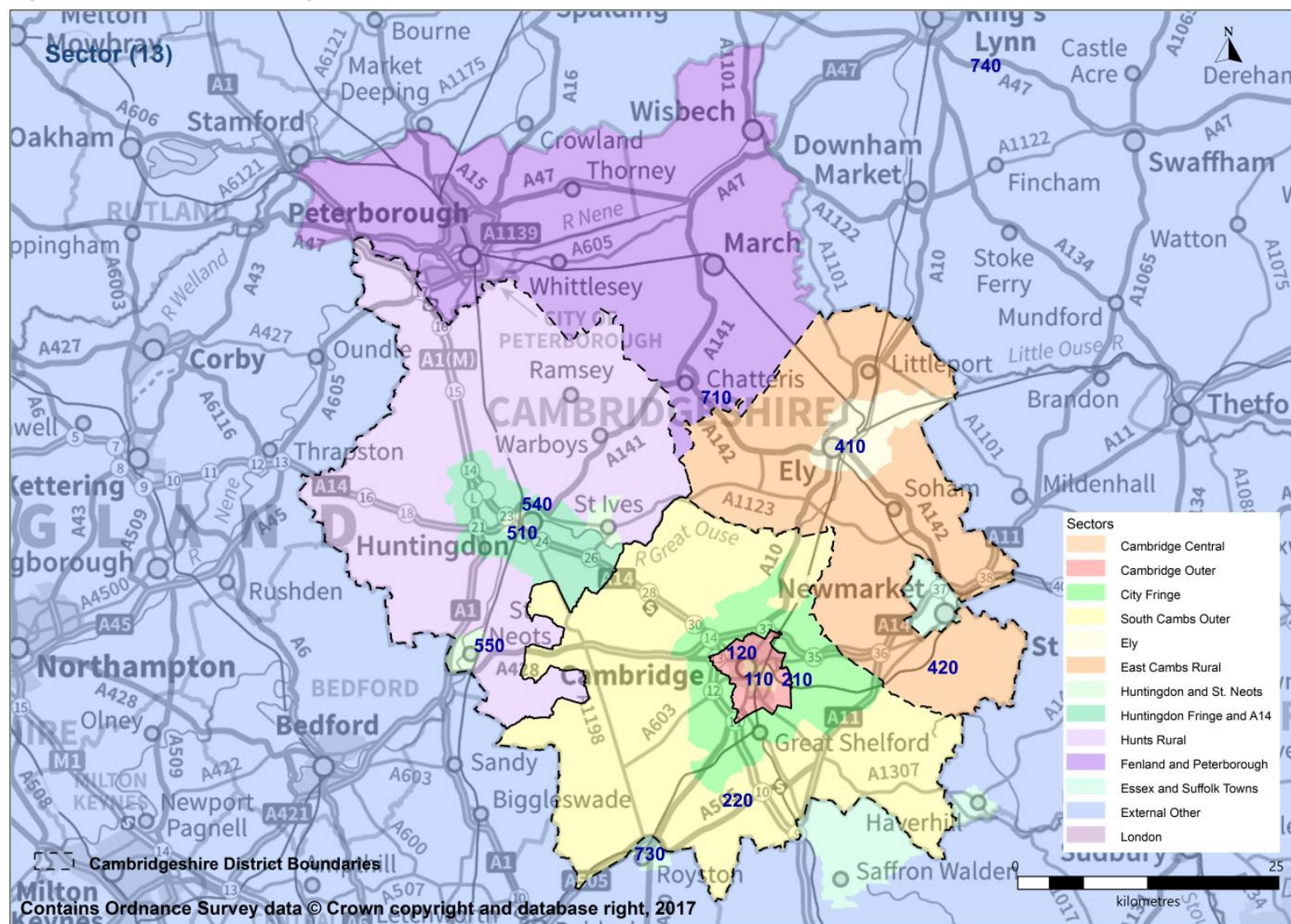


Table 7-7 - Implied Excess/Shortfall in Trip Origins by Mode (3 hour AM Peak period)

Sector (Core 13)	Implied Excess/Shortfall					Total HBW Trips in CSRM2 AM				
	Car	Bus	Rail	Cycle	Walk	Car	Bus	Rail	Cycle	Walk
Cambridge Central	161	-150	-69	-15	74	2,503	330	561	2,636	1,704
Cambridge Outer	-109	-588	93	245	361	6,638	735	778	5,738	2,751
City Fringe and Waterbeach	-42	-351	33	290	70	6,242	316	405	2,013	546
South Cambs Outer	559	-565	66	460	-519	17,982	422	1,016	1,511	722
Ely	-30	-18	69	18	-39	2,850	38	733	185	426
East Cambs Rural	-519	-94	260	12	341	11,218	194	729	370	831
Huntingdon and St. Neots	-395	-200	487	130	-22	8,801	232	1,111	761	1,481
Huntingdon Fringe and A14	57	-129	171	67	-166	6,230	118	506	501	606
Hunts Rural	337	-161	-187	63	-52	13,949	208	371	331	591
Fenland and Peterborough	-321	4	313	6	-2	3,831	120	433	27	0
Essex and Suffolk Towns	-104	-66	169	18	-17	3,501	227	305	50	5
External Other	-985	329	655	1	0	10,111	578	1,334	1	0
London	-119	133	-14	0	0	403	188	361	0	0

Table 7-8 - Implied Excess/Shortfall in Trip Destinations by Mode (3 hour AM Peak period)

Sector (Core 13)	Implied Excess/Shortfall					Total HBW Trips in CSRM2 AM				
	Car	Bus	Rail	Cycle	Walk	Car	Bus	Rail	Cycle	Walk
Cambridge Central	-1,286	-352	297	698	643	6,111	1,152	1,210	4,200	2,262
Cambridge Outer	-748	-503	181	669	401	11,768	1,024	864	4,787	2,141
City Fringe and Waterbeach	-1,087	53	147	811	76	7,434	326	301	1,940	607
South Cambs Outer	633	-362	161	173	-604	16,472	216	433	1,023	715
Ely	29	-49	38	17	-34	3,196	39	142	193	428
East Cambs Rural	-148	-18	46	-79	198	7,728	87	89	336	828
Huntingdon and St. Neots	-360	-48	52	235	122	10,110	305	195	961	1,669
Huntingdon Fringe and A14	169	-38	13	15	-158	6,335	59	68	317	438
Hunts Rural	405	-108	-48	-5	-244	9,940	93	17	281	571
Fenland and Peterborough	167	-100	-70	9	-6	3,749	60	9	47	0
Essex and Suffolk Towns	-28	-45	89	5	-21	2,598	21	158	41	3
External Other	-806	-41	846	0	0	8,299	110	1,244	0	0
London	-502	140	362	0	0	518	214	3,914	0	0

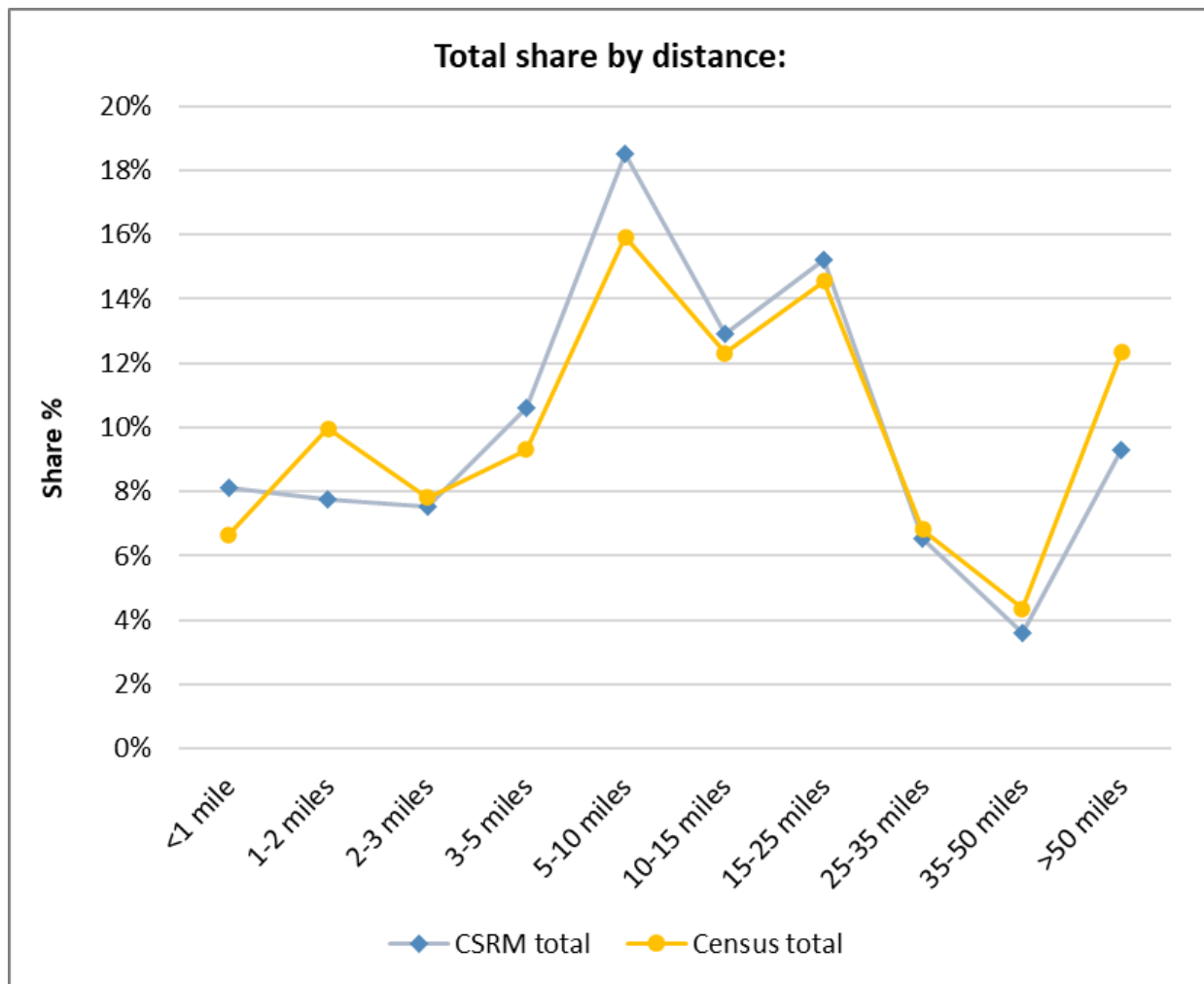
7.4. Trip Length Distributions

As well as mode shares, trip length information is also available from Census and NTS. Again, NTS is not locally-focussed whereas the Census is for the local residents, but useful inferences can be drawn. The full set of trip length distribution comparisons is presented in Appendix E.

Figure 7-3 compares the HBW trip length distributions for all modes from CSRM2 (2011 model run) and the Census, and shows a good match in most distance bands. Note that modelled distances are taken from the

network, whereas Census distances are calculated as crow-fly distances from the zone co-ordinates with an adjustment factor of 1.3: therefore, the Census distances reported may be slightly shorter than in reality.

Figure 7-3 - Trip Length Distribution Comparison between CSRM2 and Census for HBW, all modes, 2011



Looking in more detail at the individual modes in Appendix E, it can be seen that the exaggerated peak in the 5-10 miles band is driven by car mode (Figure E-2). CSRM2 appears to have too few long-distance trips by car (Figure E-2) and too many by bus (Figure E-3) compared to Census data. For the shorter distance bands, the distribution of bus trip lengths compares reasonably well against the Census (Figure E-3), while cycle matches very well across all lengths (Figure E-5). The rail (Figure E-4) and walk (Figure E-6) trip length distributions also validate well against the Census. It should also be noted that no intrazonal public transport trips exist within CSRM2 (see Section 3.8), explaining the deficit in very short distance bus trips modelled (Figure E-3). These trip length distributions have changed very little since the E-series.

The Census only provides information about usual journey to work trips. For other purposes, we consider the information available from NTS, whilst bearing in mind that NTS is not a locally-focussed dataset and so (for example) does not capture the long-distance rail commuting trips between Cambridge and London. However, by comparing the HBW results between the two data sources, we can provide a basis to interpret the trip-making patterns of the other purposes. The NTS HBW trip length distribution for all modes (Figure E-7) differs from the Census (Figure E-1) in that it lacks the peaks in the 15-25 miles and >50 miles bands. Cambridge differs from the national average because people commute from a number of large market towns in the 15-25 miles range and commuting to London is a viable option for many residents but falls into the >50 miles band. This explains the differences seen in the car, bus and rail trip length distributions (Figure E-8, Figure E-9 and Figure E-10 respectively). The walk (Figure E-12) and cycle (Figure E-11) HBW trip length distributions match well against the NTS, as there is not so much scope for regional variation in the distances people are prepared to commute by walk or cycle (even if there are differences in volumes).

Looking at the other purposes, the EB trip length distributions from CSRM2 (including HB and NHB trips) broadly match NTS (Figure E-13 to Figure E-18), with the exception of bus, where the model does not replicate

the exceptionally high peak in the NTS 3-5 miles band. A similar peak was observed in the NTS HBW distribution (Figure E-9) but not the Census (Figure E-3) and so this can be attributed to variations between the local Cambridge area and the national average.

Across all modes, there appears to be a slight trend for Education trips to be longer distance in CSRM2 than in NTS, which could reflect the rural nature of the sub-region (Figure E-19). CSRM2 has a noticeable peak for car in the 5-10 miles range (Figure E-20), which could be due to the lack of school buses in the model. CSRM2 also has peaks for bus (Figure E-21) and rail (Figure E-22) in the 15-25 miles band, which is likely to be a combined effect of pupils from the region travelling to private schools in Cambridge City and sixth form students travelling to Long Road and Hills Road sixth form colleges (due to the lack of more local sixth form provision in the region).

For Other trip purposes (HBPS, HBRV and NHBO), the overall trip length distribution for all modes matches NTS reasonably well (Figure E-25), and individually the bus, cycle and walk graphs validate well (Figure E-27, Figure E-29 and Figure E-30, respectively). For the discretionary purposes, CSRM2 has a smaller proportion of car trips in the range 2-5 miles than NTS. However, the same pattern for HBW trips vs NTS is seen in Figure E-8, whereas in Figure E-2, the CSRM2 distribution is seen to match local patterns from Census JTW. We can therefore conclude that the relatively low rate of 2-5 mile car trips is a feature of the local geography, and would be replicated were more localised data for NTS to be available. The rail graph for Other purposes exaggerates a feature that has also been present in the previous rail graphs for HBW, EB and Education: the Cambridge sub-region (in 2015) has no rail trips shorter than 5 miles (Figure E-28), simply due to the locations of the stations and the lack of intrazonal public transport trips in the model (Section 3.8).

7.5. Comparison of synthetic light vehicle trips with Highway Model

This section presents comparisons between the validated SATURN base year highway matrices and the synthetic light vehicle trip Origin-Destination matrices produced by the TDM. The synthetic matrix used for this comparison has been converted to 1-hour vehicle trips as described in Section 6.8. Since these factors are estimates based on RSI data, some variation between the figures would not be unexpected. In addition, the intrazonal trips have been filtered out of both matrices as they are not assigned in the HAM and are not a validated aspect of it, and the external-external trips have been filtered out of the HAM matrix as they are not in the synthetic matrices.

Comparison of the absolute size of the matrices in Table 7-9 shows that the total number of car trips in each peak period is very similar: the AM synthetic matrix is 2% lower than the HAM; IP 6% higher and PM 1% higher.

Table 7-9 - Comparison of total matrix sizes

Time Period	HAM Matrix total	TDM Matrix Total	Difference	% Difference
AM (08:00-09:00)	71,218	69,821	-1,397	-2%
IP (average hour 10:00-16:00)	44,982	47,480	2,498	6%
PM (17:00-18:00)	78,590	79,746	1,156	1%

Table 7-10 confirms that the overall shape of the matrices is very similar. It shows, for each time period, district and purpose, the percentage of the matrix total which is represented, summing to 100% in each column. The percentages on the whole are very similar between the HAM and the synthetic matrix, with a maximum discrepancy of 4.3 percentage points (total origins from Huntingdonshire in the AM peak).

Table 7-11 to Table 7-13 give more detail on the sector-to-sector movements within each of the matrices, showing that they are indeed very similar in shape, with no more than one percentage point difference in the proportion of the matrix between any sector-to-sector pair in any time period. However, it can be seen that there are some large differences in absolute volumes for some sector-to-sector movements, for example movements within the Huntingdonshire Rural sector where there is an absolute difference of 736 in the AM Peak. The larger discrepancies tend to be between sectors that are closer together, with a better match for the longer-distance movements within the sub-region.

Figure 7-4 to Figure 7-9 are scatter plots showing the correlation between the synthetic and HAM matrices at an individual zone level. Again, these show a good correlation between the two matrices, with R^2 values in the range 0.8-0.9.

Table 7-10 - Analysis by Trip Origins: Proportion of car trip origins by District and Purpose

District	Purpose	AM		IP		PM	
		HAM	TDM	HAM	TDM	HAM	TDM
Cambridge	HBW	6.7%	5.4%	2.5%	2.1%	11.2%	9.9%
	HBEd	4.1%	2.8%	2.0%	1.6%	1.3%	1.1%
	EB	0.9%	0.8%	1.4%	1.3%	1.3%	1.1%
	Other	4.2%	3.1%	15.0%	12.4%	7.7%	6.6%
	Total	15.9%	12.1%	20.9%	17.4%	21.5%	18.7%
South Cambridgeshire	HBW	13.3%	12.1%	3.6%	3.6%	14.4%	13.8%
	HBEd	8.8%	8.5%	2.2%	2.0%	1.2%	1.0%
	EB	1.3%	1.3%	1.7%	1.8%	1.6%	1.5%
	Other	5.7%	5.6%	20.1%	20.5%	11.4%	10.8%
	Total	29.1%	27.6%	27.5%	27.8%	28.6%	27.1%
East Cambridgeshire	HBW	6.3%	6.8%	1.6%	1.7%	5.1%	5.9%
	HBEd	3.6%	3.9%	1.0%	0.9%	0.5%	0.5%
	EB	0.6%	0.7%	0.8%	0.8%	0.7%	0.7%
	Other	2.7%	3.0%	10.1%	10.6%	5.1%	5.6%
	Total	13.2%	14.3%	13.5%	14.0%	11.4%	12.6%
Huntingdonshire	HBW	12.3%	15.4%	3.4%	3.8%	12.9%	13.9%
	HBEd	7.6%	7.7%	2.0%	1.9%	1.1%	1.0%
	EB	1.2%	1.6%	1.7%	2.1%	1.6%	1.9%
	Other	5.5%	6.3%	20.5%	23.0%	11.2%	12.2%
	Total	26.7%	30.9%	27.6%	30.8%	26.8%	29.0%
Internal Totals	HBW	38.6%	39.8%	11.1%	11.2%	43.6%	43.5%
	HBEd	24.1%	22.9%	7.2%	6.4%	4.1%	3.6%
	EB	4.0%	4.4%	5.6%	5.9%	5.1%	5.2%
	Other	18.1%	17.9%	65.7%	66.4%	35.4%	35.1%
	Total	84.8%	85.0%	89.5%	90.0%	88.3%	87.4%
External	HBW	11.1%	11.3%	2.8%	2.7%	7.8%	8.4%
	HBEd	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	EB	1.1%	1.1%	1.0%	1.0%	0.6%	0.7%
	Other	3.0%	2.7%	6.6%	6.3%	3.4%	3.6%
	Total	15.2%	15.0%	10.5%	10.0%	11.7%	12.6%
Overall Totals	HBW	49.7%	51.0%	13.9%	13.9%	51.4%	51.8%
	HBEd	24.1%	22.9%	7.2%	6.4%	4.2%	3.6%
	EB	5.0%	5.4%	6.6%	6.9%	5.8%	5.9%
	Other	21.1%	20.7%	72.3%	72.8%	38.7%	38.7%
	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

		Cambridge Central_110	Cambridge Outer_120	City Fringe_210	S Cambs Outer_220	Ely_410	E Camb Rural_420	Hunts Towns_510	Huntingdon Fringe+A14_540	Hunts Rural_550	Fenland + Peterborough_710	Essex+Suffolk Towns_730	External Other_740	London_790
HAM Validated Matrix	Cambridge Central_110	831	1,078	588	326	8	74	9	23	18	11	96	94	59
	Cambridge Outer_120	1,546	2,801	1,561	1,125	14	150	48	97	80	34	195	336	89
	City Fringe_210	656	1,728	1,413	1,529	38	250	58	134	108	43	147	272	40
	S Cambs Outer_220	609	2,633	2,260	5,033	53	327	416	399	458	103	833	1,072	103
	Ely_410	36	48	68	143	568	1,053	38	27	81	60	75	116	2
	E Camb Rural_420	299	471	577	733	1,588	1,894	108	64	186	118	503	518	16
	Hunts Towns_510	16	106	74	431	14	24	2,016	1,136	1,049	119	30	1,264	45
	Huntingdon Fringe+A14_540	26	239	124	428	17	30	1,311	1,191	973	209	20	357	17
	Hunts Rural_550	30	225	191	654	146	201	2,128	1,182	1,767	405	37	751	26
	Fenland + Peterborough_710	17	61	49	119	187	195	202	198	443	-	-	-	-
Essex+Suffolk Towns_730	188	400	372	1,244	25	240	18	37	29	-	-	-	-	
External Other_740	387	870	686	1,482	153	572	719	571	903	-	-	-	-	
London_790	28	98	94	163	1	13	16	13	23	-	-	-	-	
TDM Synthetic Matrix	Cambridge Central_110	804	890	296	251	9	47	19	16	16	3	36	48	4
	Cambridge Outer_120	1,438	2,192	957	765	37	165	73	59	58	13	99	147	13
	City Fringe_210	719	1,646	1,190	1,234	73	256	85	73	76	16	132	182	18
	S Cambs Outer_220	913	2,109	1,821	4,814	94	348	671	484	531	76	660	921	102
	Ely_410	39	89	121	92	833	748	30	19	62	33	45	114	1
	E Camb Rural_420	281	672	742	663	1,523	2,206	123	74	218	93	533	653	9
	Hunts Towns_510	109	237	181	663	37	80	1,825	903	1,093	153	25	926	35
	Huntingdon Fringe+A14_540	94	210	176	660	22	55	1,163	1,266	829	194	19	294	9
	Hunts Rural_550	135	301	278	953	121	244	2,141	1,375	2,503	1,307	39	928	24
	Fenland + Peterborough_710	26	58	68	162	151	206	272	330	906	-	-	-	-
Essex+Suffolk Towns_730	145	302	276	829	44	322	21	15	20	-	-	-	-	
External Other_740	245	535	467	1,243	239	863	934	528	1,022	-	-	-	-	
London_790	19	40	33	130	1	5	23	7	12	-	-	-	-	
Difference (2-1)	Cambridge Central_110	- 27	- 188	- 291	- 76	1	- 26	10	- 7	- 2	- 7	- 60	- 46	- 55
	Cambridge Outer_120	- 108	- 608	- 605	- 360	23	15	25	- 37	- 22	- 21	- 96	- 189	- 76
	City Fringe_210	63	- 82	- 222	- 295	34	6	27	- 61	- 32	- 27	- 14	- 90	- 22
	S Cambs Outer_220	304	- 524	- 439	- 219	41	21	255	86	73	- 27	- 173	- 151	- 1
	Ely_410	3	41	53	- 51	265	- 306	- 8	- 7	- 20	- 27	- 31	- 2	- 1
	E Camb Rural_420	- 19	201	165	- 70	- 64	311	15	10	32	- 25	30	135	- 7
	Hunts Towns_510	94	131	106	232	23	55	- 191	- 233	44	34	- 5	- 338	- 10
	Huntingdon Fringe+A14_540	68	- 29	52	232	5	25	- 148	75	-				

[illegible]

Table 7-12 - Sector-to-Sector spread of movements: Inter Peak

HAM Validated Matrix		Cambridge Central_110	Cambridge Outer_120	City Fringe_210	S Cambs Outer_220	Ely_410	E Camb Rural_420	Hunts Towns_510	Huntingdon Fringe+A14_540	Hunts Rural_550	Fenland + Peterborough_710	Essex+Suffolk Towns_730	External Other_740	London_790
	Cambridge Central_110	808	1,043	550	415	20	171	16	34	37	15	105	138	14
	Cambridge Outer_120	1,147	1,931	1,136	863	33	219	44	78	83	26	195	263	34
	City Fringe_210	700	1,228	934	991	46	272	46	81	90	28	152	278	40
	S Cambs Outer_220	455	936	999	2,582	63	256	264	334	330	49	516	647	37
	Ely_410	24	31	38	49	566	997	17	12	72	47	57	98	1
	E Camb Rural_420	187	241	271	280	1,124	1,046	43	29	114	61	342	310	6
	Hunts Towns_510	25	69	68	260	17	33	1,480	928	1,001	108	11	870	16
	Huntingdon Fringe+A14_540	29	76	76	246	16	28	929	998	745	99	15	257	6
	Hunts Rural_550	32	78	84	309	97	109	959	783	842	213	20	492	10
	Fenland + Peterborough_710	12	22	25	40	61	74	86	89	184	-	-	-	-
	Essex+Suffolk Towns_730	108	171	138	514	37	240	7	15	18	-	-	-	-
	External Other_740	110	211	199	512	74	260	429	321	563	-	-	-	-
	London_790	25	45	43	42	1	7	8	9	14	-	-	-	-

TDM Synthetic Matrix		Cambridge Central_110	Cambridge Outer_120	City Fringe_210	S Cambs Outer_220	Ely_410	E Camb Rural_420	Hunts Towns_510	Huntingdon Fringe+A14_540	Hunts Rural_550	Fenland + Peterborough_710	Essex+Suffolk Towns_730	External Other_740	London_790
	Cambridge Central_110	731	867	412	437	21	115	44	37	44	7	59	78	5
	Cambridge Outer_120	1,009	1,490	936	1,005	54	254	113	93	104	18	127	178	11
	City Fringe_210	477	926	833	1,051	81	290	101	87	102	20	141	172	10
	S Cambs Outer_220	510	985	1,048	3,226	88	309	523	434	471	63	570	648	41
	Ely_410	24	55	76	81	873	837	30	20	75	44	34	95	0
	E Camb Rural_420	139	271	301	319	938	1,269	80	56	154	62	389	413	3
	Hunts Towns_510	49	109	95	497	32	72	1,467	868	1,059	117	15	646	9
	Huntingdon Fringe+A14_540	41	90	82	403	20	48	842	1,095	767	151	12	267	3
	Hunts Rural_550	52	109	101	467	84	144	1,101	858	1,413	794	19	626	6
	Fenland + Peterborough_710	8	19	21	54	37	54	90	115	589	-	-	-	-
	Essex+Suffolk Towns_730	47	103	111	421	23	283	12	9	15	-	-	-	-
	External Other_740	76	169	160	549	78	342	504	235	536	-	-	-	-
	London_790	5	11	10	40	0	3	9	3	6	-	-	-	-

Difference (2-1)		Cambridge Central_110	Cambridge Outer_120	City Fringe_210	S Cambs Outer_220	Ely_410	E Camb Rural_420	Hunts Towns_510	Huntingdon Fringe+A14_540	Hunts Rural_550	Fenland + Peterborough_710	Essex+Suffolk Towns_730	External Other_740	London_790
	Cambridge Central_110	- 76	- 176	- 138	22	0	- 56	28	3	8	- 8	- 46	- 59	- 9
	Cambridge Outer_120	- 138	- 441	- 200	142	21	35	70	15	22	- 7	- 68	- 85	- 23
	City Fringe_210	- 222	- 303	- 101	60	34	19	55	6	13	- 8	- 10	- 106	- 30
	S Cambs Outer_220	55	49	49	643	25	54	259	100	141	14	54	1	4
	Ely_410	- 0	24	38	32	307	- 161	14	8	3	- 3	- 23	- 3	0
	E Camb Rural_420	- 48	30	30	39	- 186	224	37	27	40	1	47	103	- 3
	Hunts Towns_510	23	41	27	237	15	39	- 13	- 60	58	9	5	- 224	- 7
	Huntingdon Fringe+A14_540	11	14	6	157	4	20	- 87	97	22	52	- 3	10	- 3
	Hunts Rural_550	20	31	17	158	- 13	35	142	75	571	582	- 1	133	- 4
	Fenland + Peterborough_710	- 4	- 4	- 4	14	- 24	- 20	4	27	405	-	-	-	-
	Essex+Suffolk Towns_730	- 60	- 68	- 26	- 93	- 14	42	4	- 5	- 3	-	-	-	-
	External Other_740	- 34	- 42	- 39	37	4	82	75	- 86	- 27	-	-	-	-
	London_790	- 19	- 34	- 33	- 2	- 1	- 5	2	- 6	- 9	-	-	-	-

	Cambridge Central_110	Cambridge Outer_120	City Fringe_210	S Cambs Outer_220	Ely_410	E Camb Rural_420	Hunts Towns_510	Huntingdon Fringe+A14_540	Hunts Rural_550	Fenland + Peterborough_710	Essex+Suffolk Towns_730	External Other_740	London_790
	2%	2%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	3%	4%	3%	2%	0%	0%	0%	0%	0%	0%	0%	1%	0%
	2%	3%	2%	2%	0%	1%	0%	0%	0%	0%	0%	1%	0%
	1%	2%	2%	6%	0%	1%	1%	0%	1%	1%	1%	1%	0%
	0%	0%	0%	0%	1%	2%	0%	0%	0%	0%	0%	0%	0%
	0%	1%	1%	1%	2%	2%	0%	0%	0%	0%	1%	1%	0%
	0%	0%	0%	1%	0%	0%	3%	2%	2%	0%	0%	2%	0%
	0%	0%	0%	1%	0%	0%	2%	2%	2%	0%	0%	1%	0%
	0%	0%	0%	1%	0%	0%	2%	2%	2%	0%	0%	1%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	1%	0%	1%	0%	1%	1%	1%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	2%	2%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	2%	3%	2%	2%	0%	1%	0%	0%	0%	0%	0%	0%	0%
	1%	2%	2%	2%	0%	1%	0%	0%	0%	0%	0%	0%	0%
	1%	2%	2%	7%	0%	1%	1%	1%	1%	0%	1%	1%	0%
	0%	0%	0%	0%	2%	2%	0%	0%	0%	0%	0%	0%	0%
	0%	1%	1%	1%	2%	3%	0%	0%	0%	0%	1%	1%	0%
	0%	0%	0%	1%	0%	0%	3%	2%	2%	0%	0%	1%	0%
	0%	0%	0%	1%	0%	0%	2%	2%	2%	0%	0%	1%	0%
	0%	0%	0%	1%	0%	0%	2%	2%	3%	2%	0%	1%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%
	0%	0%	0%	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	1%	0%	1%	1%	0%	1%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	-1%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	-1%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	1%	0%	0%	1%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

		Cambridge Central_110	Cambridge Outer_120	City Fringe_210	S Cambs Outer_220	Ely_410	E Camb Rural_420	Hunts Towns_510	Huntingdon Fringe+A14_540	Hunts Rural_550	Fenland + Peterborough_710	Essex+Suffolk Towns_730	External Other_740	London_790
HAM Validated Matrix	Cambridge Central_110	1,173	1,365	867	950	25	336	16	26	34	14	333	269	40
	Cambridge Outer_120	1,405	2,679	1,666	2,201	114	671	120	192	290	103	719	1,140	129
	City Fringe_210	699	1,485	1,345	1,765	132	669	92	117	204	78	327	763	91
	S Cambs Outer_220	598	1,245	1,523	4,922	148	797	457	555	746	222	1,225	2,099	165
	Ely_410	13	29	48	74	695	1,504	24	26	143	182	69	209	1
	E Camb Rural_420	117	267	328	402	1,159	1,800	55	48	237	268	491	753	10
	Hunts Towns_510	28	81	79	432	61	150	2,171	1,349	1,909	335	25	1,701	49
	Huntingdon Fringe+A14_540	45	118	108	460	34	96	1,301	1,547	1,306	300	31	571	17
	Hunts Rural_550	39	96	97	456	96	194	1,402	1,166	1,543	674	33	932	23
	Fenland + Peterborough_710	13	27	27	67	52	103	183	213	485	-	-	-	-
	Essex+Suffolk Towns_730	159	250	270	1,166	55	569	21	25	58	-	-	-	-
External Other_740	132	328	362	1,229	132	658	736	440	1,025	-	-	-	-	
London_790	51	51	49	156	7	33	27	21	54	-	-	-	-	
TDM Synthetic Matrix	Cambridge Central_110	928	1,414	709	876	43	273	116	97	133	32	176	295	22
	Cambridge Outer_120	1,237	2,359	1,593	1,952	103	624	263	217	295	72	379	653	46
	City Fringe_210	527	1,293	1,309	1,818	142	660	209	183	262	81	356	571	39
	S Cambs Outer_220	501	1,212	1,456	4,718	127	637	828	699	916	194	1,121	1,594	149
	Ely_410	19	58	90	112	1,057	1,418	48	29	138	160	60	265	1
	E Camb Rural_420	125	294	337	416	1,114	2,055	111	71	261	229	564	1,040	7
	Hunts Towns_510	42	124	121	714	46	139	2,066	1,230	1,873	324	29	1,278	27
	Huntingdon Fringe+A14_540	35	100	101	571	29	90	1,145	1,511	1,412	404	21	667	9
	Hunts Rural_550	43	116	121	649	108	263	1,461	1,080	2,350	1,354	31	1,391	16
	Fenland + Peterborough_710	9	25	29	102	58	128	198	248	1,515	-	-	-	-
	Essex+Suffolk Towns_730	66	162	195	814	57	626	33	25	45	-	-	-	-
External Other_740	93	248	275	1,188	158	823	1,129	389	1,162	-	-	-	-	
London_790	7	19	24	127	1	11	41	11	28	-	-	-	-	
Difference (2-1)	Cambridge Central_110	- 245	49	- 157	- 75	18	- 63	99	71	99	18	- 157	26	- 18
	Cambridge Outer_120	- 169	- 320	- 73	- 250	- 11	- 48	142	25	5	- 31	- 340	- 487	- 82
	City Fringe_210	- 172	- 192	- 36	53	11	9	117	66	57	3	29	- 192	- 53
	S Cambs Outer_220	- 97	- 33	- 67	- 203	- 21	- 159	370	144	169	- 28	- 104	- 505	- 16
	Ely_410	6	29	42	38	362	- 86	24	3	- 6	- 23	8	56	0
	E Camb Rural_420	8	27	9	14	- 45	255	57	23	24	- 38	72	287	- 4
	Hunts Towns_510	15	43	42	282	- 15	- 11	- 105	- 119	- 36	- 11	4	- 423	- 22
	Huntingdon Fringe+A14_540	- 10												

[illegible]

Figure 7-4 - AM origin trip ends scatter plot

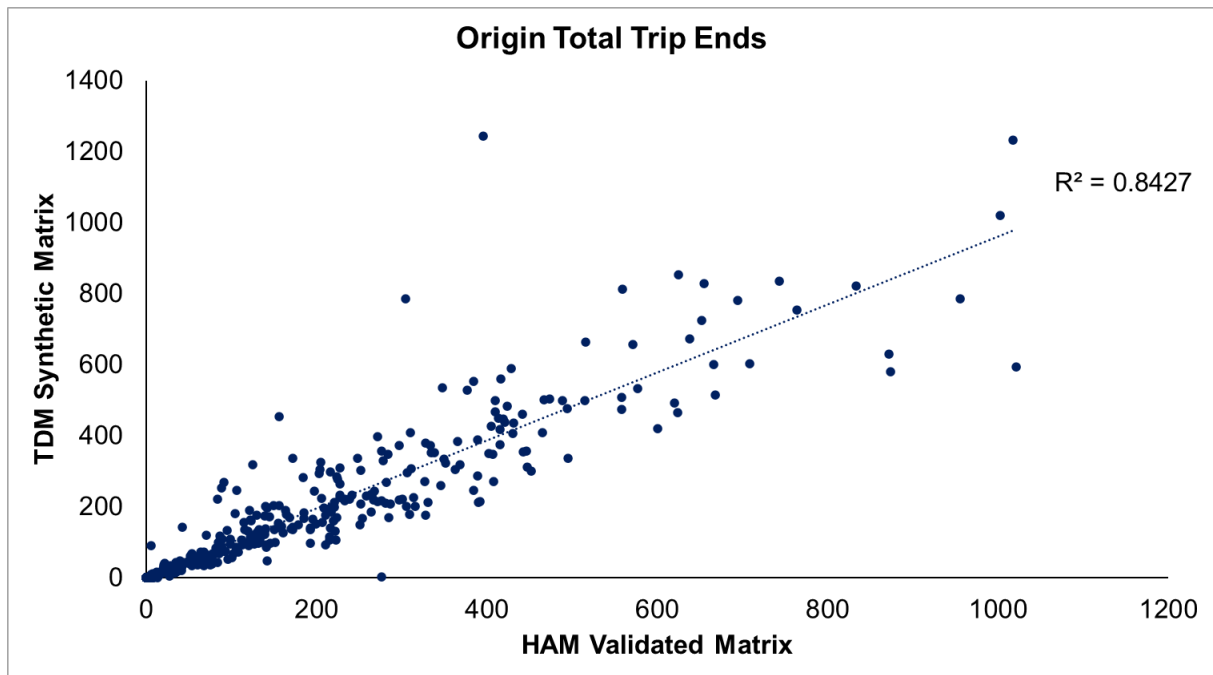


Figure 7-5 - AM destination trip ends scatter plot

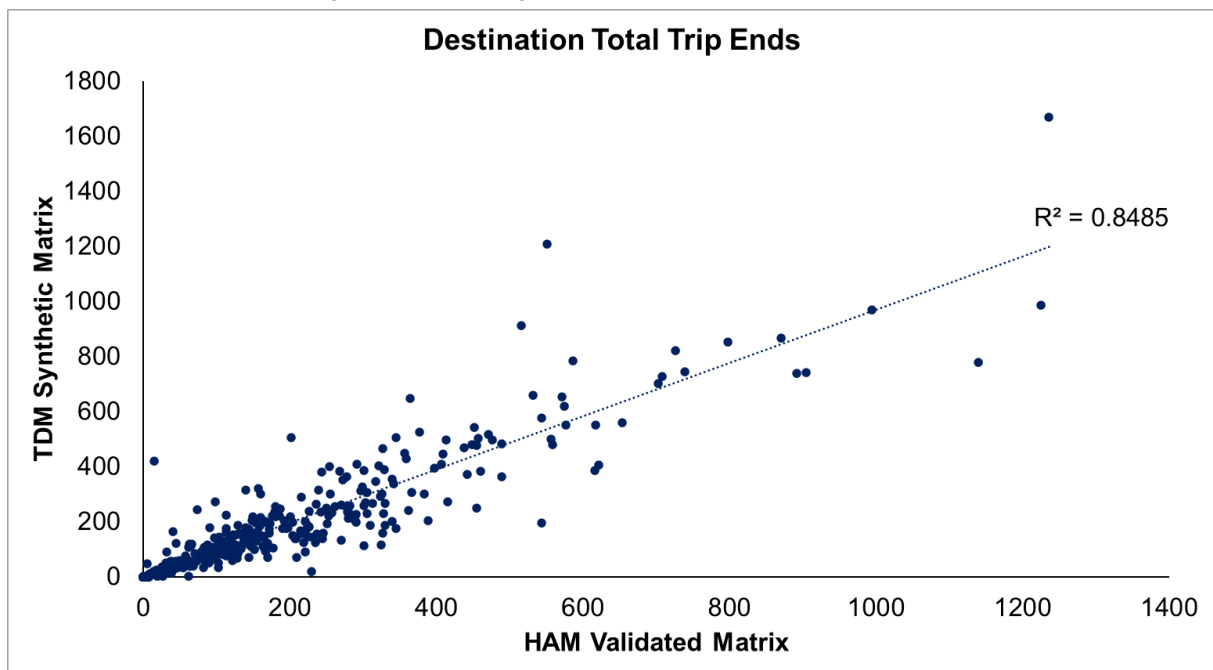


Figure 7-6 - IP origin trip ends scatter plot

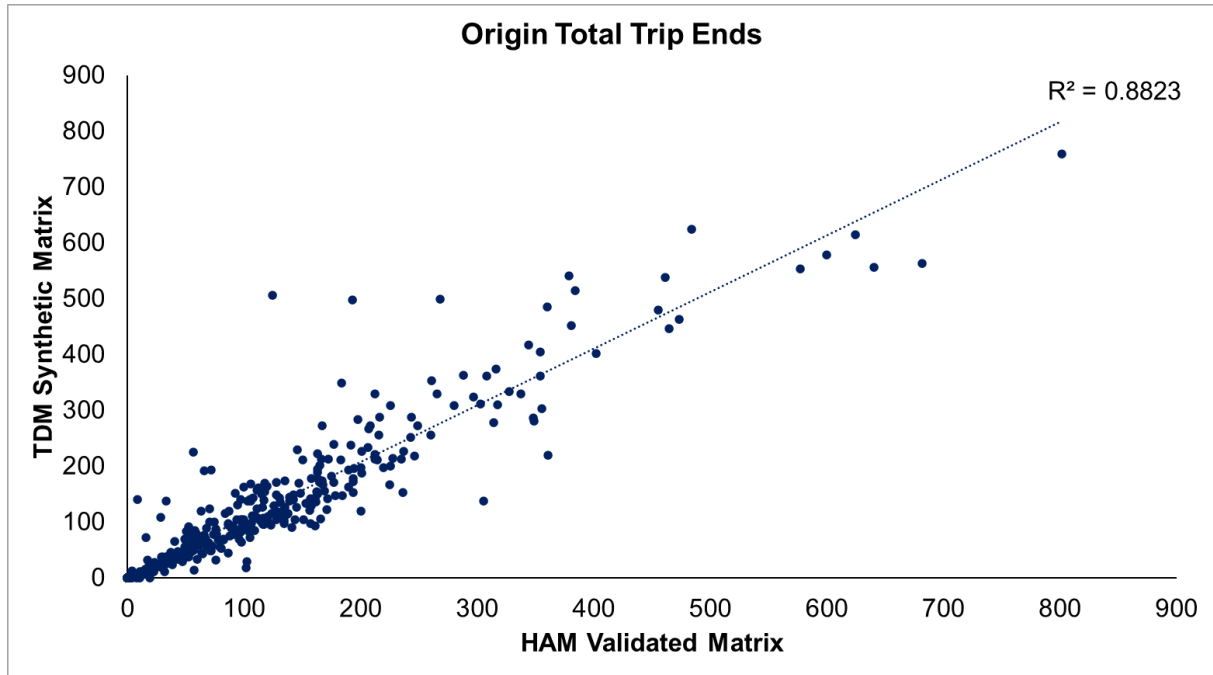


Figure 7-7 - IP destination trip ends scatter plot

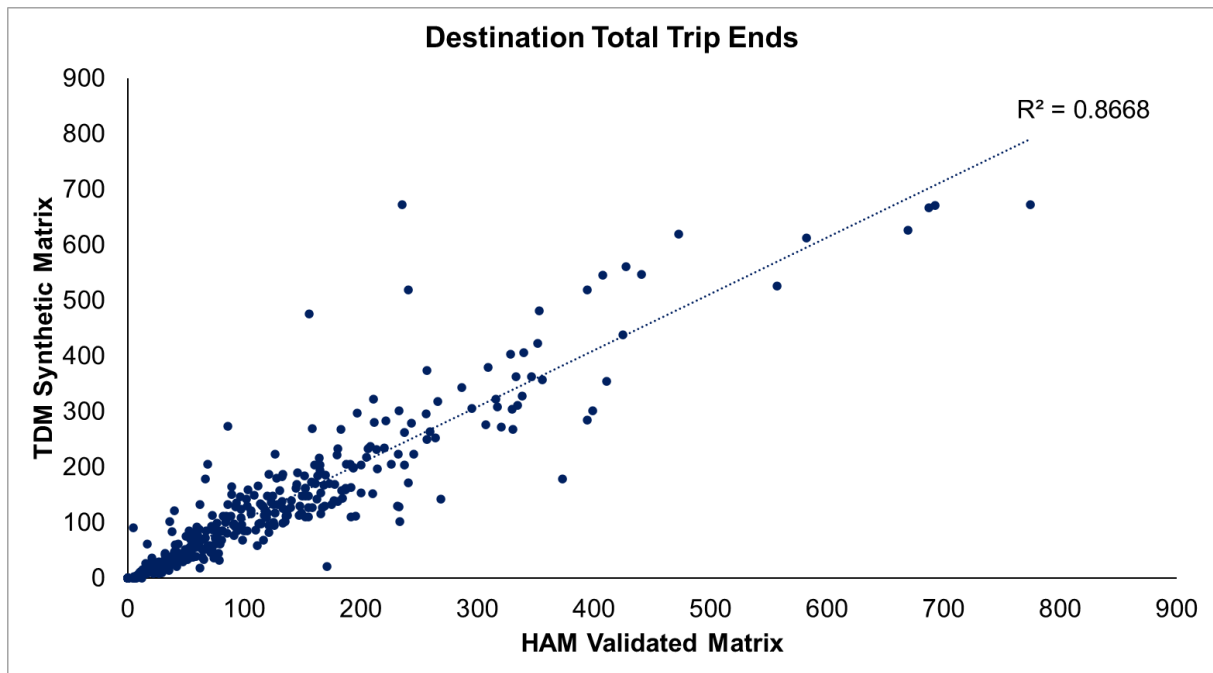


Figure 7-8 - PM origin trip ends scatter plot

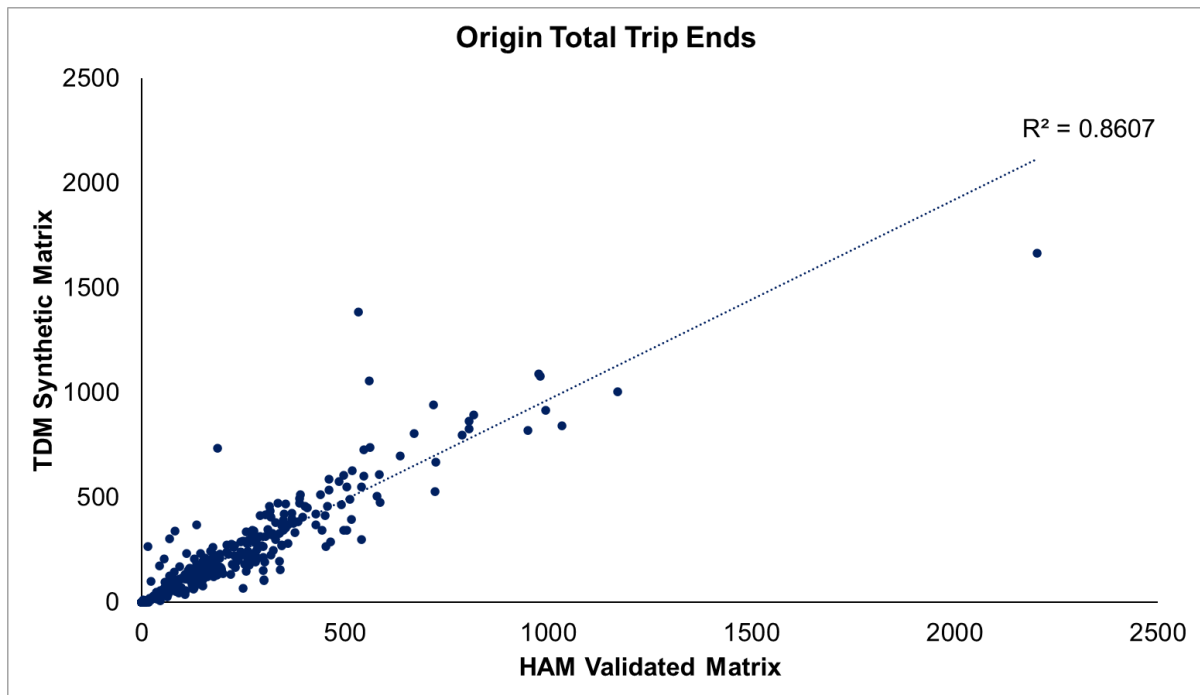
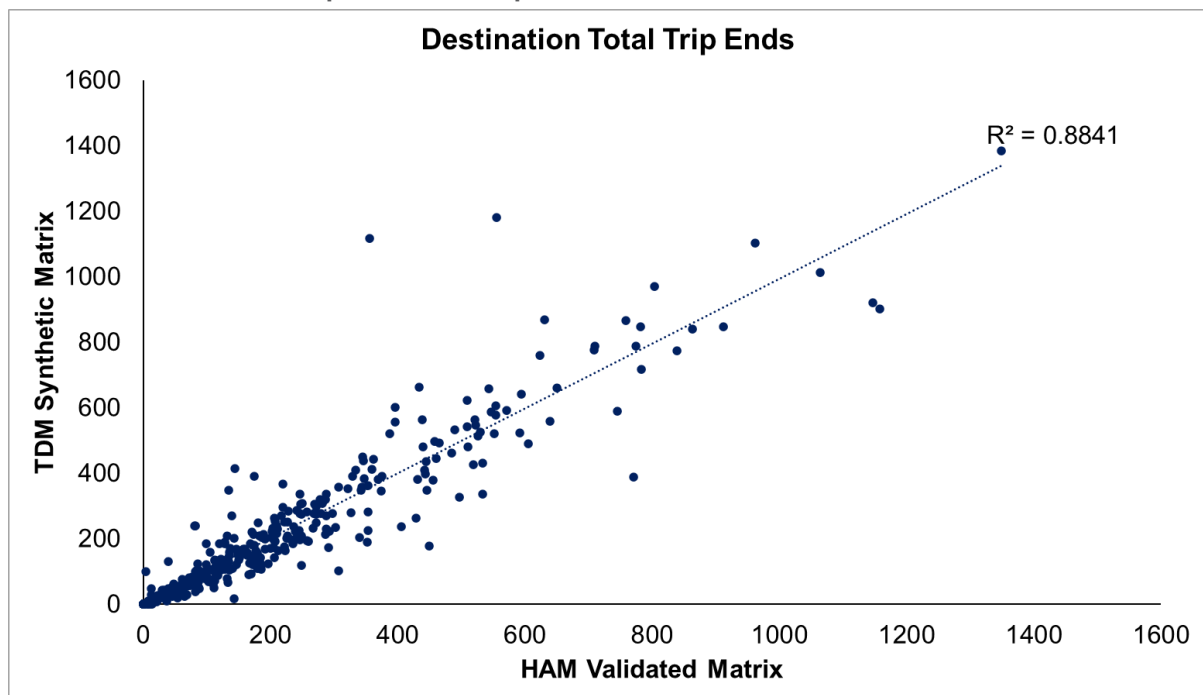


Figure 7-9 - PM destination trip ends scatter plot



7.6. Realism Testing Methodology

7.6.1. Introduction

Realism tests involve changing the cost or time characteristics within the model and determining the resulting change in output demand. The requirements for realism testing of variable demand models are set out in TAG unit M2.1 May 2020, Section 6.4. The three tests performed were:

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

A further test where car fuel cost was increased by 20% was also carried out, as a sensitivity to the first test.

All these tests are performed using the 2015 base year model. The base case uses the validated 2015 HAM highway matrix and its cost skims.

7.6.2. Car fuel cost increase

Highway demand changes can be measured in three places given the model structure. Recalling the notation of Section 6.9, there are four highway matrices produced:

- B, the 2015 base validated SATURN highway matrix;
- Sb, the base TDM synthetic matrix (validated against B: see Section 7.5);
- Sf, the alternative synthetic matrix produced by the TDM (with fuel costs increased by 10%); and
- F, the pivoted alternative-case HAM matrix.

Broadly each matrix cell in F is defined as described in Section 6.9:

$$F_{odct} = B_{odct} * Sf_{odct} / Sb_{odct} \quad (odct = \text{origin, destination, user class and time period})$$

In this realism test scenario, the demand model is iterated to convergence with the HAM. This ensures that changes in vehicle generalised cost due to re-routing and congestion changes are fully included in the elasticities reported.

The vehicle-km produced by matrix B are determined as the sum of the trips in B times the distance skim D(B) for each zone pair obtained by assigning B in the HAM:

$$VKM(B) = \text{sum}(B_{od} * D(B)_{od}) \quad (\text{for a given user class and time of day})$$

The synthetic matrix Sb is never assigned, but takes the distance skims from the base HAM, so

$$VKM(Sb) = \text{sum}(Sb_{od} * D(B)_{od})$$

The forecast matrix F is assigned and produces distance skims D(F), so

$$VKM(F) = \text{sum}(F_{od} * D(F)_{od})$$

and

$$VKM(Sf) = \text{sum}(Sf_{od} * D(F)_{od})$$

So, the three ways that highway demand change can be measured are:

- Change in the demand model (matrix Sf versus Sb);
- Change in highway matrices after pivoting, i.e. the change in the matrix F versus B; and
- Change in assigned vehicle-km in the HAM, summed over all road links in the internal study area. This will include the part of through traffic that is assigned within the study area, but does not include intrazonal movements.

7.6.3. PT fares increase

In this realism test scenario, the demand model is again iterated to convergence with the HAM. This ensures that changes in generalised cost due to re-routing and congestion changes (triggered by mode switching due to the increased fares) are fully included in the elasticities reported. Resulting elasticities are calculated on total changes in flow volume across all PT modes (excluding bus P&R), by purpose and time of day from the synthetic forecast and base matrices.

7.6.4. Car own-time increase

Car own-time elasticity is similarly calculated as the change in *trips* due to a 10% increase in travel time. This is only a single-cycle run without pivoting as the TAG values to which it is to be compared are from Stated Preference surveys (TAG M2.1 May 2020 6.4.27).

7.6.5. Realism calculations

For each test, the elasticity results have been calculated using the formula set out in TAG M2.1 May 2020, Section 6.4.5.

$$e = \frac{\log(T_1) - \log(T_0)}{\log(C_1) - \log(C_0)}$$

Where T_0 and T_1 are travel demand respectively for the Base and Alternative case, and C_0 and C_1 are the travel cost/time variable for the Base and Alternative case. When the cost has been increased by 10%, $\log(C_1) - \log(C_0) = \log(1.1)$.

Results are reported in the section below for the eight HAM user classes, with subtotals for HBW and for Other, so that the tables include results for the four main purposes (HBW, Education, EB and Other). For car own-time elasticity the results (Table 7-20) are reported for the TDM purposes with totals for Education, EB and Other.

All elasticities reported represent the “typical” weekday that CSRM2 modelled, for either the 3 and 6 hour periods of the demand model matrices, or 1 hour periods for the HAM based results.

Tours starting in external zones are largely an exogenous input to the model. Such trips have distribution and mode choice responses, but cannot choose destinations other than the study area, so they are not fully responsive. Also, the fuel elasticity target of -0.3 is a national number i.e. it relates to a population of trips consistent with the national average; whereas in the model the trips by residents are a comparable population sample, the whole matrix of trips by residents plus inbound travellers is a sample skewed towards longer trips.

It is therefore more appropriate to calculate an elasticity that includes only trips by residents, plus NHB trips with origins in the study area. All the demand matrix elasticities are done this way. Unfortunately, this is only possible where the production-attraction matrix is available, so for the HAM it is not possible to isolate trips by residents. The HAM matrix elasticities have therefore been calculated for trips with internal origins only (Table 7-16), as a proxy. The HAM network elasticities are for links in the study area including all car/LGV traffic (through traffic, residents and non-residents, etc.) on those links.

7.7. Realism Test Results

7.7.1. Introduction

TAG guidance (unit M2.1 May 2020, Section 6.4) suggests the following results should be achieved for the realism tests:

- Car fuel cost responses: in the range -0.25 to -0.35, with employer’s business trips near to -0.1, discretionary trips near to -0.4, and commuting and education somewhere near the average;
- Public transport fare responses: in the range -0.2 to -0.9, with lower values for non-discretionary purposes than discretionary purposes, and lower values in the Inter Peak than the peak periods; and
- Car own-time responses: negative and smaller in magnitude than -2.0.

Furthermore, for the iterated realism tests, TAG (M2.1 paragraph 6.3.8) recommends a gap value below 0.2%.

7.7.2. Car fuel cost responses

For this test, the car fuel cost has been increased by 10%. The test converged with a gap value of 0.063%. The tables following show respectively:

- The response of the synthetic demand model (Table 7-14);
- The response of the synthetic demand model by socio-economic class for HBW trips (Table 7-15);
- Internal-to-all movements in the HAM pivoted matrices (Table 7-16); and
- The HAM network traffic in the study area (Table 7-17).

The overall fuel price elasticities shown in Table 7-14 are slightly below the acceptable level: the TAG (M2 6.4.14) guidance suggests an annual figure in the range -0.25 to -0.35. The result of -0.23 is close to the lower

end of this range, which is to be expected as Cambridge is more congested and has higher income than average.

TAG guidance also suggests that employer's business trips should be nearer to -0.1 and discretionary nearer to -0.4, with commuting and education near the average. The low elasticity is driven particularly by HBW and Other, especially in the AM peak – due to a lack of response in mode shift or time of day choice. Employer's business is a little too low – this is potentially due to the lack of mode choice for employer's business trips with external trip ends. Variation by income appears reasonable, with those on low incomes more responsive to cost changes than those on higher incomes.

Table 7-14 - TDM Car Fuel Cost Elasticities, Study Area Residents Only

In the notation above, this is $VKM(S_f | P \text{ in study area}) / VKM(S_b | P \text{ in study area})$ ³⁵

Purpose	AM Peak 07:00-10:00	Inter Peak 10:00-16:00	PM Peak 16:00-19:00	12-hour 07:00-19:00
HBW Low Income	-0.19	-0.35	-0.26	-0.24
HBW Medium Income	-0.15	-0.31	-0.22	-0.20
HBW High Income	-0.11	-0.26	-0.17	-0.16
HBW – all incomes	-0.13	-0.28	-0.19	-0.18
Education	-0.29	-0.29	-0.29	-0.29
EB	-0.02	-0.04	-0.06	-0.04
Other Low Income	-0.25	-0.52	-0.47	-0.44
Other Medium Income	-0.16	-0.32	-0.32	-0.29
Other High Income	-0.09	-0.22	-0.20	-0.20
Other – all incomes	-0.19	-0.34	-0.34	-0.32
All light vehicles	-0.15	-0.30	-0.24	-0.23

Table 7-15 shows the same HBW results by GSeC³⁶ segmentation, which has greater variation of response between segments. The different GSeC groups have a range of 12-hour elasticities from -0.04 to -0.48, but when these are blended as income groups the variation is smaller.

³⁵ See 7.5.4 for the definition of this terminology.

³⁶ GSeC is a grouping of 2001 Census NS-SeC categories used in the model development, with GSeC 1 relating to professional occupations with higher skills/earnings, and GSeC 4 relating to lower skills/earnings. See Appendix A Glossary and Table 2-5.

Table 7-15 - TDM Car Fuel Cost Elasticities, Study Area Residents Only, HBW by GSeC

In the notation above, this is VKM(Sf | P in study area) / VKM(Sb | P in study area)

GSeC	AM Peak 07:00-10:00	Inter Peak 10:00-16:00	PM Peak 16:00-19:00	12 hour 07:00-19:00
Full Time				
GSec1	-0.04	-0.19	-0.09	-0.09
GSeC2	-0.04	-0.19	-0.09	-0.09
GSeC3	-0.14	-0.30	-0.21	-0.20
GSeC4	-0.29	-0.47	-0.40	-0.36
All Full Time	-0.12	-0.27	-0.18	-0.17
Part Time				
GSec1	-0.04	-0.19	-0.09	-0.09
GSeC2	-0.04	-0.19	-0.09	-0.09
GSeC3	-0.14	-0.29	-0.20	-0.19
GSeC4	-0.31	-0.48	-0.41	-0.38
All Part Time	-0.18	-0.33	-0.25	-0.23
All HBW	-0.13	-0.28	-0.19	-0.18

Table 7-16 and Table 7-17 relate to the HAM matrices (F and B) which are actually assigned, and the trips on the HAM network. The HAM matrix responses reported in Table 7-16 are not entirely comparable to the synthetic responses above, as the former refers to trip origins while the latter refers to residents. Also, the HAM matrix elasticities are based on the 1-hour assignments. (Note that although D-series and earlier realism test presented only internal-to-internal movements from the HAM in Table 7-16, they have now been updated to present a more comparable internal-to-all subset of the matrix (i.e. internal origins).) In the AM Peak, the results are -0.15 in the TDM versus -0.25 here. In the PM Peak, they are -0.24 in the TDM versus -0.22 here. These are close to the acceptable ranges suggested in TAG.

The HAM network elasticities, shown in Table 7-17, are lower than the matrix-based calculation. The link loads whose response are measured in Table 7-17 are *demand flows* from assignment of peak hour matrices, i.e. without SATURN's deferral of queues to subsequent time periods. The results are similar to those presented in Table 7-14 from the TDM, although it is not possible to present an overall 12-hour value because the HAM only includes three single hours. As before, the elasticities vary sensibly across the income groups (with those on lower incomes being more elastic than those on higher incomes), and the patterns across purposes align with the TAG expectations: discretionary trips are higher than the average, EB trips are lower than average, and HBW and HBEd are close to the average.

Table 7-16 - HAM Matrix Car Fuel Cost Elasticities, Internal Origins Only

In the notation above, this is VKM(F | Orig and Dest in study area) / VKM(B | Orig and Dest in study area)

Purpose	User Class	AM Peak 08:00-09:00	Inter Peak 10:00-16:00 average	PM Peak 17:00-18:00
HBW Low Income	UC1	-0.26	-0.37	-0.27
HBW Medium Income	UC2	-0.20	-0.31	-0.22
HBW High Income	UC3	-0.15	-0.26	-0.16
HBW - all incomes	UC1-UC3	-0.18	-0.29	-0.19
Education	UC4	-0.31	-0.31	-0.32
EB	UC5	-0.10	-0.08	-0.03
Other Low Income	UC6	-0.54	-0.44	-0.41
Other Medium Income	UC7	-0.42	-0.39	-0.30
Other High Income	UC8	-0.32	-0.38	-0.22
Other - all incomes	UC6-UC8	-0.43	-0.40	-0.32
All light vehicles	UC1-UC8	-0.25	-0.35	-0.22

Table 7-17 - HAM Network Car Fuel Cost Elasticities, on Links in Study Area

Purpose	User Class	AM Peak 08:00-09:00	Inter Peak 10:00-16:00 average	PM Peak 17:00-18:00
HBW Low Income	UC1	-0.21	-0.34	-0.22
HBW Medium Income	UC2	-0.16	-0.33	-0.19
HBW High Income	UC3	-0.11	-0.24	-0.17
HBW - all incomes	UC1-UC3	-0.14	-0.28	-0.18
Education	UC4	-0.25	-0.30	-0.23
EB	UC5	-0.01	-0.07	-0.05
Other Low Income	UC6	-0.38	-0.41	-0.40
Other Medium Income	UC7	-0.27	-0.34	-0.24
Other High Income	UC8	-0.17	-0.27	-0.17
Other - all incomes	UC6-UC8	-0.29	-0.34	-0.28
All light vehicles	UC1-UC8	-0.18	-0.31	-0.21

7.7.2.1. Sensitivity Test

Given the low elasticity responses to the car fuel cost increase of 10% reported above, TAG guidance (M2.1, paragraph 6.4.12) recommends an increase of 20% also to be tested. This has been carried out as an additional sensitivity test, with the results shown in Table 7-18. This test converged with a gap value of 0.085%. These results are directly comparable with those for the 10% fuel cost increase shown previously in Table 7-14. This test exhibits the same patterns as the earlier test, but crucially the overall elasticity result is -0.25, which is within the bounds indicated by the guidance.

Table 7-18 - TDM Car Fuel Cost Elasticities (20% increase), Study Area Residents Only

In the notation above, this is VKM(Sf | P in study area) / VKM(Sb | P in study area)³⁷

³⁷ See 7.5.4 for the definition of this terminology.

Purpose	AM Peak 07:00-10:00	Inter Peak 10:00-16:00	PM Peak 16:00-19:00	12-hour 07:00-19:00
HBW Low Income	-0.22	-0.38	-0.29	-0.27
HBW Medium Income	-0.17	-0.32	-0.24	-0.22
HBW High Income	-0.12	-0.27	-0.18	-0.17
HBW – all incomes	-0.15	-0.30	-0.21	-0.20
Education	-0.31	-0.31	-0.31	-0.31
EB	-0.02	-0.05	-0.07	-0.04
Other Low Income	-0.26	-0.53	-0.48	-0.45
Other Medium Income	-0.17	-0.33	-0.33	-0.30
Other High Income	-0.09	-0.23	-0.20	-0.20
Other – all incomes	-0.20	-0.35	-0.36	-0.32
All light vehicles	-0.16	-0.31	-0.26	-0.25

7.7.3. Public transport fare responses

The public transport fare elasticity test results are shown in Table 7-19. This test converged with a gap value of 0.092%, which is well within the 0.2% required. The majority of the results fall within the range recommended by TAG M2.1 (6.4.21), which is from -0.2 to -0.9. The 12-hour average is -0.43, which is comfortably in the range. The HBW and discretionary/other elasticities decrease with increasing income, as would be expected.

Table 7-19 - Public Transport Own-Cost Elasticity

In the notation above, this is $\text{Trips}(\text{Sf} | \text{P in study area}) / \text{Trips}(\text{Sb} | \text{P in study area})$

Purpose	AM Peak 07:00-10:00	Inter Peak 10:00-16:00	PM Peak 16:00-19:00	12 hour 07:00-19:00
HBW Low Income	-0.72	-0.56	-0.41	-0.57
HBW Medium Income	-0.62	-0.45	-0.32	-0.46
HBW High Income	-0.50	-0.35	-0.23	-0.35
HBW - all incomes	-0.56	-0.40	-0.27	-0.41
Education	-0.37	-0.39	-0.37	-0.37
EB	-0.11	-0.14	-0.22	-0.15
Other Low Income	-0.45	-0.72	-0.77	-0.69
Other Medium Income	-0.25	-0.43	-0.46	-0.41
Other High Income	-0.13	-0.25	-0.27	-0.24
Other - all incomes	-0.32	-0.54	-0.55	-0.51
All purposes	-0.40	-0.48	-0.38	-0.43

7.7.4. Car own-time responses

The car own-time trip elasticities are shown in Table 7-20, based on a single model cycle as specified above. The number of car trips made decreases with an increase in journey times for all purposes, with an overall 12-hour elasticity of -0.15 (which is well within the TAG recommendation of being negative and smaller in magnitude than -2.0).

Table 7-20 - Demand Model Synthetic Matrix Car Own-Cost Elasticity (Car trips with respect to an increase in journey times)

In the notation above, this is Trips(Sf | P in study area) / Trips(Sb | P in study area)

Purpose	AM Peak 07:00-10:00	Inter Peak 10:00-16:00	PM Peak 16:00-19:00	12 hour 07:00-19:00
HBW	-0.25	-0.15	-0.21	-0.22
Education – School	-0.37	-0.37	-0.37	-0.37
Education – Higher	-0.19	-0.19	-0.19	-0.19
Education	-0.35	-0.34	-0.33	-0.35
HBEB	-0.05	-0.05	-0.11	-0.07
NHBEB	-0.07	-0.06	-0.04	-0.06
Total EB	-0.05	-0.05	-0.10	-0.07
HBPS	-0.07	-0.09	-0.12	-0.09
HBRV	-0.10	-0.12	-0.16	-0.13
NHBO	-0.12	-0.04	-0.06	-0.05
Total Other	-0.09	-0.09	-0.13	-0.10
All purposes	-0.21	-0.11	-0.17	-0.15

The overall elasticity to car journey time is relatively low, and suggests a response about 60-65% as elastic as for fuel costs. These responses are very similar overall to the D-series model. In terms of trip purposes, commuting is slightly less elastic (-0.22 vs -0.24), Education elasticity is slightly higher (-0.35 vs -0.30) and the Other elasticity higher (-0.10 vs -0.08).

8. Public Transport and Cycle Calibration and Validation

8.1. Introduction

This chapter describes the data available for verification of non-car modes in 2015 and 2019, and how the model compares to those observations. Data was available for comparisons against bus patronage, P&R usage, rail station usage and cycling volumes in and around Cambridge, as detailed in Section 8.2.

The validation of the public transport and cycle assignment models can also be regarded as an indirect validation of the sub-mode choice in the transport demand model, as it is the demand matrices produced by these up-stream models that give rise to the link loads. All modelled values presented in this chapter relate to the 12-hour demand model, comprising three hours of AM Peak (07:00-10:00), six hours of Inter Peak (10:00-16:00) and three hours of PM Peak (16:00-19:00).

Section 8.3 analyses the observed bus data and finds evidence that the surveys may be underestimating the true bus patronage levels, for a number of reasons. It then goes on to consider the comparability of the observed and modelled data – the most notable difference being the absence of dedicated school buses from the model. The results show that the broad patterns of bus passenger trips are correct, and the modelled values are higher than the observed (which is to be expected, given the earlier analysis suggesting that the observed data is an underestimate). The patronage for Guided Bus journeys is a more straightforward comparison (the issues with missing survey data and dedicated school buses do not arise here), and here the modelled values are a good match to the observations.

More detailed analysis of the bus patronage in different corridors (broadly, approaching Cambridge from the north, east, south or west) suggests that trips from the north and east are captured reasonably well, but the model shows too many bus trips from the west and south.

P&R and P&A usage has been compared against three separate data sources in Section 8.4. These comparisons show that the model validates reasonably well in terms of the spread across sites. However, the model estimates are low compared with traffic and parking counts, but high compared to ridership counts. This may illustrate the uncertainty or variation in observed data, or indicate that car occupancies for P&R are lower than for other car-based trips.

Section 8.5 compares the modelled rail usage against the two available data sources, and finds that the model generally gives a good representation of the balance between stations. There seem to be some issues with the observed data at Cambridge station – the two sources give conflicting evidence. Even so, the model appears to underrepresent rail trips to and from Cambridge station, particularly for non-commuting purposes. Other stations validate reasonably well.

The observed cycle link count data are single-day counts so naturally have a large confidence interval. In this context, it is difficult to draw conclusions about the cycle link flow validation, although the Census data (Section 7.3) suggested the model was performing well. The cycle network coverage has been reviewed with CCC and deemed to be sufficient, and the attractiveness of cycling in and around Cambridge has been captured as well as possible in a strategic multi-modal model. In addition, as part of the F-Series model release as described in section 6.2 above, different weights to the cycle generalised costs have been assigned to different types of cycle infrastructure to take into account people's behaviours when making route and mode choices when cycling on safer or less safe paths. Overall, the validation of cycle trips has improved considerably compared with CSRM1, and represents the high levels of cycle use in Cambridge, across a variety of locations. However, it is recognised that the observed data remains variable, and the different types of cycle trip in Cambridge are hard to represent in the model. For example, cycle access trips to other modes, short cycle trips, and use by students are all very hard both to quantify and to represent.

In summary, the model provides a sensible comparison with the data available, within the apparent limitations of that observed data.

8.2. Data Availability

The following sources of observed data are described in this chapter and used for comparison against model results:

- November 2015 bus survey, commissioned by Cambridgeshire County Council (CCC) and delivered by WSP;

- Bus ticket sales data from Stagecoach, also covering November 2015;
- 2014/15 and 2018/19 estimates of rail station usage published by the Office of Rail and Road (ORR), derived from rail ticket sales data;
- Rail passenger count surveys at Cambridge station, supplied by DfT and derived from 2014 counts by Great Northern (Govia Thameslink Railway), Greater Anglia and Arriva CrossCountry. Since 2018, Cambridge station became one of the monitored UK stations and the data for the 2019 usage has been made available online; and
- CCC cycle surveys for Cambridge and the surrounding area.

8.3. Bus

8.3.1. Bus survey and Stagecoach ticket data (including Park & Ride buses)

The two main sources of bus data were a survey conducted in November 2015 and Stagecoach ticket sales data for the whole of November 2015.

The survey was commissioned by CCC through WSP, and was conducted by Tracsis. It was a questionnaire that collected data on start and end point, time of day, purpose, traveller type and number of bus trips per week. It was handed out to bus passengers in Cambridgeshire on each route between 7am and 7pm. Passengers were offered an incentive to complete the survey.

The Stagecoach ticket sales data was provided by WSP from Stagecoach on 10 January 2016 and covers all Stagecoach bus tickets sold in Cambridgeshire in November 2015. This data has been used in conjunction with the surveys to provide an estimate of the survey sample rate for Stagecoach routes, and to expand the survey data to provide a bigger picture of bus passenger movements across the study area.

As part of the 2019 present year validation exercise, the same ticket sales dataset was provided by Stagecoach for October and November 2019. Unfortunately, due to lack of surveys in 2019, it has not been possible to use this database in the same way as it cannot be expanded to origin-destination movements. An analysis between 2015 and 2019 tickets selling data, showed an overall decline in number of tickets sold. However, this is related to the fact that people use more contactless payments rather than purchasing the tickets, which is not captured in the Stagecoach ticket selling data – so does not necessarily provide any indication of a change in patronage.

Table 8-1 shows a comparison between the number of survey results obtained on each route and the ticket data by route. The average percentage of surveyed passengers is 14% but varies significantly over the different routes, as shown.

The ticket sales data gives information on the date, route, direction, time (half hour period), board stage and the number of tickets sold. No destination is given, but the information is believed to reasonably capture bus boardings including each time a multi-trip ticket is used (e.g. MegaRider, or return leg), as the driver records the boarding. To determine the number of people on the service on an average day, only the data from Tuesday to Thursday in the four full weeks of November was used. There are no school or university holidays during November, so these did not need accounting for. Analysis showed that this gave a reasonable representation of the average number of passengers per day.

By combining the survey data and ticket sales data, the number of passengers crossing the Cambridge Radial Cordon³⁸ were estimated. This was done by scaling the ticket sales by proportions from the survey to suggest the number of passengers that crossed this cordon. This could then be compared to the modelled number of bus passenger journeys crossing over the same cordon.

³⁸ The Cambridge radial cordon is the same cordon used consistently in the HAM validation and the cycle validation: Figure 8-1 shows this cordon (number 3) along with others used in the HAM validation.

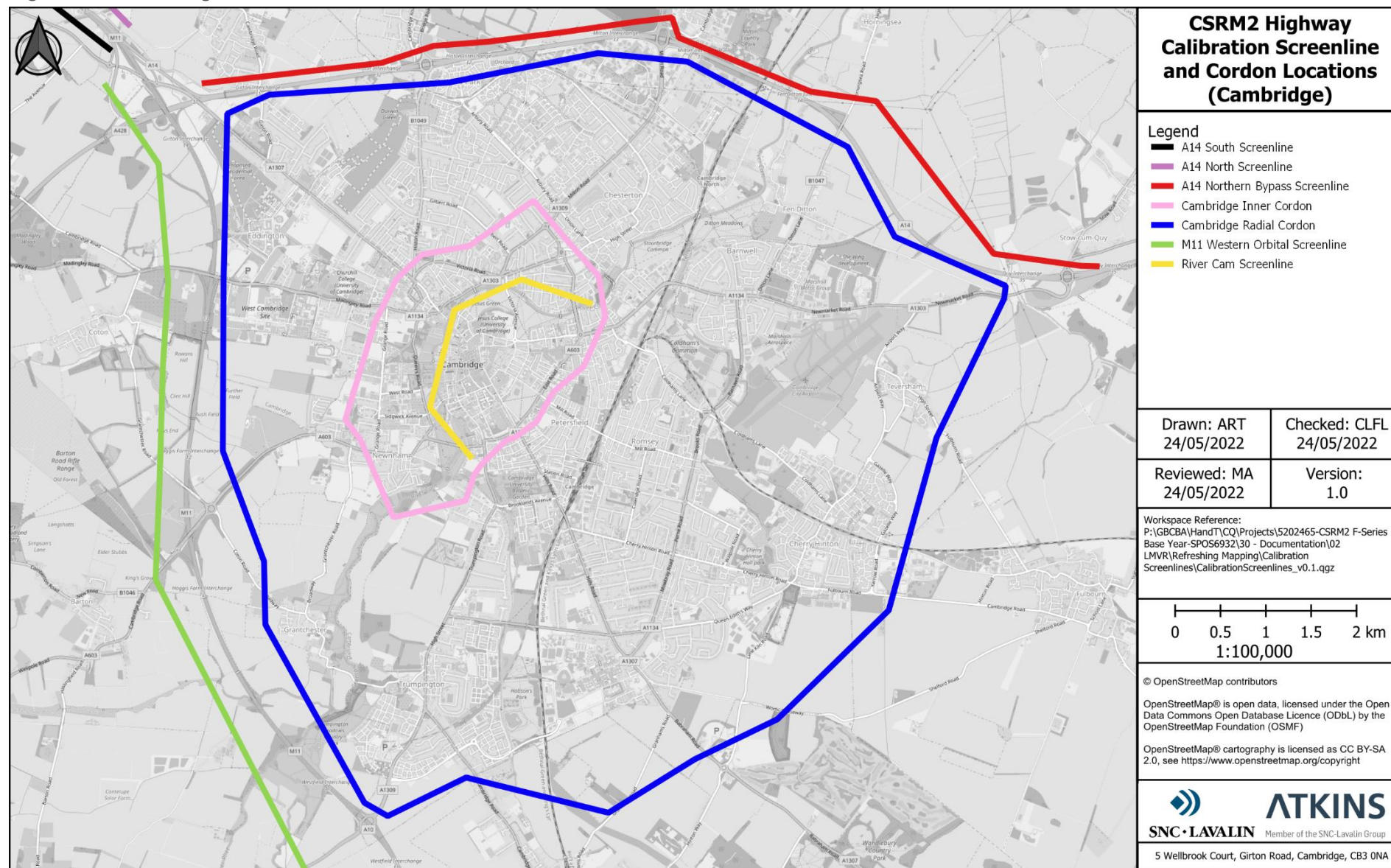
Table 8-1 - Bus Survey Sample Rates

Route No.	Survey Date(s)	Total Valid Survey Results	Average ticket sales per day on the date(s) of Route Survey	Percentage of passengers surveyed
Citi 1	18/11/2015	792	7,762	10%
Citi 2	03/11/2015	580	4,390	13%
Citi 3	18/11/2015 & 19/11/2015	698	5,153	14%
Uni 4	17/11/2015	167	1,056	16%
Citi 4	03/11/2015	434	1,477	29%
Citi 5	04/11/2015	211	1,721	12%
Citi 6	04/11/2015	166	822	20%
Citi 7	04/11/2015	207	2,469	8%
Citi 8	10/11/2015	282	2,818	10%
9	24/11/2015	303	1,621	19%
10	23/11/2015	157	745	21%
11	23/11/2015	161	753	21%
12	24/11/2015	205	997	21%
13 / 13A	12/11/2015 & 16/11/2015 & 17/11/2015	664	2,895	23%
15 / 15A	11/11/2015	37	130	28%
16A	16/11/2015	11	60	18%
17	17/11/2015	44	269	16%
18	12/11/2015	123	737	17%
26	17/11/2015	139	427	33%
30	23/11/2015	47	241	20%
35	23/11/2015	56	283	20%
66	11/11/2015	142	491	29%
77 (Red P&R)	16/11/2015	441	2,846	16%
88 (Blue P&R)	04/11/2015	295	2,059	14%
95	24/11/2015	45	76	59%
99 (Green P&R)	10/11/2015	406	3,499	12%
A	11/11/2015	623	6,088	10%
B	12/11/2015	666	5,540	12%
X5	19/11/2015	403	3,787	11%
R	17/11/2015	67	300	22%
31	17/11/2015	25	N/A (Go Whippet service)	
75	17/11/2015	28	N/A (Go Whippet service)	
Total		8,625	61,512	14%

Source of passenger survey: Commissioned by CCC, via WSP; carried out by Tracsis

Source of ticket sales data: Stagecoach

Figure 8-1 - Cambridge Radial Cordon and other HAM screenlines and cordons



Review of bus data

There were some shortfalls in the use and analysis of this data:

- Some of the ticket sales data and survey data was lost because it contained errors or could not be classified into zones. Approximately 5.5% of the Stagecoach ticket data was discarded due to this; and
- As the ticket data was only from Stagecoach, passenger numbers on Go Whippet and other bus services were not included in the ticket sales data.

In particular, services which either had no survey results, or are not run by Stagecoach in Cambridge include 27, 16A, X8, U4, 1, 2, 3, 8, 15, 75, 110, 114, 196, 1A, 7A, X5 and X3.

The Cambridgeshire Annual Traffic Monitoring Report³⁹ suggests that the total number of guided bus journeys in 2015 was 3.65 million (paragraph 10). The equivalent figure from the Stagecoach ticket data was 3.33 million, which is approximately 9% lower. This gives an indication of the scale of the shortfall in the bus patronage estimated from the ticket sales data, and provides some context for analysing the results from the model.

Ticket sales data was also provided by Stagecoach for the whole year of 2014. This allowed investigations into the variability by month. By analysing the Mean and Standard Deviation of this data, the 95% confidence interval for the number of passengers is the mean plus or minus 9% of the overall ticket sales.

8.3.2. Model values for comparison

The modelled passenger totals are extracted from all links with bus trips crossing over the observed cordon, so they are “like with like” comparisons with the observed data from the buses surveyed.

Time of day definition

Both the model and the Stagecoach ticket data define time periods by time of departure whereas the survey has used the midpoint of each trip to determine the time period. This inherently creates a small mismatch, but it is not expected to have much impact on the comparisons and results. In addition, buses running late will tend to push observed passengers later in the day than they would be in the model, but this effect is also expected to be small.

School buses

It has not been possible to include school contract buses in the model, as there is not sufficient information available about these routes. Education trips are generated and assigned within the model, and do have the opportunity to use bus services where they are coded, but the split between “public” and “dedicated” bus services is not currently modelled.

For movements into schools in Cambridge this may provide a reasonable level of journey options for many pupils. It does raise a number of issues for comparison against the model:

- The assigned loads by service include school pupils, which should not be taken to imply that they are on those services “in reality” given that there are some dedicated bus services into Cambridge. The analysis below (Section 8.3.3) shows education trips separately, to allow a judgement to be made about the validity of the modelled bus flows in light of the absence of dedicated school buses in the model.
- In some more rural zones, public bus service levels are poor but dedicated school buses are provided. Given the lack of dedicated school buses in the model, this would lead to a lower bus mode share for pupils from those areas, and should be kept in mind when interpreting the results.
- Rail is an important mode choice for some independent schools in Cambridge, but is not a mode choice that is observed for public schools in the national data. The education mode specific constants in the model encourage parents to drive their children to local rail stations in order to access these Cambridge schools. It may be that the model over-estimates rail use by school pupils as a result. Blocking off these rail modes without providing school buses causes unnecessarily high car use for education in those zones, so it has been left as compromise solution in the current version of the model.

8.3.3. Model comparison against bus survey data

This section provides analysis of the comparisons between the observed data (from the passenger survey and Stagecoach ticket data described above) and the modelled bus passenger journeys over the Cambridge Radial

³⁹ https://ccc-live.storage.googleapis.com/upload/www.cambridgeshire.gov.uk/residents/travel-roads-and-parking/Traffic_monitoring_report_2015.pdf?inline=true, retrieved 7th December 2017

Cordon (see Figure 8-1). Analysis is also presented on the four corridors; North, East South and West. This is in order to check the relative proportions from the different directions.

Figure 8-2 shows a comparison between the modelled and observed bus passenger trips (Stagecoach ticket data) over the Cambridge Radial Cordon (including Guided Bus and P&R services where they cross the cordon). Education trips have been shown separately as school buses are not included in the observed data (but some school pupils will travel on public buses). This graph shows that the general pattern of modelled totals is broadly correct. The modelled values are always higher in total than the observed data, but this is to be expected due to the missing observed data, as mentioned above.

Figure 8-2 - Comparison between modelled and observed bus passenger journeys, Cambridge Radial Cordon

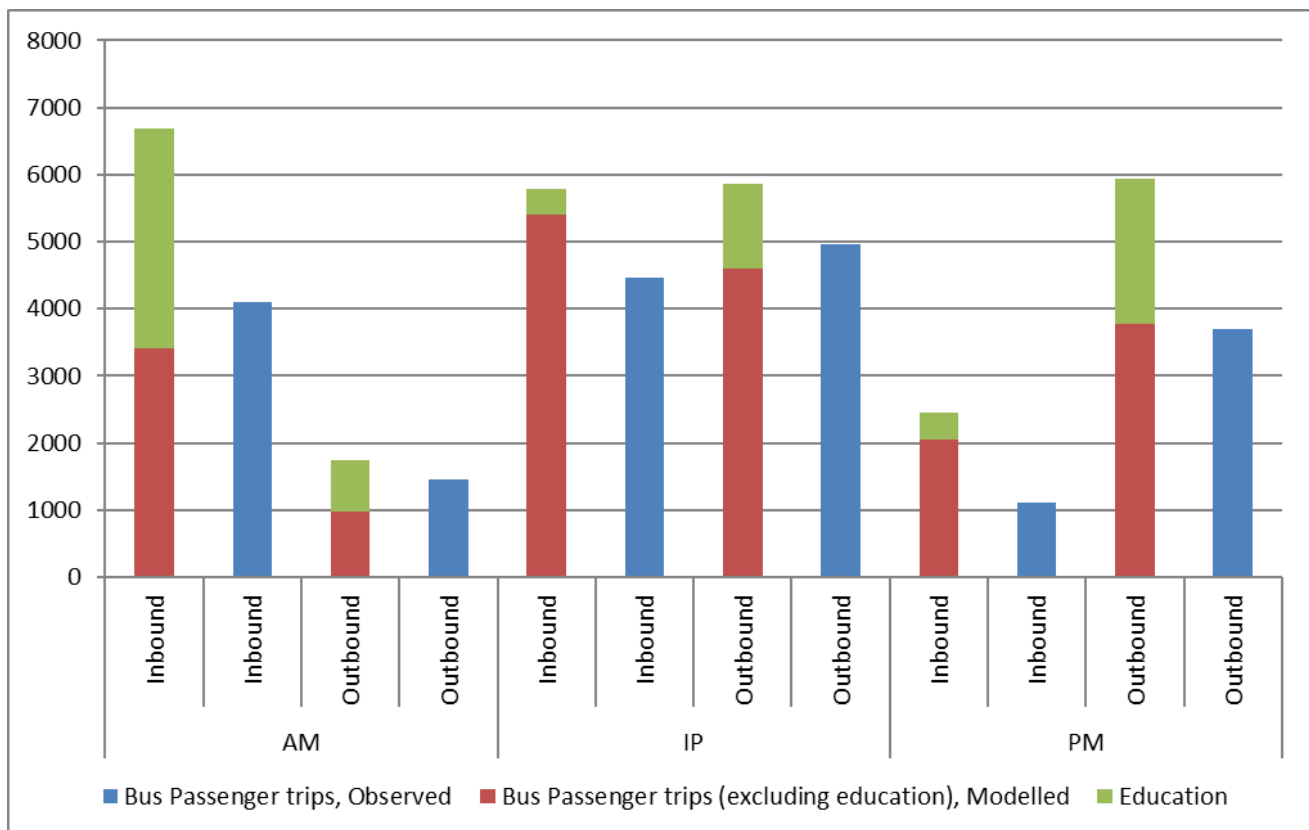


Table 8-2 shows the values given in the graph above, for trips excluding education.

Table 8-2 - Comparison between modelled and observed bus passenger journeys, Cambridge Radial Cordon, excluding education

Time Period	Direction	Modelled Bus Passengers	Observed Bus Passengers	Percentage difference
AM	Inbound	3,408	4,099	-17%
	Outbound	984	1,464	-33%
IP	Inbound	5,402	4,464	21%
	Outbound	4,591	4,967	-8%
PM	Inbound	2,057	1,118	84%
	Outbound	3,778	3,700	2%
Totals	Inbound	10,866	9,681	12%
	Outbound	9,352	10,131	-8%

Figure 8-3 shows the equivalent comparison for Guided Buses in isolation. Here the model and the observed data can be compared directly (as the missing observed Whippet services represent only a very small proportion of all buses on the busway, and it is understood there are no guided school buses so any education trips are genuinely on the public buses) and are similar. Table 8-3 shows the values given in this graph.

Figure 8-3 - Comparison between modelled and observed Guided Bus passenger journeys, Cambridge Radial Cordon

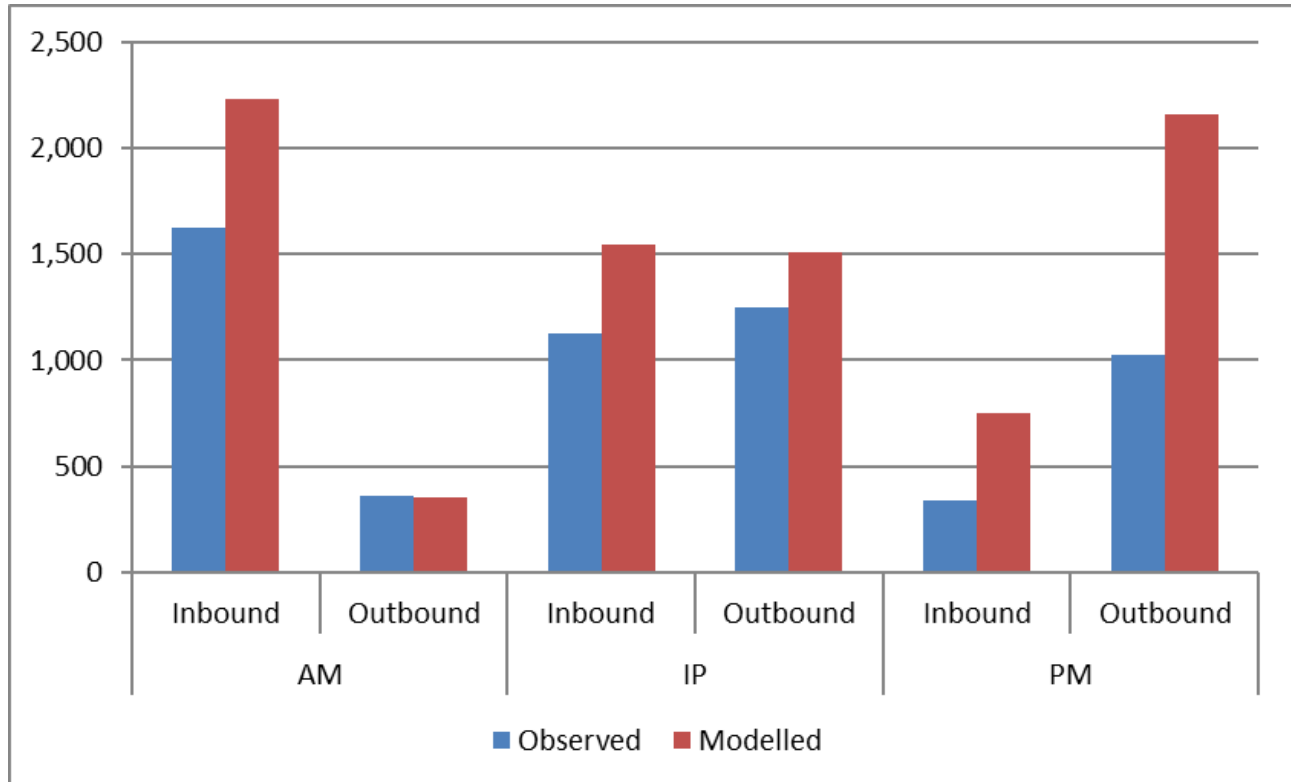


Table 8-3 - Comparison between modelled and observed Guided Bus passenger journeys, Cambridge Radial Cordon

Time Period	Direction	Modelled Guided Bus Passengers	Observed Guided Bus Passengers	Percentage difference
AM	Inbound	2,231	1,621	38%
	Outbound	357	362	-1%
IP	Inbound	1,542	1,124	37%
	Outbound	1,509	1,246	21%
PM	Inbound	748	340	120%
	Outbound	2,155	1,021	111%
Totals	Inbound	4,521	3,086	47%
	Outbound	4,021	2,629	53%

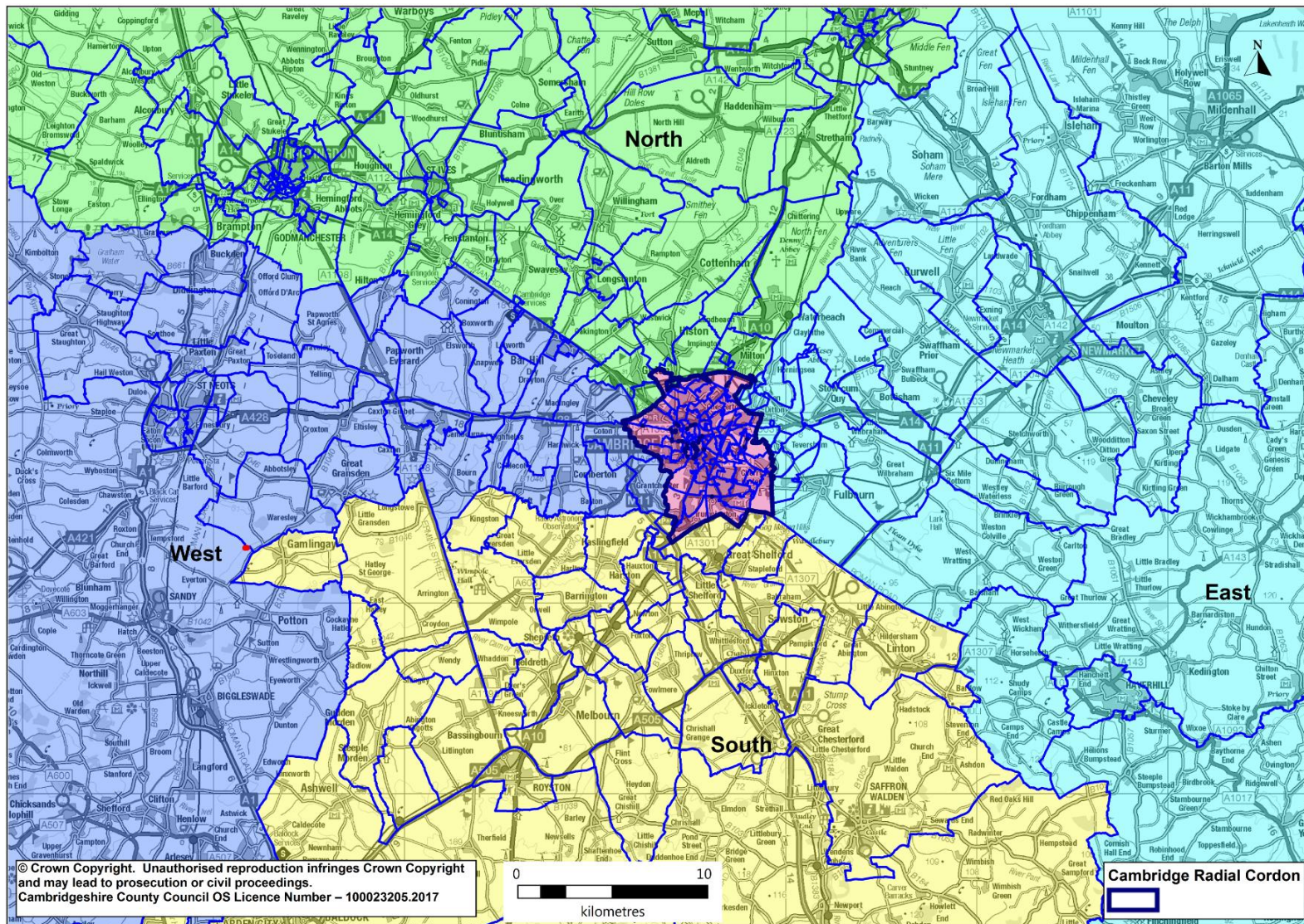
Analysis of the proportion of journeys entering Cambridge across the Cambridge Radial Cordon on each corridor (North, East, South and West) is shown in Table 8-4, comparing the observed ticket sales/survey data and the equivalent modelled totals over links. Education trips are included in these comparisons. Figure 8-4 shows the regions defined as North, South, East and West for the purpose of this analysis.

Overall, the proportions of bus trips to Cambridge from the north and east match the observed data reasonably well, but there appear to be too many modelled bus trips from the west and south.

Table 8-4 - Comparison between directional distribution of bus trips into Cambridge

Trip Origin	Observed			Modelled		
	AM	IP	PM	AM	IP	PM
North	49%	44%	48%	44%	24%	19%
East	31%	33%	30%	19%	30%	30%
South	12%	10%	15%	21%	23%	30%
West	8%	13%	7%	15%	22%	21%
Total	100%	100%	100%	100%	100%	100%

Figure 8-4 Map showing the North, East, South, West division for bus corridor analysis



8.4. Park & Ride

The term “Park & Ride” (P&R) generically refers to all users of P&R sites, but there are some important distinctions to be made between different types of P&R user.

- “Standard” P&R usage is to drive from home to the P&R site and then catch a bus to the ultimate destination (and then the same in reverse – catch a bus back to the same P&R site and then drive home). This is referred to as “Park & Bus” for clarity in the text below.
- “Kiss & Ride” refers to people who are dropped off at the P&R site (either by a formal taxi, or a lift from friends/family) – so they do arrive at the P&R site by car and depart by bus (and vice versa on the return journey), but they don’t leave a car parked in the car park.
- “Park & Active” (P&A) describes those P&R users who drive to the P&R site and park their car, but then complete their journey by walking or cycling to their destination instead of catching a bus. Data suggests this is a significant proportion of P&R site usage at some sites.
- “Walk/Cycle & Bus” refers to users who arrive at the P&R site by walking or cycling – so they do not park a car in the car park – but then complete their journey by bus. Again, data suggests this is a significant proportion of P&R site usage at some sites.
- It is also possible in some cases for users to interchange between bus services at P&R sites (e.g. from the number 5 service to a guided bus service at Longstanton P&R site) – but this is understood to be relatively uncommon and would be a pure public transport journey in modelling terms, so is not further considered here.

As discussed in section 1.1, the F-series of CSRM2 has made significant enhancements to the representation of P&R trips in the model, by adding P&A as a mode choice and by making use of additional data (not available when CSRM2 was originally built) to improve the calibration and validation of P&R site usage.

There were four sets of observed data relating to P&R flows. For the purposes of model calibration and validation, all of these datasets are considered at a 12-hour level (07:00-19:00) without any breakdown of individual time periods:

- **Stagecoach ticket data (“observed bus passenger flows”)** – gives the number of ticket sales at each P&R site for Stagecoach services. This dataset is available for both 2015 and 2019. Note that the Guided Busway P&R sites (Longstanton and St Ives) are also served by some Whippet bus services, so the observed number of bus passengers at these sites should be lower than the model.
- **P&R site inbound vehicle counts (“observed vehicle flows”)** – these traffic counts were collected at each P&R site for the validation of the HAM, giving total numbers of vehicles into each site over a 12-hour period. The data for Trumpington P&R was modified to remove trips accessing the John Lewis depot, by calculating the observed “bus passengers per vehicle” ratio at Babraham Road P&R and applying this to the observed Trumpington P&R bus passengers. This dataset is available for 2015 and 2019
- **CCC car parking data (“observed car parking”)** – provides the total number of cars parking in each of the city P&R Sites in May 2015 (total across the whole month). In order to calculate a 12-hour average car park usage, these monthly totals were assumed to be spread equally over six days (Monday to Saturday) with no overnight stays. Due to this assumption of no cars on a Sunday, it is likely that this data slightly overestimates the number of cars on each weekday. This dataset is not available for the Guided Busway P&R sites, nor for 2019. However, it provides a useful additional datapoint for the city sites in 2015, for comparison with the vehicle flows.
- **P&A usage** – further data collected in November 2018 was used to examine the significance of “non-standard” usage of P&R sites and has further been used to enhance the calibration of the model by calculating the proportion of car arrivals which continued their journey by walk or cycle instead of bus. This data was only available for three of the P&R sites (Trumpington, Babraham Road and Madingley Road), but gives a useful indication of the scale and variability of this type of P&R usage. It is also noted that car parking charges were in force at the P&R sites in 2015 but had been removed by the time these surveys were collected – so the number of P&A trips in 2015 may have been lower due to the disincentive of the parking charge (especially at St Ives, where the car park is commonly used to access the town centre). However, the calculated proportions should be reasonably comparable to the 2019 model.

Each of these datasets have different attributes and allow for a number of different comparisons to be drawn between modelled and observed data. Table 8-5 summarises the attributes of each dataset and the modelled data available for comparison. Since none of the observed data is directly comparable with any of the modelled data, two additional “implied” sets of data have been derived from the observed data, to provide ranges within which the modelled flows could be expected to sit. These are:

- “Implied P&R person flows” – this is calculated from the observed vehicle flow data, assuming the maximum CSRM2 car occupancy (for any purpose) to give a maximum bound in most cases, providing an estimate of the number of people completing their onward journey by bus, walk or cycle after arriving at a P&R site by car; and
- “Implied vehicle flows” – this is calculated from the observed bus passenger data, adding in an allowance for the proportion of P&R car park users who actually walk or cycle rather than catching a bus, and assuming the minimum car occupancy to give a maximum bound again – providing an estimate of the number of vehicles arriving at each P&R site.

Table 8-5 - Attributes of the Observed Datasets and Modelled Data

Data type	Unit	Includes Park & Bus?	Includes Kiss & Ride?	Includes Park & Walk/Cycle?	Includes Walk/Cycle & Bus?
Observed bus passenger flows	Persons	✓	✓		✓
Modelled P&R person flows	Persons	✓	✓	✓	
Observed vehicle flows	Vehicles	✓	✓	✓	
Observed car parking*	Vehicles	✓		✓	
Modelled vehicle flows	Vehicles	✓		✓	
Implied P&R person flows	Persons	✓	✓	✓	
Implied vehicle flows	Vehicles	✓	✓		✓

* NB: for city P&R sites only (not Longstanton or St Ives) in 2015

Figure 8-5 and Figure 8-6 compare the modelled 2015 and 2019 P&R person flows against the observed bus passenger flows and implied P&R person flows, while Figure 8-7 and Figure 8-8 compare the modelled 2015 and 2019 P&R vehicle flows against the observed vehicle flows, observed car parking and implied vehicle flows. When interpreting these charts, the following points have been considered important (drawing on the information presented above):

- For Figure 8-5 and Figure 8-6, the P&R person flows:
 - The observed bus passenger flows are generally expected to be lower than the modelled P&R person flows, except at sites where the number of passengers accessing the site by non-car modes exceeds the level of Park & Walk/Cycle trips. There is no data available to quantify this, but Milton, Longstanton and to some extent St Ives P&R sites have good walk and cycle access to nearby population centres and so we might expect them to be the exceptions to this rule. In addition, Longstanton and St Ives are served by some non-Stagecoach bus services, which would make the observed bus passenger flows even lower.
 - The implied P&R person flows have been calculated as an upper bound by assuming the maximum car occupancy, except again at those sites where there is a high number of people accessing the site by walk and cycle (Milton, Longstanton and perhaps St Ives). In the event, the observed bus passenger flows and implied P&R person flows at these three exception sites are very similar, and so we could simply expect the modelled data to be close to this.
- For Figure 8-7 and Figure 8-8, the P&R vehicle flows:
 - The observed car parking data should exclude Kiss & Ride trips and therefore would be expected to be lower than the observed vehicle flows. No data is available on the volumes of Kiss & Ride usage, so this cannot be quantified – but if the two datasets were otherwise identical, then the car parking should always be strictly lower than the vehicle flows and the car parking data should be directly comparable to the modelled vehicle flows (as they both exclude Kiss & Ride). However, the car parking data was supplied as a single monthly total at each site, and some assumptions had to be applied to convert this to a 12-hour average (as described above) – so it is not a robust dataset.
 - The observed vehicle flows are perhaps a more robust dataset, except at Trumpington where it was processed to remove the John Lewis depot trips. This data is not directly comparable to the modelled P&R vehicle flows, as the observed data includes Kiss & Ride but the modelled data does not – so we would expect the modelled data to be lower than the observed data in the majority of cases.
 - The implied vehicle flows have been calculated as an upper bound by assuming the minimum car occupancy factor, and also factoring in an allowance for cars that were parked for Park & Walk/Cycle

trips rather than Park & Bus. This Park & Walk/Cycle allowance was calculated based on November 2018 data, by which time there were no parking charges at the P&R sites – so is likely to be a generous estimate for 2015. Therefore, the modelled vehicle flows are all expected to fall below these implied vehicle flows.

In the majority of cases in all four charts, the modelled values sit within the expected range of observed values – notwithstanding the inherent differences in each datapoint described above. The biggest anomaly is at the Maddingley Road P&R site in 2019, where it appears the increased development (particularly jobs) on the Cambridge West site has caused many people in the model to park at the P&R site and walk or cycle to Cambridge West. It is understood that there is a University of Cambridge Park & Cycle site with an additional 300 parking spaces at Cambridge West, which is not included in CSRM2 and could account for many of the additional trips using the Maddingley Road P&R site.

Figure 8-5 - Comparison between modelled and observed person flows (2015)

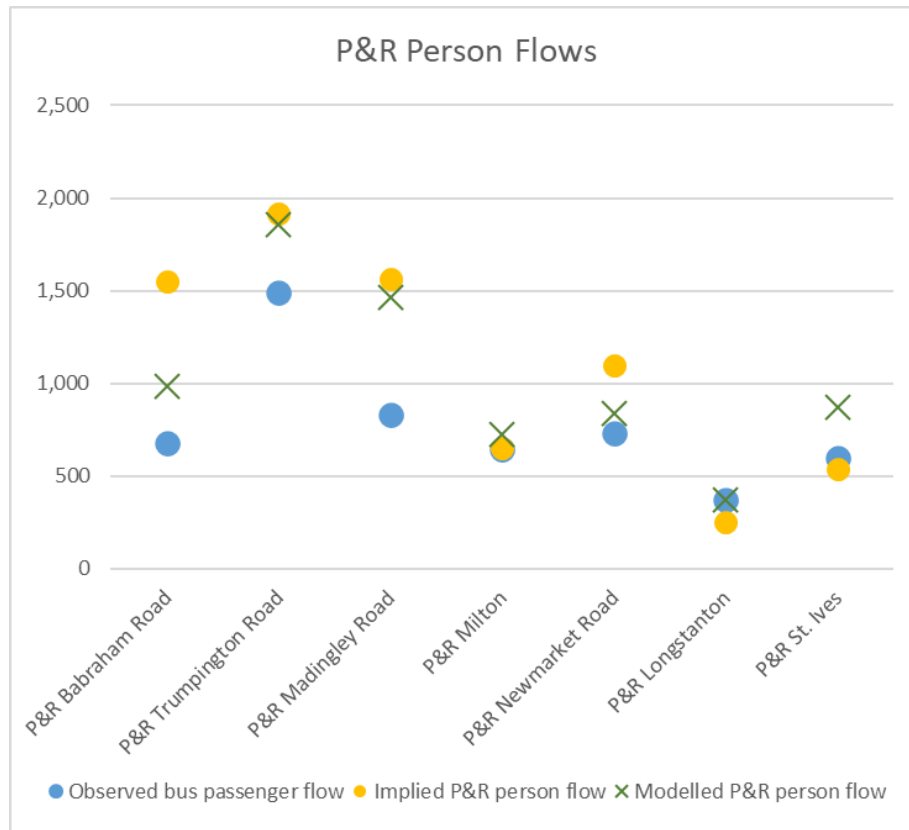


Figure 8-6 - Comparison between modelled and observed person flows (2019)

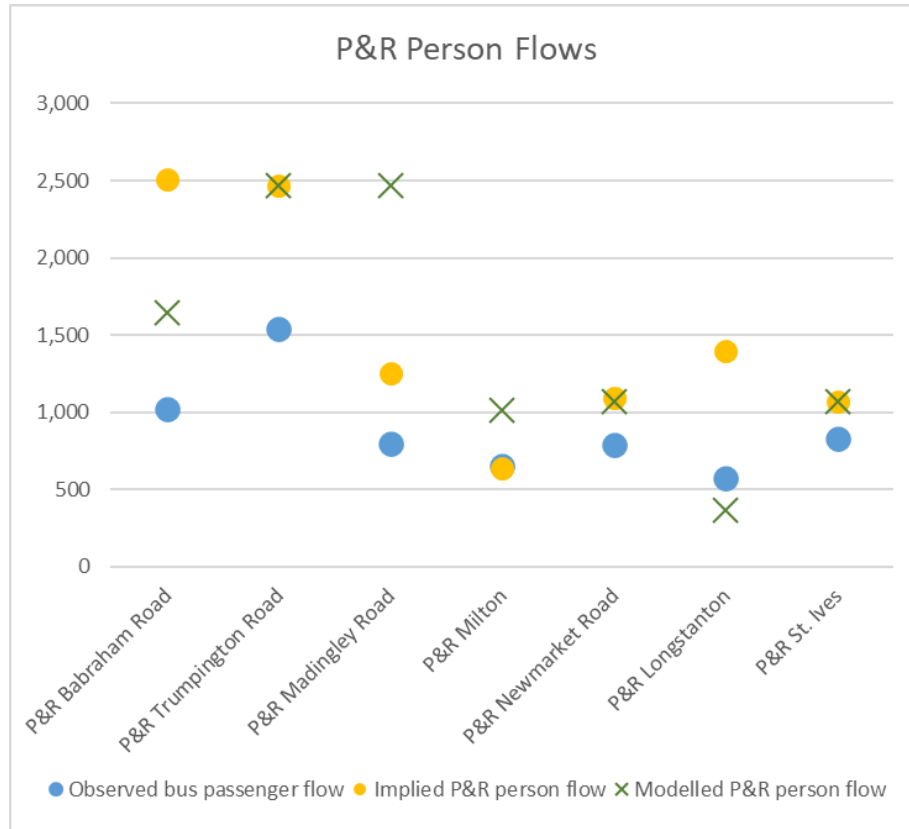


Figure 8-7 - Comparison between modelled and observed vehicle flows (2015)

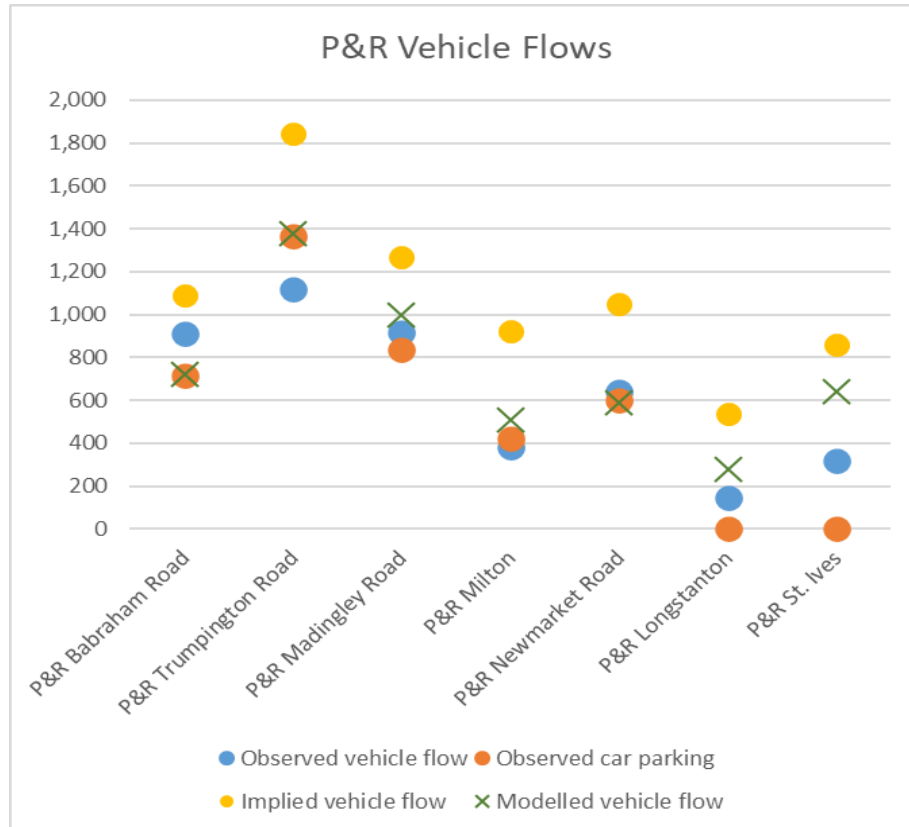
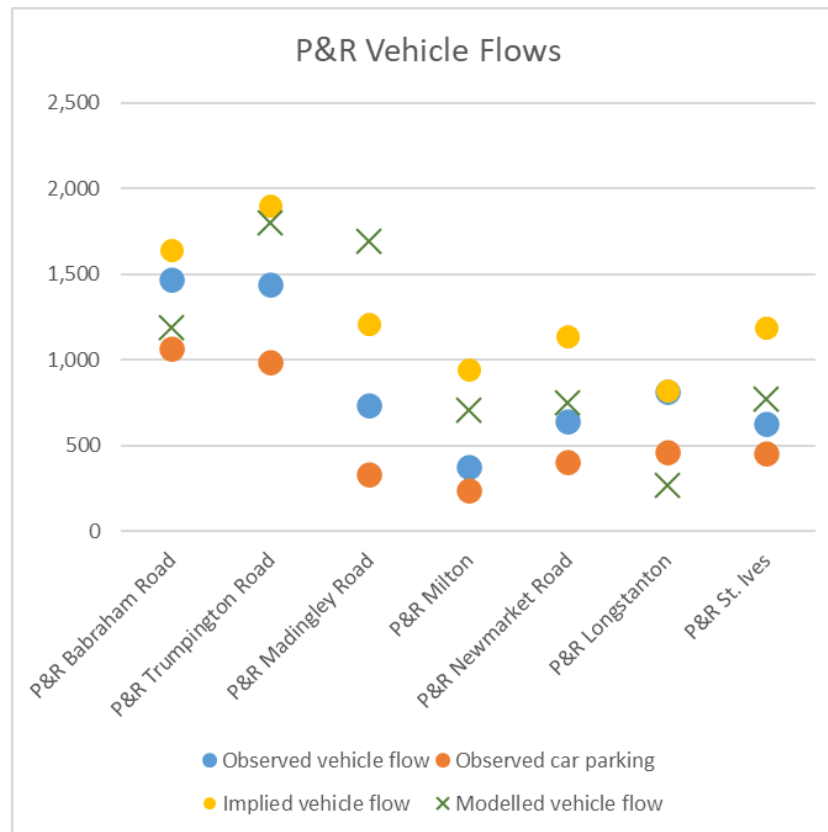


Figure 8-8 - Comparison between modelled and observed vehicle flows (2019)



These comparisons show that the model validates reasonably well in terms of the spread across sites. The introduction of the P&A movements captures movements that were not included before and helps to understand better behaviours at the P&R sites.

8.5. Rail

Table 8-6 and Figure 8-9 compare the Office of Rail and Road (ORR) published 24-hour daily station usage estimates (2014/15) with CSRM2 2015 modelled flows of people entering and exiting each station in 12 hours, while Table 8-7 and Figure 8-10 show the equivalent comparison for the 2019 PYV.

This shows a reasonable match for most stations, except for Cambridge where the CSRM2 value is less than half the ORR value (as was also the case in the E-series and earlier). Although we would expect Cambridge station to have relatively high usage outside of the 12-hour modelled period (approximately 20%), this does not account for the whole discrepancy. However, later comparisons against other datasets suggest there may be an issue with the ORR data in this instance.

The model does not include the whole of the catchment area for Royston station, as it is in an external area: external-to-external trips are not captured in the CSRM2 demand model. Figure 3-19 shows the modelled catchment areas for each station and demonstrates that up to half of the true catchment for Royston station is not included in the model. Therefore, its modelled usage shown below seems reasonable for the trips that would be expected to be captured in CSRM2. The same explanation applies to Newmarket and March – being external stations, the model does not include the whole of their catchment areas; and to some extent St Neots, which is situated at the edge of the modelled area.

The decline in modelled usage at Whittlesford Parkway station between 2015 and 2019 is due to highway congestion discouraging people from accessing the station in the AM peak. However, the HAM peak hour is 08:00-09:00 whereas it is likely that in reality many people access the station earlier than that to travel to London.

Littleport station continues to have higher modelled values than observed, in both 2015 and 2019 (and as it also did in previous series of CSRM2, despite efforts to improve it).

Table 8-6 - Comparison between ORR and CSRM2 daily station usage (2015)

Station	ORR St Usage 2014/15 Total	CSRM2 2015 Total
Main Stations		
Cambridge	40,078	19,583
Huntingdon	6,807	3,817
Royston	5,362	1,905
St. Neots	4,893	3,917
Ely	7,955	7,718
Whittlesford	1,749	2,014
Internal Local Stations		
Foxton	362	629
Shepreth	407	629
Meldreth	1,028	1,230
Shelford	615	953
Waterbeach	1,466	2,150
Littleport	916	1,946
External Local Stations (only trips to study area in model)		
Newmarket	1,114	861
March	1,456	189

Figure 8-9 - Graph showing comparison between ORR and CSRM2 daily station usage (2015)

Note that Cambridge ORR Y-axis has been cut off to allow sensible scale for other stations

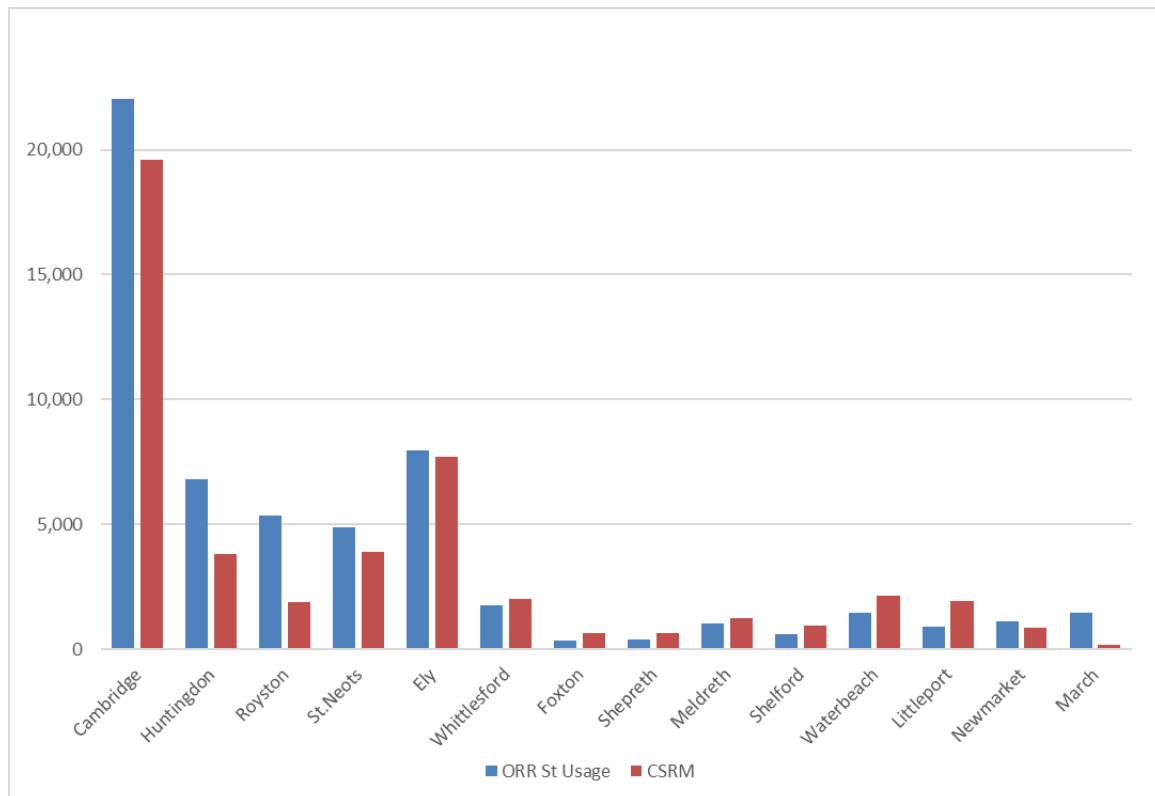


Table 8-7 - Comparison between ORR and CSRM2 daily station usage (2019)

Station	ORR St Usage 2018/19 Total	CSRM2 2019 Total
Main Stations		
Cambridge	46,090	20,609
Cambridge North	3,127	6,360
Huntingdon	6,871	4,050
Royston	5,643	2,264
St. Neots	5,098	3,738
Ely	9,180	8,570
Whittlesford	2,147	1,759
Internal Local Stations		
Foxton	392	531
Shepreth	445	569
Meldreth	1,136	1,162
Shelford	798	2,011
Waterbeach	1,568	2,153
Littleport	957	1,390
External Local Stations (only trips to study area in model)		
Newmarket	1,366	1,182
March	1,569	242

Figure 8-10 - Graph showing comparison between ORR and CSRM2 daily station usage(2019)

Note that Cambridge ORR Y-axis has been cut off to allow sensible scale for other stations

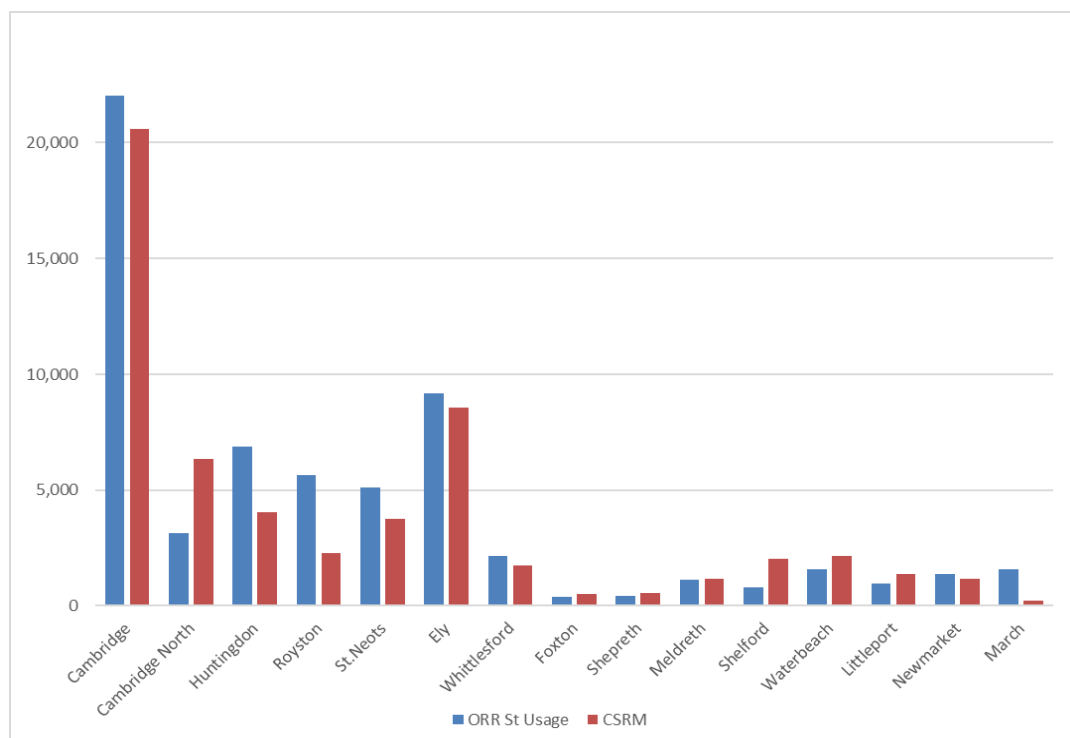


Table 8-8 and Figure 8-11 show the comparison between the DfT passenger counts at Cambridge station (Autumn 2014 and 2019, average weekday) and CSRM2 (number of passengers on trains arriving at and departing from Cambridge station). Note that for this comparison, CSRM2 data represents rail arrivals and departures (not including interchange) whilst the DfT data may include people alighting at Cambridge and switching trains.

This data conflicts with the ORR station usage shown above: if only 33,227 passengers travelled to, from *and through* Cambridge station on trains in 12 hours, then it cannot be true that 40,078 passengers boarded and alighted at Cambridge in 24 hours as this would require an implausibly high level of Off-Peak activity (between 19:00 and 07:00). The same behaviour is shown in the 2019 data.

Notwithstanding doubts about the data sources, the CSRM2 passenger volumes are generally much lower than the observed values. The AM Peak is closer to the observed values, suggesting that commuting trips may be more accurately represented than other purposes (as a large proportion of AM trips are commuting trips). This aligns with the results given in Section 7.3, where the district-level rail mode share for Cambridge City matched the Census very well, and suggests that there is a deficit in trips being made for other purposes by rail to Cambridge station. The interchanges (being present in the DfT data but not the CSRM2 modelled values) may also account for some of the discrepancy.

Table 8-8 - Comparison between DfT Passenger Count and CSRM2, arrivals and departures at Cambridge Station (2015)

	DfT Pax Count (2014)	CSRM2 (2015)	Percentage difference from DfT Pax Count
Arrivals – AM	6,009	6,962	16%
Departures – AM	4,191	3,455	-18%
Arrivals – IP	5,380	2,939	-45%
Departures – IP	5,738	3,372	-41%
Arrivals – PM	5,286	2,922	-45%
Departures – PM	6,623	4,837	-27%
Total	33,227	24,487	-26%

Figure 8-11 - Graph showing comparison between DfT passenger count and CSRM2 for arrivals and departures at Cambridge Station (2015)

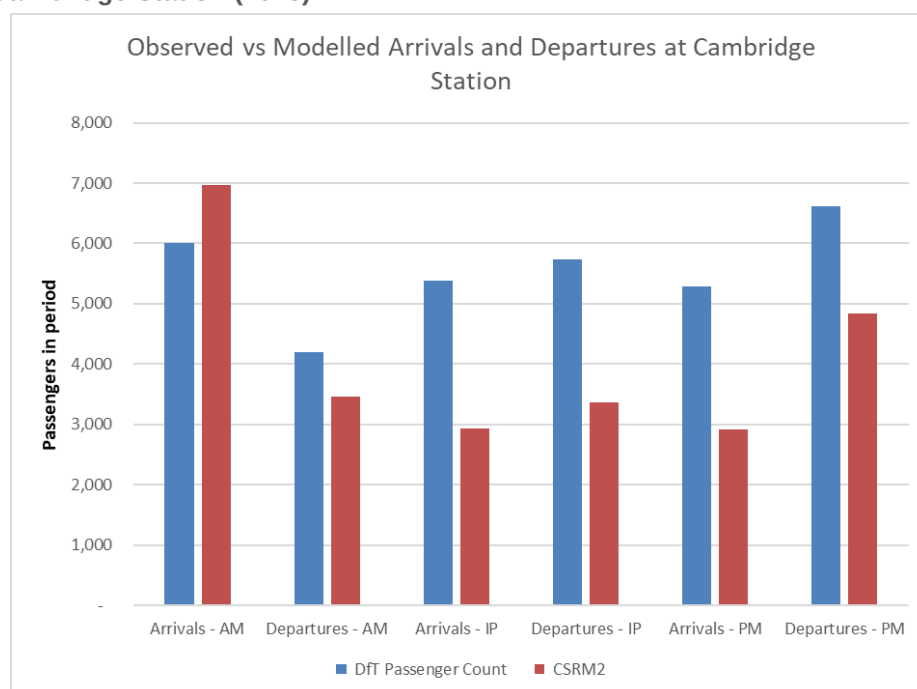
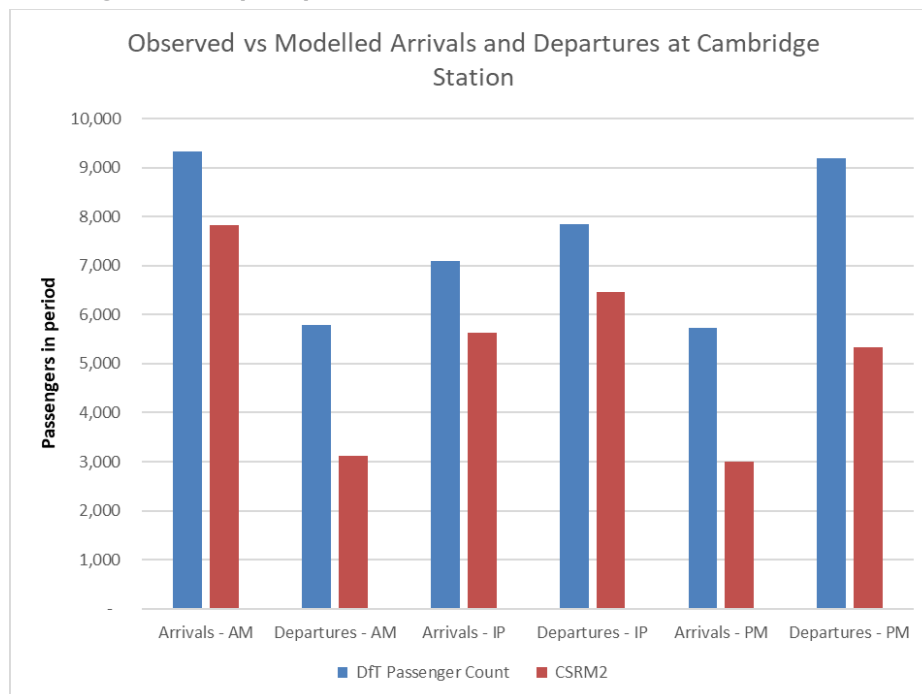


Table 8-9 - Comparison between DfT Passenger Count and CSRM2, arrivals and departures at Cambridge Station (2019)

	DfT Pax Count (2019)	CSRM2 (2019)	Percentage difference from DfT Pax Count
Arrivals – AM	9,320	7,823	-16%
Departures – AM	5,779	3,122	-46%
Arrivals – IP	7,099	5,626	-21%
Departures – IP	7,846	6,464	-18%
Arrivals – PM	5,735	3,004	-48%
Departures – PM	9,186	5,328	-42%
Total	44,965	31,368	-30%

Figure 8-12 - Graph showing comparison between DfT passenger count and CSRM2 for arrivals and departures at Cambridge Station (2019)



8.6. Cycle

Single day cycle count data was provided by CCC for a radial cordon of Cambridge, a river screenline, market towns in Cambridgeshire and the set of Cambridge cycle route monitoring counts. This was originally provided for the years 2011 to 2015, and was more recently also acquired for 2016 and then 2019. Three data sets for cycle trips have been used, as shown in Figure 8-13:

- A radial cordon (which matches the Cambridge Radial Cordon used in the highway validation);
- A river screenline with all links that cross the River Cam in Cambridge City (again, aligning with the River Cam screenline used in the highway validation); and
- The Cambridge Route Monitoring sites on a selection of cycle links around the wider city area.

The River Cam screenline and Cambridge Route Monitoring sites were surveyed by CCC in May 2015 and 2019 during normal term time. The Radial Cordon was surveyed in September 2015 before the university term and October / November 2019. This means that university students were included in the modelled output, but not in the 2015 observed data for this cordon.

Table 8-10 shows the 2015 modelled and the observed data across the three count sets. The modelled totals are calculated from the sum of the number of cycles over all of the network links that represent each of the count locations. This is to ensure consistency between the observed and the modelled data for the comparisons. The equivalent comparison for 2019 is presented in Table 8-11.

Table 8-10 - CSRM2 2015 versus CCC data: number of cyclists

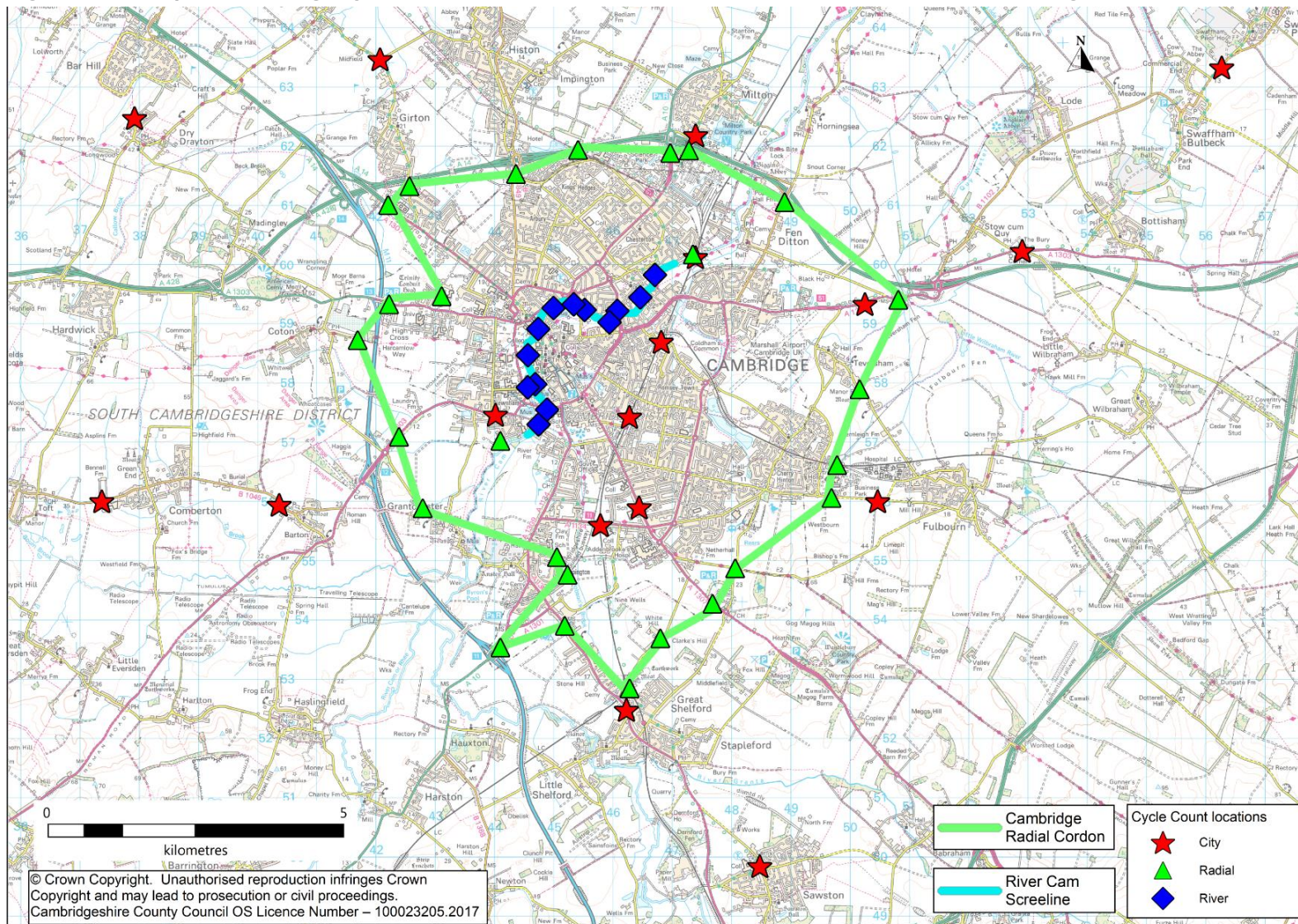
Cordon	Time period	Observed	Modelled	Percentage Difference
Radial Cordon Inbound	AM (7-10)	2,686	3,454	29%
	IP (10-16)	1,383	4,149	200%
	PM (16-19)	1,449	2,405	66%
	Total	5,518	10,009	81%
Radial Cordon Outbound	AM (7-10)	1,392	2,276	64%
	IP (10-16)	1,278	4,649	264%
	PM (16-19)	2,027	3,234	60%
	Total	4,697	10,159	116%
River Screenline Northbound	AM (7-10)	3,693	2,831	-23%
	IP (10-16)	6,053	5,287	-13%
	PM (16-19)	5,666	4,493	-21%
	Total	15,411	12,611	-18%
River Screenline Southbound	AM (7-10)	5,955	5,259	-12%
	IP (10-16)	5,851	5,143	-12%
	PM (16-19)	4,808	2,938	-39%
	Total	16,614	13,340	-20%
Cambridge Route Monitoring sites	AM (7-10)	6,336	6,101	-4%
	IP (10-16)	5,293	7,482	41%
	PM (16-19)	6,058	5,314	-12%
	Total	17,687	18,897	7%

Table 8-11 - CSRM2 2019 versus CCC data: number of cyclists

Cordon	Time period	Observed	Modelled	Percentage Difference
Radial Cordon Inbound	AM (7-10)	3,865	4,471	16%
	IP (10-16)	1,850	5,233	183%
	PM (16-19)	1,793	2,978	66%
	Total	7,508	12,682	69%
Radial Cordon Outbound	AM (7-10)	2,116	2,849	35%
	IP (10-16)	1,920	5,808	203%
	PM (16-19)	2,846	4,313	52%
	Total	6,882	12,970	88%
River Screenline Northbound	AM (7-10)	3,939	2,580	-34%
	IP (10-16)	6,592	5,465	-17%
	PM (16-19)	6,596	4,359	-34%
	Total	17,127	12,404	-28%
River Screenline Southbound	AM (7-10)	7,026	5,127	-27%
	IP (10-16)	6,342	5,310	-16%
	PM (16-19)	5,280	2,759	-48%
	Total	18,648	13,197	-29%
Cambridge Route Monitoring sites	AM (7-10)	5,504	5,930	8%
	IP (10-16)	4,085	8,004	96%
	PM (16-19)	5,199	5,218	0%
	Total	14,788	19,152	30%

Considering the variability of the data, especially with regard to the difference between the cycle counts in 2015 and 2019, we conclude that the modelled cycle counts are a reasonable representation of the number of cycles around Cambridge, within the limits of the data.

Figure 8-13 - Map of Cambridge cycle counts on Radial Cordon, River screenline and Route Monitoring sites



9. Conclusions

9.1. Summary of Model Development

The CSRM has been refreshed retaining its base year of 2015 to simulate the movement of traffic on the strategic road network within the Cambridge sub-region for the primary purpose of assessing and appraising schemes related to the GCP, the resultant update is named CSRM2. The model can be used to test and assess the traffic impacts of future land-use scenarios, proposed highway schemes and mitigation measures. The model covers the Cambridgeshire districts of Cambridge City, South Cambridgeshire, East Cambridgeshire and Huntingdonshire. The area of detailed highway simulation modelling covers Cambridge and Huntingdon, including the A14 and M11. The external area covers the rest of Great Britain in a skeletal form. The current version of the model is the CSRM2 F-series, and includes numerous refinements and improvements that have been implemented since the original CSRM2 refresh.

The base model represents a typical weekday (Tuesday – Thursday) in November 2015, and has a Present Year Validation representing October 2019. It covers the AM peak (07:00 – 10:00), inter-peak (10:00 – 16:00) and PM peak (16:00 – 19:00) periods with highway assignment for single hours from each period. The model has utilised data from a number of local and national sources, supplemented by bespoke data collected for the study.

This Model Development and Validation Report has described the development of the variable demand model, public transport, walk and cycle modelling, including assessment of 2015 and 2019 trip ends, development of synthetic demand matrices, and coding of transport networks. The report covers the calibration of the model to local data, and validation of response using realism tests in line with TAG guidance.

9.2. Summary of Calibration and Validation

Sections 7.1 and 8.1 summarise the approach to calibration and validation, and the results achieved. The model replicates well the overall mode shares and trip length distribution data available, with sensible variations in comparison with national data (for example, higher cycle mode share than in the NTS) and a good level of fit against the Census Journey to Work data when modelling 2011 input assumptions. There are some discrepancies for commuting by rail vs car trips to/from external areas.

There is generally a good correlation between the synthetic vehicle matrices and the validated highway assignment matrices, both in terms of the number of origin and destination trips by zone, and the patterns of movement at a sector-sector level. The model pivoting process has facilities in place to avoid distortions caused by any residual discrepancies.

The realism tests show that the model performs broadly within TAG standards, and with appropriate variation by purpose and traveller type. The sensitivity to car fuel cost changes is at the lower end of the TAG range, though this is in line with CSRM1 and reflects the above average incomes and existing congestion within the study area. The car journey time elasticities are at the low end of the range, around 60% of those for car fuel costs, similar to earlier versions of the model.

The broad patterns and levels of bus passenger trips in the model are shown to be correct. The calibration of individual bus corridors is more mixed, although it achieves a reasonable fit within the considered limitations of the observed data available. Likewise, local data on P&R and P&A data is partly contradictory, but the model is considered to represent a good balance based on the evidence available, and matches the variation in the attraction of each site well.

Rail usage has been matched reasonably well at the station level, barring some uncertainties relating to the total patronage of Cambridge station itself. Observed data suggests more rail trips using Cambridge station than projected by the model, despite the evidence shown in Section 7.3 that the model over-estimates rail commuting trips.

Local cycle validation has been problematic due to the high variability in the CCC counts as expected given many are for a single day. These may reflect real variations in cycling or inherent uncertainty in cycle counts. In addition, the 2015 counts differ from the 2019 data in date of collection and weather conditions, which are highly affecting people's willingness to cycle.

The 2019 PYV has been carried out following the TAG guidance as per the base year (subject to data availability) in absence of further guidelines. The validation was not as extensive as the 2015 base year due to data availability. For 2019, the model is running as a forecast year capturing the impact on traffic of changing demand and other mode shares and hence results are the outcome of the full range of model responses. The

PYV exercise has produced results that remain reasonably in line with those obtained for 2015, having taken into account the changes in demands and costs in the intervening four-year period. This has confirmed that CSRM2 would still meet an adequate level of precision and accuracy despite its base year now being older than the five years recommended by TAG.

9.3. Conclusion on model uses

On the basis of this work, the model is considered to be suitable for the strategic analysis and forecasting of travel demand and transport impacts, as outlined in Section 1.3. For specific scheme appraisals or scheme development it is recommended that a review is undertaken of relevant aspects of local calibration, to ensure that the model represents sufficiently well the transport behaviour related to the scheme in question.

Appendices

Appendix A. Glossary

ATCO-CIF	A file format for public transport data: the Association of Transport Coordinating Officers – Common Interchange Format
CCC	Cambridgeshire County Council
CSRM	Cambridge Sub-Regional Model
Demand-supply gap or “% gap”	Demand-supply measure of convergence as defined in TAG M2.1 Section 6.3
Development zone	Development zones are a set of zones which sit over the base zones and don’t necessarily share boundaries (although any one zone does not cross a district boundary). They do not exist in the base model, but are expected to have significant growth in dwellings and/or jobs by 2031.
DfT	Department for Transport
External	Outside of the study area, as defined in Section 2.2
Baseline scenario	The Baseline scenario is a set of forecast assumptions in five year steps from 2026 to 2041, agreed by Cambridgeshire County Council, that consist of a core forecast that other schemes can be built on
GB	Cambridgeshire Guided Bus
GSeC	Grouped Socio-economic Classification – an aggregation of the NS-SeC that broadly divides the populace into bands depending on the type of work done
Growth Zone	A base zone which is forecast to have significant increases in dwellings and/or jobs in forecast years
HAM	Highway Assignment Model, in this case the SATURN model
Headway	The headway of a public transport service is defined as the elapsed time between services in a modelled time period, normally calculated as an average. For example, a bus service which operates 3 times in the morning peak (07:00-10:00) has a 60-minute headway. Headway is used to calculate wait times for PT services.
HB	Home-Based – of trip purposes, meaning that one end is the traveller’s home
HBEB	Home-Based Employer’s Business - a trip from home on work time that is not a normal journey to work
HBEd	Home-Based Education – any trip from home to a place of education
HBPS	Home-Based Personal Business and Shopping – any trip from home that is either for shopping or to enable the individual to carry out non-business transactions
HBRV	Home-Based Recreation and Visiting – any trip from home that is either for visiting friends and family or for pleasure
HBW	Home-Based Work – that is, commuting trips, as opposed to business trips
HGV	Heavy Goods Vehicle (e.g. articulated lorry)
Internal	Within the study area, as defined in Section 2.2
Interzonal	A trip where the start and end points are within the Study Area, but not within the same Transport Model Zone
Intrazonal	A trip where the start and end points are within the same Transport Model zone. (The CSRM2 Model only models intrazonal trips in ‘internal’ zones.)

LGV	Light Goods Vehicle (e.g. van)
LU	Land Use
MEPLAN	WSP's transport and land use modelling software suite
NHB	Non-Home-Based – of trips meaning that neither end is the home of the individual making the trip
NHBEB	Non-Home-Based Employer's Business – a trip for business purposes, not starting at home – e.g. from one office to another office location
NHBO	Non-Home-Based Other – any trip where neither end is the traveller's home and which is not for Employer's Business
NPD	National Pupil Database
NS-SeC	National Statistics Socio-economic Classification – a division of the populace into bands for the purposes of correlating National Statistics
NTS	National Travel Survey
O-D	Origin-Destination, referring to a matrix of one-way trip legs
ONS	Office for National Statistics
P-A	Production-Attraction, referring to a matrix of movements from a trip generator to a trip attractor (e.g. home to work). A P-A movement may represent an out-and-return trip tour at different times of day, or a single Origin-Destination trip, depending on the trip purpose.
Park & Ride or "P&R"	Park & Ride, including both conventional bus-based Park & Ride sites and Guided Bus based sites.
Park & Active or "P&A"	Trips from a Park & Ride site whose end leg happens by Active modes instead of bus or Guided Bus
ppk	Pence per kilometre – units of cost used in the SATURN HAM
ppm	Pence per minute – units of cost used in the SATURN HAM
PT	Public Transport. The PT modes in CSRM2 are bus, rail, and guided bus, and for assignment the bus or Guided Bus legs of P&R journeys
RPI	Retail Prices Index – a standard measure of inflation
RSI	Roadside Interviews – survey technique used to obtain site specific data on travel patterns
Study Area	Defined in Section 2.2
TDM	Transport Demand Model
TOD	Time of Day, usually referring to the division of the day into the following periods: AM Peak, Inter Peak, PM Peak, Off Peak
UC	User Class – used in the SATURN HAM to denote trips by purpose and (for HBW and Discretionary trips) by income of the individual making the trip
VOC	Vehicle Operating Costs – a set of calculated assumed costs for the use of Cars per unit distance travelled
VOT	Value of Time – a measure of the perceived equivalent monetary cost to an individual of unit time spent travelling
TAG	Department for Transport – Transport Analysis Guidance https://www.gov.uk/guidance/transport-analysis-guidance-tag

Appendix B. Zone Definitions

Figure B-1 - Zone Plan: Study Area

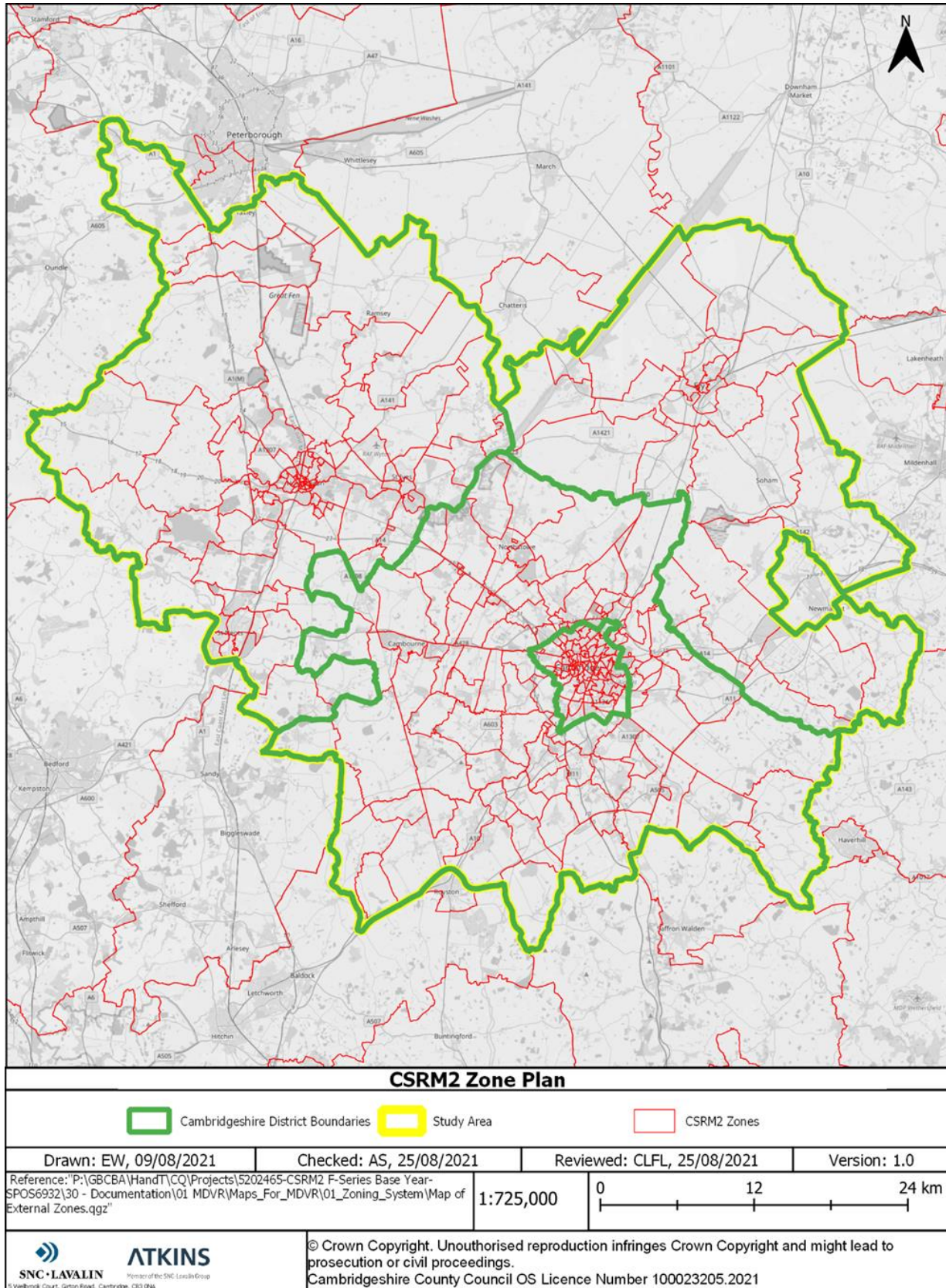


Figure B-2 - Cambridge Zone Detail

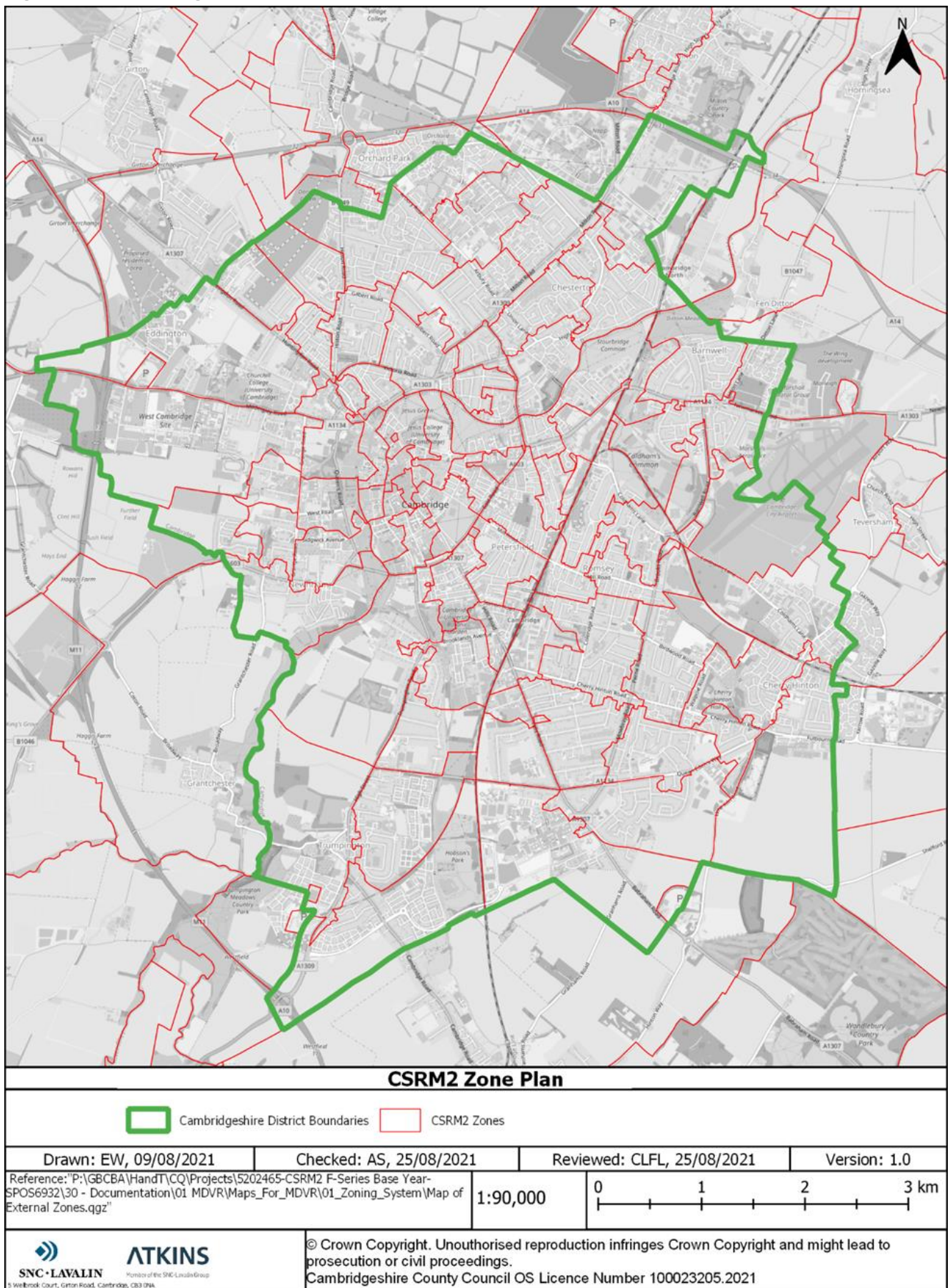


Figure B-3 Huntingdon Zone Detail



CSRM2 Zone Plan

 CSRM2 Zones

Drawn: EW, 09/08/2021

Checked: AS, 25/08/2021

Reviewed: CLFL, 25/08/2021

Version: 1.0

Reference: "P:\GBCBA\HandT\CQ\Projects\5202465-CSRM2 F-Series Base Year-SPOS6932\30 - Documentation\01 MDVR\Maps_For_MDVR\01_Zoning_System\Map of External Zones.qgz"

1:60,000

0 1 2 km



SNC • LAVALIN

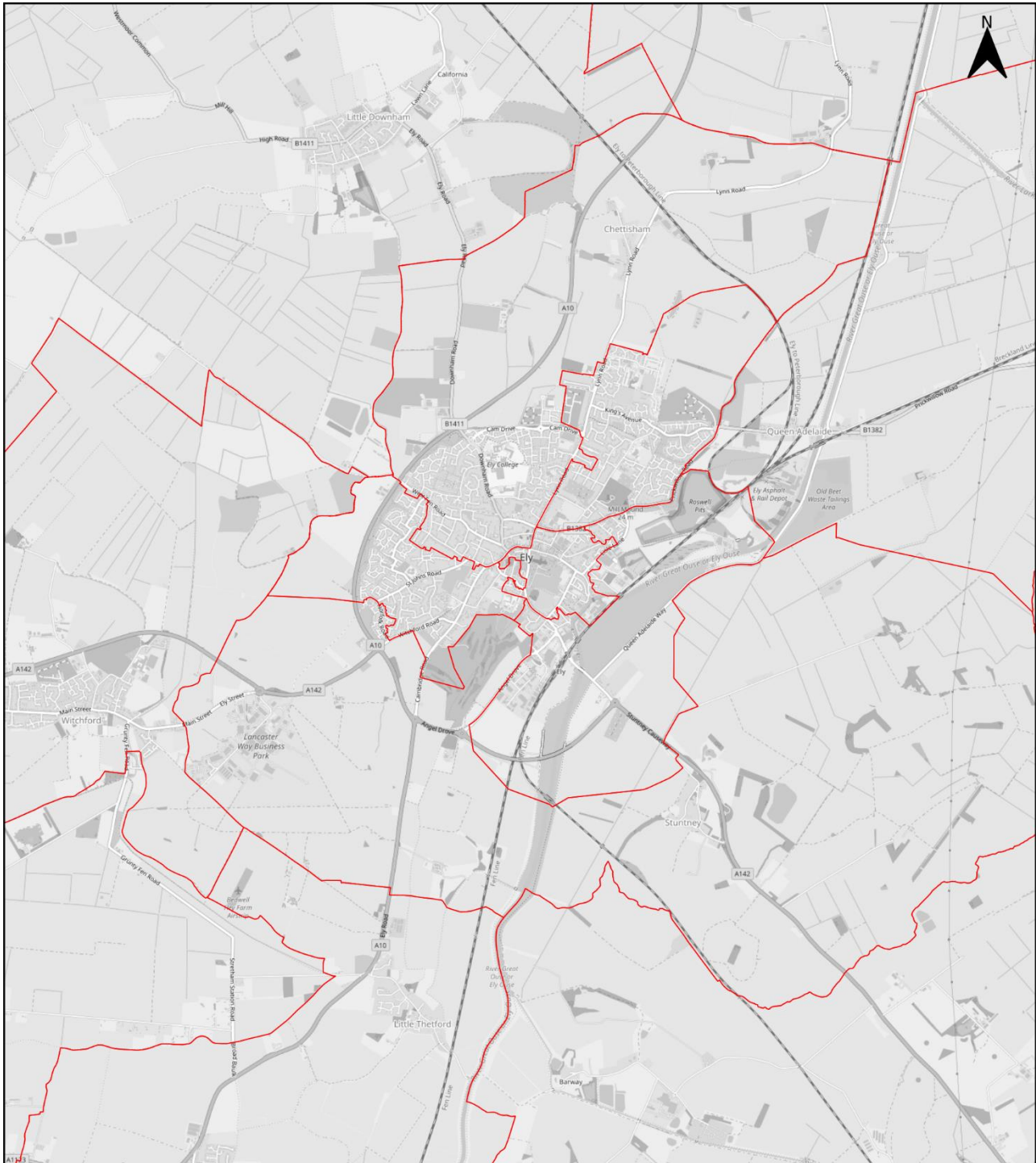


ATKINS
Member of the SNC-Lavalin Group

5 Welbeck Court, Gilton Road, Cambridge, CB3 0NA

© Crown Copyright. Unauthorised reproduction infringes Crown Copyright and might lead to prosecution or civil proceedings.
Cambridgeshire County Council OS Licence Number 100023205.2021

Figure B-4 Ely Zone Detail



CSR2 Zone Plan

CSR2 Zones

Drawn: EW, 09/08/2021

Checked: AS, 25/08/2021

Reviewed: CLFL, 25/08/2021

Version: 1.0

Reference: "P:\GBCBA\HandT\CQ\Projects\5202465-CSR2 F-Series Base Year-SPOS6932\30 - Documentation\01 MDVR\Maps_For_MDVR\01_Zoning_System\Map of External Zones.qgz"

1:90,000

0 1 2 km



SNC • LAVALIN
Member of the SNC-Lavalin Group
5 Westbrook Court, Gilton Road, Cambridge, CB3 0PA



© Crown Copyright. Unauthorised reproduction infringes Crown Copyright and might lead to prosecution or civil proceedings.
Cambridgeshire County Council OS Licence Number 100023205.2021

Figure B-5 St Ives Zone Detail

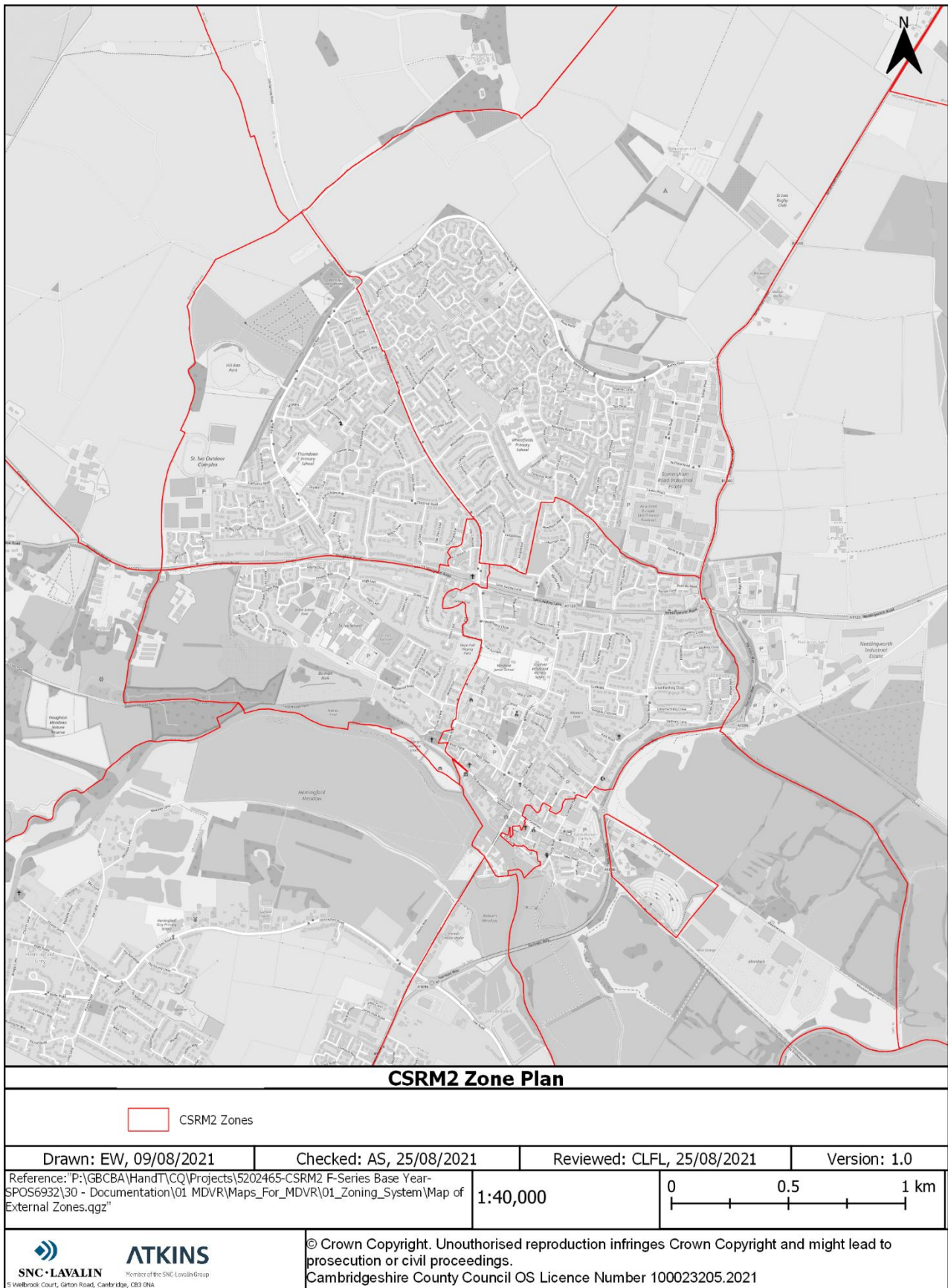
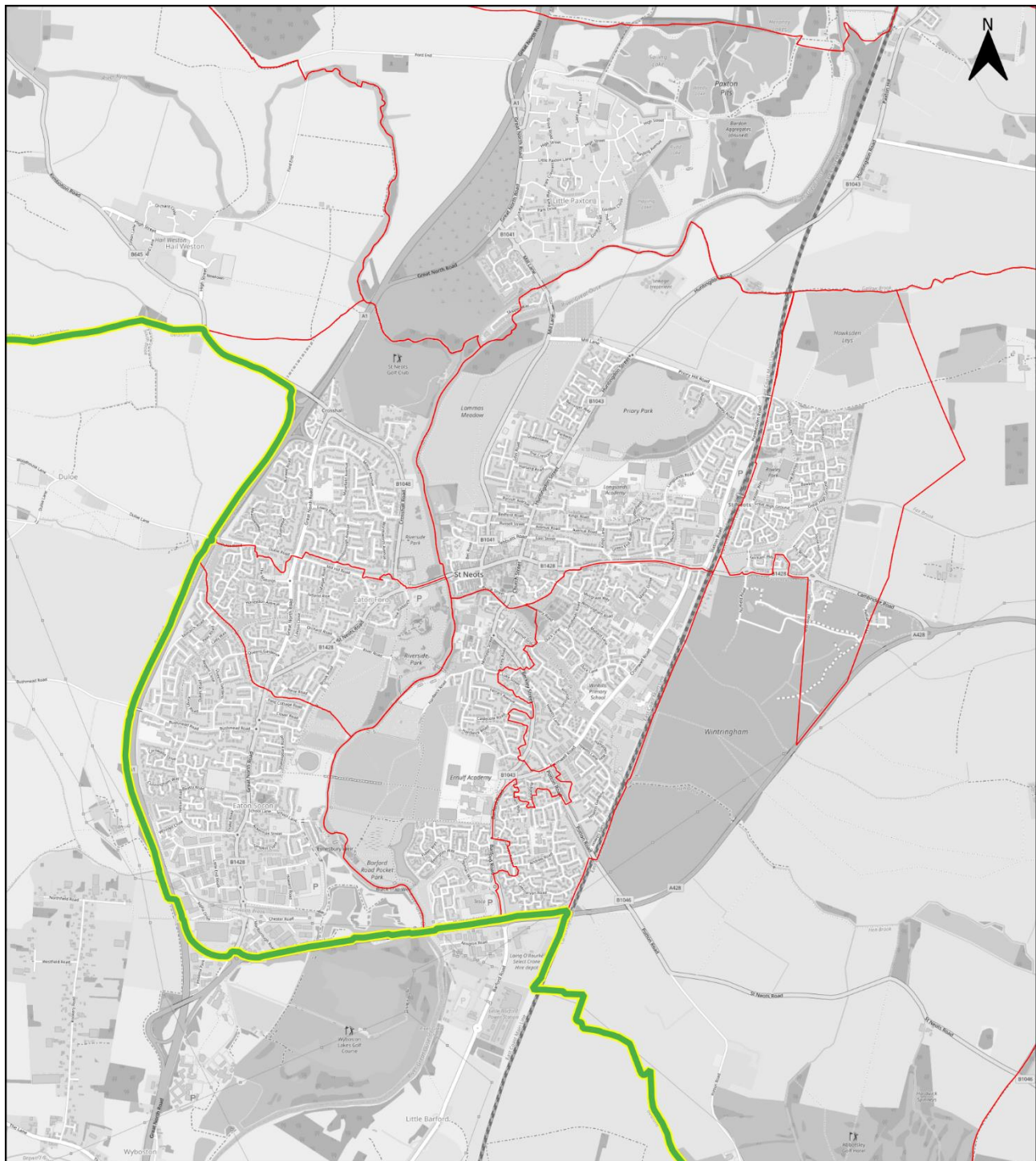


Figure B-6 St Neots Zone Detail



CSR2 Zone Plan

Cambridgeshire District Boundaries
 LAD Boundaries 02
 CSR2 Zones

Drawn: EW, 09/08/2021

Checked: AS, 25/08/2021

Reviewed: CLFL, 25/08/2021

Version: 1.0

Reference: "P:\GBCBA\HandT\CQ\Projects\5202465-CSR2 F-Series Base Year-SPOS6932\30 - Documentation\01 MDVR\Maps_For_MDVR\01_Zoning_System\Map of External Zones.qgz"

1:60,000

0 2 km



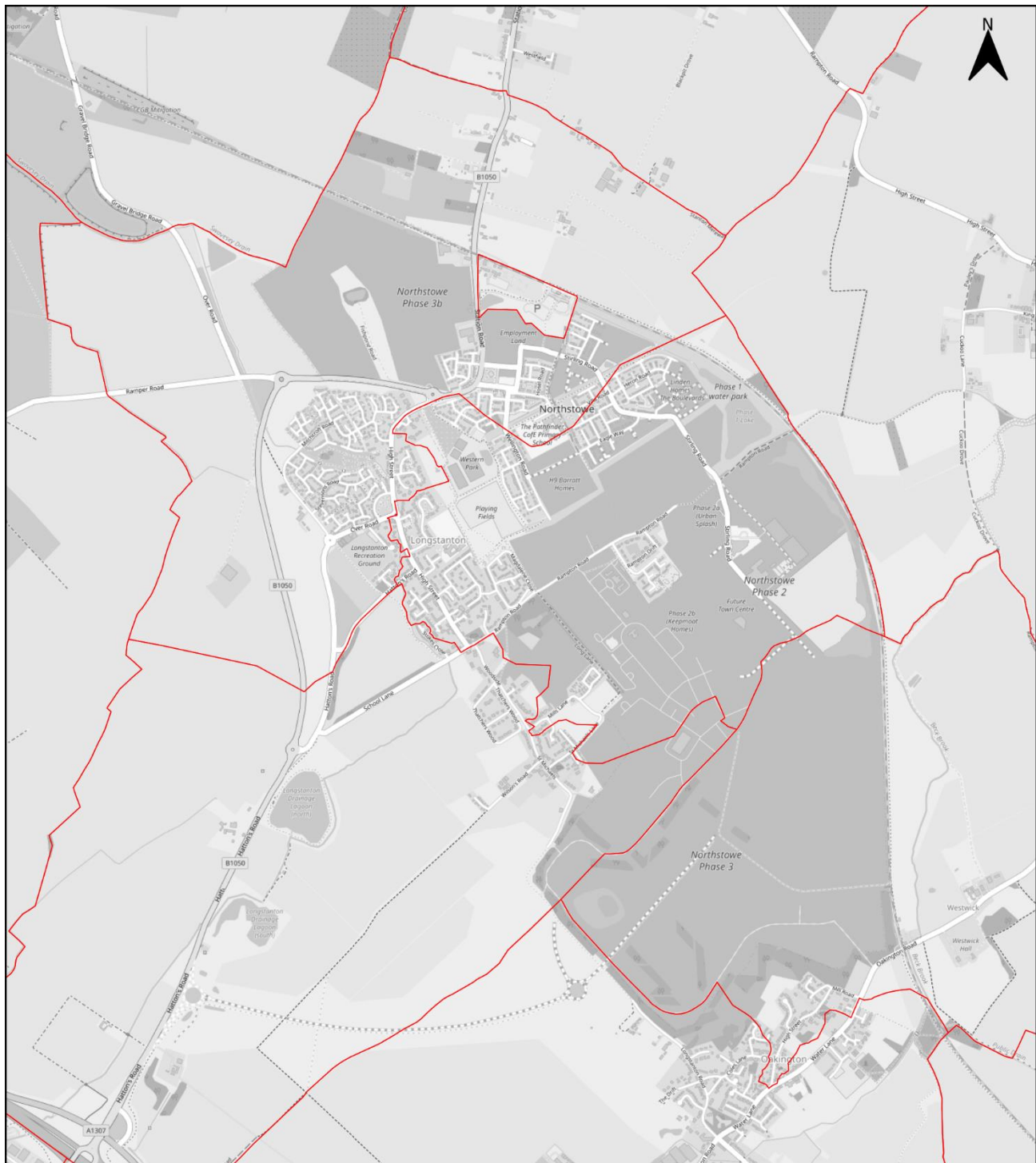
SNC • LAVALIN
Member of the SNC-Lavalin Group



ATKINS
Member of the SNC-Lavalin Group

© Crown Copyright. Unauthorised reproduction infringes Crown Copyright and might lead to prosecution or civil proceedings.
Cambridgeshire County Council OS Licence Number 100023205.2021

Figure B-7 Northstowe Zone Detail



CSR2 Zone Plan

 CSR2 Zones

Drawn: EW, 09/08/2021

Checked: AS, 25/08/2021

Reviewed: CLFL, 25/08/2021

Version: 1.0

Reference: "P:\GBCBA\HandT\CQ\Projects\5202465-CSR2 F-Series Base Year-SPOS6932\30 - Documentation\01 MDVR\Maps_For_MDVR\01_Zoning_System\Map of External Zones.qgz"

1:45,000

0 0.5 1 km



SNC • LAVALIN
5 Welbrook Court, Gilton Road, Cambridge, CB3 0NA



ATKINS
Member of the SNC-Lavalin Group

© Crown Copyright. Unauthorised reproduction infringes Crown Copyright and might lead to prosecution or civil proceedings.
Cambridgeshire County Council OS Licence Number 100023205.2021

Table B-1 - List of CSRM2 Base Model Zones

Zone Number	Zone Name
<i>Cambridge</i>	
101	Queen Edith's Way 1
102	Newmarket Road
103	Newmarket Road Retail Park and Tesco (plus some residential)
104	Barnwell
105	Barnwell Road 2
106	Barnwell Road 1
107	Victoria Road
108	Histon Road 1
109	Arbury 2
110	Trinity College and Magdalene College
111	Mount Pleasant / Queen's Road
112	Madingley Rise Site
113	Histon Road 2
114	Huntingdon Road / Oxford Road
115	Cherry Hinton 4
116	Cherry Hinton 5 and ARM
117	Perne Road / Cherry Hinton Road
118	Leisure Park and Clifton Road Industrial Estate and Hills Rd 6th form college
119	Coleridge Road
120	Cowley Road
121	Chesterton 5
122	Chesterton 6
123	Chesterton 7
124	King's Hedges 3
125	Burleigh Street / Parkside
126	Park Street Car Park
127	Grand Arcade and Sidney Street
128	Grafton Centre
129	Maids Causeway
130	Bridge Street / Jesus Lane
131	New Museums Site and Peterhouse
132	Downing Site / Trumpington Street
133	St Andrew's Street
134	Jesus Lane / Drummer Street
135	Trinity Street
136	Newnham
137	Barton Road 2

Zone Number	Zone Name
138	Barton Road 1
139	Grange Road 1
140	South of Madingley Road
141	Sturton Street
142	Hills Road / Mil Road
143	Cambridge Railway Station
144	Queen Anne Car Park
145	East Road
146	Homerton College
147	Addenbrooke's and Long Rd 6th Form College
148	Queen Edith's Way 2
149	Long Road 2
150	Hills Road 2
151	Romsey 2
152	Mill Road 2
153	Romsey 1
154	Mill Road 1
155	Addenbrooke's Road
156	Brooklands Avenue
157	Long Road 1
158	Trumpington 3
159	Trumpington 2
160	Trumpington 1
161	Hills Road 1
162	Chesterton 4
163	Arbury 1
164	Chesterton 3
165	Chesterton 2
166	Chesterton 1
167	Sainsburys, Coldhams Lane
168	King's Hedges 2
169	King's Hedges 1
170	Cherry Hinton 2
171	Cherry Hinton 1
172	Fen Ditton
173	Cambridge Airport 1
174	Castle Park
175	Darwin Green 1 and Huntingdon Road
176	Beehive Centre, Cambridge
177	King's College and St Catharine's College, Cambridge

Zone Number	Zone Name
178	CB1 / Station Road / Hills Road
179	Barton Road 3
180	Grange Road 2
181	John Lewis Depot
<i>South Cambridgeshire</i>	
201	Fulbourn Tesco and Hospital
202	Girton 1
203	Orchard Park
204	Cambridge Science Park
205	Green End
206	Cambridge Airport 2
207	Landbeach
208	Horseheath and The Camps
209	Balsham
210	Bar Hill East
211	Dry Drayton
212	Bar Hill West
213	Boxworth
214	Barton
215	Grantchester
216	Coton
217	Madingley
218	Bassingbourn 2
219	Bassingbourn 1
220	Whaddon
221	Cambourne
222	Caxton
223	Bourn
224	Croxton and Eltisley
225	Kingston
226	Toft
227	Caldecote
228	Childerley
229	Comberton
230	Cottenham and Rampton
231	Oakington 1
232	Oakington 2
233	Imperial War Museum, Duxford
234	Fowlmere
235	Foxton

Zone Number	Zone Name
236	Fulbourn
237	Gamlingay
238	Hatley and Croydon
239	Girton 2
240	Hardwick
241	Hauxton
242	Harston
243	Harlton and Haslingfield
244	Great and Little Eversden
245	Histon
246	Impington
247	Bartlow
248	Linton
249	Longstanton 2
250	Longstanton 1
251	Land between Bar Hill and Longstanton
252	Melbourn
253	Great Chishill and Heydon
254	Meldreth
255	Shepreth
256	Butt Lane tip
257	Milton West
258	Barrington
259	Wimpole and Orwell
260	Papworths
261	Fen Drayton
262	Elsworth
263	Sawston
264	Swavesey
265	Teversham 2
266	Teversham 1
267	Abingtons
268	Pampisford
269	Hinxton
270	Mordens 2
271	Mordens 1
272	Tadlow
273	Stapleford
274	Newton
275	Little Shelford

Zone Number	Zone Name
276	Great Shelford
277	Horningsea
278	Stow-cum-Quy
279	Fen Ditton
280	Great Wilbraham
281	Waterbeach
282	Whittlesford
283	Over
284	Willingham
285	Cherry Hinton 3
286	Conington
287	Lolworth
288	Duxford
289	Thriplow
290	Land east of Ditton Lane
291	Bar Hill Hotel and Golf Club
292	Cambridge Services, Swavesey
293	Buckingway Business Park, Swavesey
294	Trumpington Meadows
295	Histon Road
296	Chesterton Sidings
297	Bourn Airfield
298	Babraham Research Campus
299	Granta Park
301	Milton East
302	Cambridge Research Park
<i>East Cambridgeshire</i>	
401	Ely 1
402	Ely 2
403	Ely 3
404	Ely 4
405	Ely 5
406	Prickwillow
407	Ely 7
408	Westleys
409	Stetchworth
410	Witchford
411	Haddenham
412	Fordham and Isleham
413	Littleport

Zone Number	Zone Name
414	Soham
415	Little Downham
416	Sutton
417	Swaffhams
418	Bottisham
419	Lode
420	Stretham
421	Cheveley
422	Burwell
423	Mepal
<i>Huntingdonshire</i>	
501	Alconbury
502	Huntingdon Racecourse
503	Beaufort Park, Huntingdon
504	Ermine Business Park, Huntingdon
505	Stukeleys
506	Brampton rural
507	Grafham
508	Brampton 5
509	Brampton 4
510	Brampton 3
511	Southoe
512	Buckden
513	Needingworth
514	Bluntisham
515	Catworth and Keyston
516	Folksworth
517	Water Newton and Elton
518	Fenstanton
519	Godmanchester 5
520	Godmanchester 4
521	Godmanchester 3
522	Godmanchester 2
523	Cardinal Distribution Park, Godmanchester
524	Godmanchester 1
525	Offords
526	Huntingdon 27
527	Huntingdon 26
528	Huntingdon Riverside car park
529	Huntingdon 24

Zone Number	Zone Name
530	Huntingdon 23
531	Huntingdon 22
532	Huntingdon 21
533	Huntingdon 20
534	Huntingdon 28
535	Huntingdon 19
536	Huntingdon 18
537	Huntingdon 17
538	Huntingdon 16
539	Huntingdon 15
540	Huntingdon 14
541	Huntingdon 13
542	Huntingdon 12
543	Huntingdon 11
544	Huntingdon 10
545	Huntingdon 9
546	Hinchingbrooke School and residential
547	Hinchingbrooke Hospital
548	Huntingdon 8
549	Huntingdon 7
550	Huntingdon 6
551	Huntingdon 5
552	Huntingdon 4
553	Huntingdon 3
554	Huntingdon 2
555	Huntingdon 1
556	Hinchingbrooke residential
557	Great Staughton
558	Kimbolton
559	Ramsey
560	St Ives 4
561	St Ives 3
562	St Ives 2
563	St Ives 1
564	St Neots 6
565	St Neots 5
566	St Neots 4
567	St Neots 3
568	Sawtry and Giddings
569	Pidley and Oldhurst

Zone Number	Zone Name
570	Somersham
571	Stilton and Holme
572	Hilton
573	Wyton and Houghton
574	Kings Ripton
575	Huntingdon Rural 1
576	Warboys
577	Bury and Wistow
578	Yaxley
579	Farcet
580	Hemingfords
581	Brampton 2
582	Brampton 1
583	Hinchingbrooke, Police Headquarters
584	Earith
585	Ellington
586	Toseland and Yelling
587	Great Gransden
588	Abbotsley
589	Hinchingbrooke Business Park
590	St Ives 5
591	St Neots 2
592	St Neots 1
593	Stagecoach Depot, Fenstanton
594	Brampton Hut Services
595	Hinchingbrooke 3
596	RAF Wyton residual use
597	Love's Farm, St Neots
598	East of St Neots
599	Huntingdon Life Sciences aka Envigo, south of Alconbury
<i>Development Zones (All inactive in 2015 base; some are active in 2019 PYV – see below)</i>	
601-699	Devt Zone 601-699
<i>Development Zones (Active in 2019 PYV)</i>	
601	Alconbury Weald South
602	Northstowe Phase 1
603	Northstowe Phase 2
604	St Neots East
605	North Ely
607	Clay Farm, Long Road Cambridge

Zone Number	Zone Name
611	Total-NIAB
612	Bearscroft Farm
613	Total Clay Farm
615	North West Cambridge - Cambridge City
616	Alconbury Weald Centre
617	Alconbury Weald North
634	Grange Lane Area, Littleport
<i>External</i>	
701	Chatteris
702	Wisbech and Whittlesey
711	East Essex
712	Inner M25 East
713	South West
714	North West
715	East Hertfordshire
716	Suffolk
717	Wales and West Midlands
718	Scotland and North East
719	South Coast
720	Oxford / Northampton
721	East Northamptonshire
722	South Essex
723	East Midlands
724	Midlands
725	West Essex
726	North Hertfordshire
727	Royston
728	North Peterborough
729	East Norfolk
730	West Norfolk
731	Bedford
732	South Peterborough
733	Central London
734	South Hertfordshire
735	Haverhill
736	Bury St Edmunds
737	Saffron Walden
738	Stansted
739	Newmarket

Zone Number	Zone Name
740	Inner M25 West
741	Mildenhall
742	Tempsford
<i>Park & Ride Zones</i>	
971	Babraham Road P&R
972	Trumpington P&R
973	Madingley Road P&R
974	Milton P&R
975	Newmarket Road P&R
976	Longstanton P&R
977	St Ives P&R
<i>Dummy Park & Ride Zones</i>	
978-998	Dummy P&R Zone 1-21

Appendix C. Link types and modes

Network modes represent a travel stage, see Section 3.2. This table shows AM link types. For IP, add 200; for PM, add 400.

Table C-1 - Link types (AM Peak IDs) and relevant network modes

Link Type	Link type description	Network Modes
1	Road (car, bus and Gbus) usage	Bus ride
2	Painted cycle lanes	Cycle
3	Road with shared cyclists and drivers (speed ≤ 50kph)	Cycle
4	Road with shared cyclists and drivers (speed > 50kph and ≤ 70kph)	Cycle
5	Road with shared cyclists and drivers (speed > 70kph)	Cycle
6	CAM Tunnels - bus and Gbus but no walk/cycle	Bus ride
11	Cycle access	Cycle
12	Cycle egress	Cycle
15	Walk access	Walk
16	Cycle park	Cycle interchange
17	Cycle lane only	Cycle
21	Car drive to Park and Ride (LHM characteristics) - Bus P&R	Normal Car drive to Park and Ride interchange
22	Car drive to Park and Ride (LHM characteristics) - Main Station P&R	Normal Car drive to Park and Ride interchange
23	Car drive to Park and Ride (LHM characteristics) - Local Station P&R	Normal Car drive to Park and Ride interchange
24	Car drive from Park and Ride (LHM characteristics) - Bus P&R	Normal Car drive from Park and Ride interchange
25	Car drive from Park and Ride (LHM characteristics) - Main Station P&R	Normal Car drive from Park and Ride interchange
26	Car drive from Park and Ride (LHM characteristics) - Local Station P&R	Normal Car drive from Park and Ride interchange
27	Car drive to Park and Ride (LHM characteristics) - P&A P&R	Normal Car drive to Park and Active interchange
28	Car drive from Park and Ride (LHM characteristics) - P&A	Normal Car drive from Park and Active interchange
30	Bus ride	Bus ride
31	Bus zone connector	Bus access/egress
32	Bus access (model creates internally)	Bus access/egress
33	Bus board (model creates internally)	Bus access/egress
34	Bus alight (model creates internally)	Bus access/egress
35	Bus egress (model creates internally)	Bus access/egress
36	Bus wait (model created internally)	Bus access/egress

Link Type	Link type description	Network Modes
37	Bus-only lane	Bus ride
38	Bus entry (model creates internally)	Walk dummy (for entry and exit PT links)
39	Bus exit (model creates internally)	Walk dummy (for entry and exit PT links)
40	Rail ride	Rail ride
41	Rail connector	Rail access/egress
42	Rail access (model created internally)	Rail access/egress
43	Rail board (model created internally)	Rail access/egress
44	Rail alight (model created internally)	Rail access/egress
45	Rail egress (model created internally)	Rail access/egress
46	Rail wait (model created internally)	Rail access/egress
47	Rail track	Rail ride
48	Rail entry (model creates internally)	Walk dummy (for entry and exit PT links)
49	Rail exit (model creates internally)	Walk dummy (for entry and exit PT links)
50	Walk network	Walk
51	Walk egress	Walk
60	Car park at Cambridge Rail services	Car parks at Cambridge Rail services
61	Car park at Huntingdon Rail services	Car parks at Huntingdon Rail services
62	Car park at Ely Rail services	Car parks at Ely Rail services
63	Car park at St Neots Rail services	Car parks at St Neots Rail services
64	Car park at Local Rail services	Car parks at Local Rail services
65	Car park at Cambridge North Rail services (from 2019)	Car parks at Cambridge North Rail services
67	Car park at Foxton Rail services (forecast years only)	Car parks at Foxton Rail services
68	Car parks at Whittlesford Rail Services	Car parks at Whittlesford Rail Services
70	Car park at Milton P&R bus services	Car parks at Milton P&R bus services
71	Car park at New Market P&R bus services	Car parks at New Market P&R bus services
72	Car park at Babraham P&R bus services	Car parks at Babraham P&R bus services
73	Car park at Trumpington P&R bus services	Car parks at Trumpington P&R bus services
74	Car park at Madingley P&R bus services	Car parks at Madingley P&R bus services
75	Car park at Waterbeach P&R bus services	Car park at Waterbeach P&R bus services
76	Car park at St. Ives P&R bus services	Car parks at St. Ives P&R Guided bus services
77	Car park at Longstanton P&R bus services	Car parks at Longstanton P&R Guided bus services

Link Type	Link type description	Network Modes
78	Car park at Waterworks P&R bus services (forecast years only)	Car parks at Waterworks P&R bus services
79	Car park at Scotland Farm P&R bus services (forecast years only)	Car parks at Scotland Farm P&R bus services
80	Guided Bus ride	Guided bus ride
81	Guided Bus connector	Guided bus access/egress
82	Guided Bus access (model created internally)	Guided bus access/egress
83	Guided Bus board (model created internally)	Guided bus access/egress
84	Guided Bus alight (model created internally)	Guided bus access/egress
85	Guided Bus egress (model created internally)	Guided bus access/egress
86	Guided Bus wait (model created internally)	Guided bus access/egress
87	Guided Bus track	Bus ride
88	Guided Bus entry (model creates internally)	Walk dummy (for entry and exit PT links)
89	Guided bus exit (model creates internally)	Walk dummy (for entry and exit PT links)
90	Car park at M11 J11 P&R bus services (forecast years only)	Car parks at M11 J11 P&R bus services
91	Car park at A1307 P&R bus services (forecast years only)	Car park at A1307 P&R bus services
95	Walk Intrazonal	Walk
96	Cycle Intrazonal	Cycle

Appendix D. Gamma values used for NHB trip generation

This appendix records the gamma values used for generating non-home-based trips from home-based trips within the TDM. These values were calculated from NTS data, 2004-2014. Values below 0.0001 are not shown in these tables.

Table D-1 - Gamma values for generating NHBEB trips

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Car	AM	Car	HBW	AM	0.01254
Car	AM	Car	HBW	OP	0.00840
Car	AM	Car	HBEB	AM	0.07959
Car	AM	Car	HBEB	OP	0.09795
Car	IP	Car	HBW	AM	0.04977
Car	IP	Car	HBW	IP	0.02004
Car	IP	Car	HBW	OP	0.01240
Car	IP	Car	HBEB	AM	0.30819
Car	IP	Car	HBEB	IP	0.24174
Car	IP	Car	HBEB	OP	0.08718
Car	PM	Car	HBW	AM	0.00894
Car	PM	Car	HBW	IP	0.00805
Car	PM	Car	HBW	OP	0.00318
Car	PM	Car	HBW	PM	0.00484
Car	PM	Car	HBEB	AM	0.05102
Car	PM	Car	HBEB	IP	0.06440
Car	PM	Car	HBEB	OP	0.04510
Car	PM	Car	HBEB	PM	0.05732
PT	AM	Car	HBW	AM	0.00029
PT	AM	Car	HBW	OP	0.00020
PT	AM	Car	HBEB	AM	0.00088
PT	AM	Car	HBEB	OP	0.00109
PT	AM	PT	HBW	AM	0.00206
PT	AM	PT	HBW	OP	0.00060
PT	AM	PT	HBEB	AM	0.01843
PT	AM	PT	HBEB	OP	0.02985
PT	AM	Cycle	HBW	AM	0.00018
PT	AM	Cycle	HBW	OP	0.00033
PT	AM	Cycle	HBEB	AM	0.01843
PT	AM	Cycle	HBEB	OP	0.02985
PT	AM	Walk	HBW	AM	0.00038
PT	AM	Walk	HBEB	AM	0.01843
PT	AM	Walk	HBEB	OP	0.02985
PT	IP	Car	HBW	AM	0.00116
PT	IP	Car	HBW	IP	0.00047

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
PT	IP	Car	HBW	OP	0.00029
PT	IP	Car	HBEB	AM	0.00341
PT	IP	Car	HBEB	IP	0.00268
PT	IP	Car	HBEB	OP	0.00097
PT	IP	PT	HBW	AM	0.01080
PT	IP	PT	HBW	IP	0.00753
PT	IP	PT	HBW	OP	0.01486
PT	IP	PT	HBEB	AM	0.05096
PT	IP	PT	HBEB	IP	0.02866
PT	IP	PT	HBEB	OP	0.04189
PT	IP	Cycle	HBW	AM	0.00042
PT	IP	Cycle	HBW	IP	0.00031
PT	IP	Cycle	HBW	OP	0.00011
PT	IP	Cycle	HBEB	AM	0.05096
PT	IP	Cycle	HBEB	IP	0.02866
PT	IP	Cycle	HBEB	OP	0.04189
PT	IP	Walk	HBW	AM	0.00122
PT	IP	Walk	HBW	IP	0.00135
PT	IP	Walk	HBEB	AM	0.05096
PT	IP	Walk	HBEB	IP	0.02866
PT	IP	Walk	HBEB	OP	0.04189
PT	PM	Car	HBW	AM	0.00021
PT	PM	Car	HBW	IP	0.00019
PT	PM	Car	HBW	PM	0.00011
PT	PM	Car	HBEB	AM	0.00057
PT	PM	Car	HBEB	IP	0.00071
PT	PM	Car	HBEB	OP	0.00050
PT	PM	Car	HBEB	PM	0.00064
PT	PM	PT	HBW	AM	0.00243
PT	PM	PT	HBW	IP	0.00306
PT	PM	PT	HBW	OP	0.00101
PT	PM	PT	HBEB	AM	0.01142
PT	PM	PT	HBEB	IP	0.01807
PT	PM	PT	HBEB	OP	0.01463
PT	PM	Cycle	HBW	IP	0.00018
PT	PM	Cycle	HBEB	AM	0.01142
PT	PM	Cycle	HBEB	IP	0.01807
PT	PM	Cycle	HBEB	OP	0.01463
PT	PM	Walk	HBW	AM	0.00019
PT	PM	Walk	HBEB	AM	0.01142
PT	PM	Walk	HBEB	IP	0.01807
PT	PM	Walk	HBEB	OP	0.01463
Cycle	AM	Car	HBEB	OP	0.00011
Cycle	AM	PT	HBEB	AM	0.00687
Cycle	AM	PT	HBEB	OP	0.01113

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Cycle	AM	Cycle	HBW	AM	0.00143
Cycle	AM	Cycle	HBW	OP	0.00263
Cycle	AM	Cycle	HBEB	AM	0.00687
Cycle	AM	Cycle	HBEB	OP	0.01113
Cycle	AM	Walk	HBEB	AM	0.00687
Cycle	AM	Walk	HBEB	OP	0.01113
Cycle	IP	Car	HBEB	AM	0.00034
Cycle	IP	Car	HBEB	IP	0.00027
Cycle	IP	PT	HBW	AM	0.00045
Cycle	IP	PT	HBW	IP	0.00032
Cycle	IP	PT	HBW	OP	0.00062
Cycle	IP	PT	HBEB	AM	0.01900
Cycle	IP	PT	HBEB	IP	0.01068
Cycle	IP	PT	HBEB	OP	0.01562
Cycle	IP	Cycle	HBW	AM	0.00338
Cycle	IP	Cycle	HBW	IP	0.00248
Cycle	IP	Cycle	HBW	OP	0.00084
Cycle	IP	Cycle	HBEB	AM	0.01900
Cycle	IP	Cycle	HBEB	IP	0.01068
Cycle	IP	Cycle	HBEB	OP	0.01562
Cycle	IP	Walk	HBEB	AM	0.01900
Cycle	IP	Walk	HBEB	IP	0.01068
Cycle	IP	Walk	HBEB	OP	0.01562
Cycle	PM	PT	HBW	AM	0.00010
Cycle	PM	PT	HBW	IP	0.00013
Cycle	PM	PT	HBEB	AM	0.00426
Cycle	PM	PT	HBEB	IP	0.00673
Cycle	PM	PT	HBEB	OP	0.00545
Cycle	PM	Cycle	HBW	AM	0.00076
Cycle	PM	Cycle	HBW	IP	0.00145
Cycle	PM	Cycle	HBEB	AM	0.00426
Cycle	PM	Cycle	HBEB	IP	0.00673
Cycle	PM	Cycle	HBEB	OP	0.00545
Cycle	PM	Walk	HBEB	AM	0.00426
Cycle	PM	Walk	HBEB	IP	0.00673
Cycle	PM	Walk	HBEB	OP	0.00545
Walk	AM	Car	HBW	AM	0.00096
Walk	AM	Car	HBW	OP	0.00064
Walk	AM	Car	HBEB	AM	0.00527
Walk	AM	Car	HBEB	OP	0.00649
Walk	AM	PT	HBW	AM	0.00169
Walk	AM	PT	HBW	OP	0.00050
Walk	AM	PT	HBEB	AM	0.03378
Walk	AM	PT	HBEB	OP	0.05471
Walk	AM	Cycle	HBW	AM	0.00066

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Walk	AM	Cycle	HBW	OP	0.00121
Walk	AM	Cycle	HBEB	AM	0.03378
Walk	AM	Cycle	HBEB	OP	0.05471
Walk	AM	Walk	HBW	AM	0.00239
Walk	AM	Walk	HBW	OP	0.00038
Walk	AM	Walk	HBEB	AM	0.03378
Walk	AM	Walk	HBEB	OP	0.05471
Walk	IP	Car	HBW	AM	0.00380
Walk	IP	Car	HBW	IP	0.00153
Walk	IP	Car	HBW	OP	0.00095
Walk	IP	Car	HBEB	AM	0.02041
Walk	IP	Car	HBEB	IP	0.01601
Walk	IP	Car	HBEB	OP	0.00577
Walk	IP	PT	HBW	AM	0.00887
Walk	IP	PT	HBW	IP	0.00619
Walk	IP	PT	HBW	OP	0.01220
Walk	IP	PT	HBEB	AM	0.09341
Walk	IP	PT	HBEB	IP	0.05252
Walk	IP	PT	HBEB	OP	0.07678
Walk	IP	Cycle	HBW	AM	0.00155
Walk	IP	Cycle	HBW	IP	0.00114
Walk	IP	Cycle	HBW	OP	0.00038
Walk	IP	Cycle	HBEB	AM	0.09341
Walk	IP	Cycle	HBEB	IP	0.05252
Walk	IP	Cycle	HBEB	OP	0.07678
Walk	IP	Walk	HBW	AM	0.00759
Walk	IP	Walk	HBW	IP	0.00842
Walk	IP	Walk	HBW	OP	0.00042
Walk	IP	Walk	HBEB	AM	0.09341
Walk	IP	Walk	HBEB	IP	0.05252
Walk	IP	Walk	HBEB	OP	0.07678
Walk	PM	Car	HBW	AM	0.00068
Walk	PM	Car	HBW	IP	0.00061
Walk	PM	Car	HBW	OP	0.00024
Walk	PM	Car	HBW	PM	0.00037
Walk	PM	Car	HBEB	AM	0.00338
Walk	PM	Car	HBEB	IP	0.00426
Walk	PM	Car	HBEB	OP	0.00299
Walk	PM	Car	HBEB	PM	0.00380
Walk	PM	PT	HBW	AM	0.00200
Walk	PM	PT	HBW	IP	0.00251
Walk	PM	PT	HBW	OP	0.00083
Walk	PM	PT	HBEB	AM	0.02093
Walk	PM	PT	HBEB	IP	0.03311
Walk	PM	PT	HBEB	OP	0.02681

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Walk	PM	Cycle	HBW	AM	0.00035
Walk	PM	Cycle	HBW	IP	0.00067
Walk	PM	Cycle	HBEB	AM	0.02093
Walk	PM	Cycle	HBEB	IP	0.03311
Walk	PM	Cycle	HBEB	OP	0.02681
Walk	PM	Walk	HBW	AM	0.00116
Walk	PM	Walk	HBW	IP	0.00035
Walk	PM	Walk	HBW	OP	0.00034
Walk	PM	Walk	HBEB	AM	0.02093
Walk	PM	Walk	HBEB	IP	0.03311
Walk	PM	Walk	HBEB	OP	0.02681

Table D-2 - Gamma values for generating NHBO trips

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Car	AM	Car	HBW	AM	0.03042
Car	AM	Car	HBW	OP	0.01175
Car	AM	Car	HBEB	AM	0.03066
Car	AM	Car	HBEB	OP	0.02948
Car	AM	Car	HBEd	12hr	0.15447
Car	AM	Car	HBPS	AM	0.18059
Car	AM	Car	HBRV	AM	0.18059
Car	IP	Car	HBW	AM	0.15567
Car	IP	Car	HBW	IP	0.09395
Car	IP	Car	HBW	OP	0.05355
Car	IP	Car	HBEB	AM	0.14987
Car	IP	Car	HBEB	IP	0.14254
Car	IP	Car	HBEB	OP	0.03064
Car	IP	Car	HBEd	12hr	0.16789
Car	IP	Car	HBPS	AM	0.27166
Car	IP	Car	HBPS	IP	0.25684
Car	IP	Car	HBRV	AM	0.27166
Car	IP	Car	HBRV	IP	0.25684
Car	PM	Car	HBW	AM	0.08654
Car	PM	Car	HBW	IP	0.06013
Car	PM	Car	HBW	OP	0.02777
Car	PM	Car	HBW	PM	0.04844
Car	PM	Car	HBEB	AM	0.06719
Car	PM	Car	HBEB	IP	0.06124
Car	PM	Car	HBEB	OP	0.02621
Car	PM	Car	HBEB	PM	0.04010
Car	PM	Car	HBEd	12hr	0.06827
Car	PM	Car	HBPS	AM	0.07142

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Car	PM	Car	HBPS	IP	0.05602
Car	PM	Car	HBPS	PM	0.07954
Car	PM	Car	HBRV	AM	0.07142
Car	PM	Car	HBRV	IP	0.05602
Car	PM	Car	HBRV	PM	0.07954
PT	AM	Car	HBW	AM	0.00038
PT	AM	Car	HBW	OP	0.00015
PT	AM	Car	HBEB	AM	0.00029
PT	AM	Car	HBEB	OP	0.00027
PT	AM	Car	HBEd	12hr	0.00182
PT	AM	Car	HBPS	AM	0.00306
PT	AM	Car	HBRV	AM	0.00306
PT	AM	PT	HBW	AM	0.00162
PT	AM	PT	HBW	OP	0.00325
PT	AM	PT	HBEB	AM	0.01250
PT	AM	PT	HBEB	OP	0.01053
PT	AM	PT	HBEd	12hr	0.00586
PT	AM	PT	HBPS	AM	0.02036
PT	AM	PT	HBRV	AM	0.02036
PT	AM	Cycle	HBW	OP	0.00010
PT	AM	Cycle	HBEB	AM	0.01250
PT	AM	Cycle	HBEB	OP	0.01053
PT	AM	Cycle	HBEd	12hr	0.00013
PT	AM	Cycle	HBPS	AM	0.00087
PT	AM	Cycle	HBRV	AM	0.00087
PT	AM	Walk	HBEB	AM	0.01250
PT	AM	Walk	HBEB	OP	0.01053
PT	AM	Walk	HBEd	12hr	0.00114
PT	AM	Walk	HBPS	AM	0.00240
PT	AM	Walk	HBRV	AM	0.00240
PT	IP	Car	HBW	AM	0.00193
PT	IP	Car	HBW	IP	0.00116
PT	IP	Car	HBW	OP	0.00066
PT	IP	Car	HBEB	AM	0.00140
PT	IP	Car	HBEB	IP	0.00133
PT	IP	Car	HBEB	OP	0.00029
PT	IP	Car	HBEd	12hr	0.00198
PT	IP	Car	HBPS	AM	0.00460
PT	IP	Car	HBPS	IP	0.00435
PT	IP	Car	HBRV	AM	0.00460
PT	IP	Car	HBRV	IP	0.00435
PT	IP	PT	HBW	AM	0.04327
PT	IP	PT	HBW	IP	0.01474
PT	IP	PT	HBW	OP	0.00679
PT	IP	PT	HBEB	AM	0.04821

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
PT	IP	PT	HBEB	IP	0.02998
PT	IP	PT	HBEB	OP	0.01716
PT	IP	PT	HBEd	12hr	0.03605
PT	IP	PT	HBPS	AM	0.10602
PT	IP	PT	HBPS	IP	0.07125
PT	IP	PT	HBRV	AM	0.10602
PT	IP	PT	HBRV	IP	0.07125
PT	IP	Cycle	HBW	AM	0.00149
PT	IP	Cycle	HBW	IP	0.00022
PT	IP	Cycle	HBW	OP	0.00029
PT	IP	Cycle	HBEB	AM	0.04821
PT	IP	Cycle	HBEB	IP	0.02998
PT	IP	Cycle	HBEB	OP	0.01716
PT	IP	Cycle	HBEd	12hr	0.00034
PT	IP	Cycle	HBPS	AM	0.00190
PT	IP	Cycle	HBPS	IP	0.00127
PT	IP	Cycle	HBRV	AM	0.00190
PT	IP	Cycle	HBRV	IP	0.00127
PT	IP	Walk	HBW	AM	0.00462
PT	IP	Walk	HBW	IP	0.00181
PT	IP	Walk	HBW	OP	0.00168
PT	IP	Walk	HBEB	AM	0.04821
PT	IP	Walk	HBEB	IP	0.02998
PT	IP	Walk	HBEB	OP	0.01716
PT	IP	Walk	HBEd	12hr	0.00247
PT	IP	Walk	HBPS	AM	0.00354
PT	IP	Walk	HBPS	IP	0.00471
PT	IP	Walk	HBRV	AM	0.00354
PT	IP	Walk	HBRV	IP	0.00471
PT	PM	Car	HBW	AM	0.00107
PT	PM	Car	HBW	IP	0.00074
PT	PM	Car	HBW	OP	0.00034
PT	PM	Car	HBW	PM	0.00060
PT	PM	Car	HBEB	AM	0.00063
PT	PM	Car	HBEB	IP	0.00057
PT	PM	Car	HBEB	OP	0.00024
PT	PM	Car	HBEB	PM	0.00037
PT	PM	Car	HBEd	12hr	0.00080
PT	PM	Car	HBPS	AM	0.00121
PT	PM	Car	HBPS	IP	0.00095
PT	PM	Car	HBPS	PM	0.00135
PT	PM	Car	HBRV	AM	0.00121
PT	PM	Car	HBRV	IP	0.00095
PT	PM	Car	HBRV	PM	0.00135
PT	PM	PT	HBW	AM	0.01633

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
PT	PM	PT	HBW	IP	0.01158
PT	PM	PT	HBW	OP	0.00675
PT	PM	PT	HBW	PM	0.00221
PT	PM	PT	HBEB	AM	0.01496
PT	PM	PT	HBEB	IP	0.01901
PT	PM	PT	HBEB	OP	0.02043
PT	PM	PT	HBEd	12hr	0.01522
PT	PM	PT	HBPS	AM	0.00960
PT	PM	PT	HBPS	IP	0.01931
PT	PM	PT	HBPS	PM	0.05364
PT	PM	PT	HBRV	AM	0.00960
PT	PM	PT	HBRV	IP	0.01931
PT	PM	PT	HBRV	PM	0.05364
PT	PM	Cycle	HBW	AM	0.00047
PT	PM	Cycle	HBW	IP	0.00015
PT	PM	Cycle	HBEB	AM	0.01496
PT	PM	Cycle	HBEB	IP	0.01901
PT	PM	Cycle	HBEB	OP	0.02043
PT	PM	Cycle	HBPS	AM	0.00061
PT	PM	Cycle	HBPS	IP	0.00027
PT	PM	Cycle	HBPS	PM	0.00044
PT	PM	Cycle	HBRV	AM	0.00061
PT	PM	Cycle	HBRV	IP	0.00027
PT	PM	Cycle	HBRV	PM	0.00044
PT	PM	Walk	HBW	AM	0.00187
PT	PM	Walk	HBW	IP	0.00076
PT	PM	Walk	HBW	OP	0.00037
PT	PM	Walk	HBW	PM	0.00025
PT	PM	Walk	HBEB	AM	0.01496
PT	PM	Walk	HBEB	IP	0.01901
PT	PM	Walk	HBEB	OP	0.02043
PT	PM	Walk	HBEd	12hr	0.00046
PT	PM	Walk	HBPS	AM	0.00034
PT	PM	Walk	HBPS	IP	0.00065
PT	PM	Walk	HBPS	PM	0.00120
PT	PM	Walk	HBRV	AM	0.00034
PT	PM	Walk	HBRV	IP	0.00065
PT	PM	Walk	HBRV	PM	0.00120
Cycle	AM	Car	HBEd	12hr	0.00015
Cycle	AM	Car	HBPS	AM	0.00033
Cycle	AM	Car	HBRV	AM	0.00033
Cycle	AM	PT	HBEB	AM	0.00163
Cycle	AM	PT	HBEB	OP	0.00137
Cycle	AM	PT	HBPS	AM	0.00020
Cycle	AM	PT	HBRV	AM	0.00020

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Cycle	AM	Cycle	HBW	AM	0.00106
Cycle	AM	Cycle	HBW	OP	0.00397
Cycle	AM	Cycle	HBEB	AM	0.00163
Cycle	AM	Cycle	HBEB	OP	0.00137
Cycle	AM	Cycle	HBEd	12hr	0.01529
Cycle	AM	Cycle	HBPS	AM	0.04514
Cycle	AM	Cycle	HBRV	AM	0.04514
Cycle	AM	Walk	HBEB	AM	0.00163
Cycle	AM	Walk	HBEB	OP	0.00137
Cycle	AM	Walk	HBEd	12hr	0.00027
Cycle	IP	Car	HBW	AM	0.00011
Cycle	IP	Car	HBEB	AM	0.00017
Cycle	IP	Car	HBEB	IP	0.00016
Cycle	IP	Car	HBEd	12hr	0.00017
Cycle	IP	Car	HBPS	AM	0.00049
Cycle	IP	Car	HBPS	IP	0.00046
Cycle	IP	Car	HBRV	AM	0.00049
Cycle	IP	Car	HBRV	IP	0.00046
Cycle	IP	PT	HBW	AM	0.00085
Cycle	IP	PT	HBW	IP	0.00029
Cycle	IP	PT	HBW	OP	0.00013
Cycle	IP	PT	HBEB	AM	0.00627
Cycle	IP	PT	HBEB	IP	0.00390
Cycle	IP	PT	HBEB	OP	0.00223
Cycle	IP	PT	HBPS	AM	0.00102
Cycle	IP	PT	HBPS	IP	0.00068
Cycle	IP	PT	HBRV	AM	0.00102
Cycle	IP	PT	HBRV	IP	0.00068
Cycle	IP	Cycle	HBW	AM	0.05859
Cycle	IP	Cycle	HBW	IP	0.00855
Cycle	IP	Cycle	HBW	OP	0.01162
Cycle	IP	Cycle	HBEB	AM	0.00627
Cycle	IP	Cycle	HBEB	IP	0.00390
Cycle	IP	Cycle	HBEB	OP	0.00223
Cycle	IP	Cycle	HBEd	12hr	0.04010
Cycle	IP	Cycle	HBPS	AM	0.09915
Cycle	IP	Cycle	HBPS	IP	0.06595
Cycle	IP	Cycle	HBRV	AM	0.09915
Cycle	IP	Cycle	HBRV	IP	0.06595
Cycle	IP	Walk	HBW	AM	0.00032
Cycle	IP	Walk	HBW	IP	0.00012
Cycle	IP	Walk	HBW	OP	0.00012
Cycle	IP	Walk	HBEB	AM	0.00627
Cycle	IP	Walk	HBEB	IP	0.00390
Cycle	IP	Walk	HBEB	OP	0.00223

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Cycle	IP	Walk	HBEd	12hr	0.00058
Cycle	IP	Walk	HBPS	AM	0.00010
Cycle	IP	Walk	HBPS	IP	0.00014
Cycle	IP	Walk	HBRV	AM	0.00010
Cycle	IP	Walk	HBRV	IP	0.00014
Cycle	PM	Car	HBPS	AM	0.00013
Cycle	PM	Car	HBPS	IP	0.00010
Cycle	PM	Car	HBPS	PM	0.00014
Cycle	PM	Car	HBRV	AM	0.00013
Cycle	PM	Car	HBRV	IP	0.00010
Cycle	PM	Car	HBRV	PM	0.00014
Cycle	PM	PT	HBW	AM	0.00032
Cycle	PM	PT	HBW	IP	0.00023
Cycle	PM	PT	HBW	OP	0.00013
Cycle	PM	PT	HBEB	AM	0.00194
Cycle	PM	PT	HBEB	IP	0.00247
Cycle	PM	PT	HBEB	OP	0.00266
Cycle	PM	PT	HBPS	IP	0.00019
Cycle	PM	PT	HBPS	PM	0.00051
Cycle	PM	PT	HBRV	IP	0.00019
Cycle	PM	PT	HBRV	PM	0.00051
Cycle	PM	Cycle	HBW	AM	0.01873
Cycle	PM	Cycle	HBW	IP	0.00574
Cycle	PM	Cycle	HBW	OP	0.00336
Cycle	PM	Cycle	HBEB	AM	0.00194
Cycle	PM	Cycle	HBEB	IP	0.00247
Cycle	PM	Cycle	HBEB	OP	0.00266
Cycle	PM	Cycle	HBEd	12hr	0.00999
Cycle	PM	Cycle	HBPS	AM	0.03152
Cycle	PM	Cycle	HBPS	IP	0.01384
Cycle	PM	Cycle	HBPS	PM	0.02290
Cycle	PM	Cycle	HBRV	AM	0.03152
Cycle	PM	Cycle	HBRV	IP	0.01384
Cycle	PM	Cycle	HBRV	PM	0.02290
Cycle	PM	Walk	HBW	AM	0.00013
Cycle	PM	Walk	HBEB	AM	0.00194
Cycle	PM	Walk	HBEB	IP	0.00247
Cycle	PM	Walk	HBEB	OP	0.00266
Cycle	PM	Walk	HBEd	12hr	0.00011
Walk	AM	Car	HBW	AM	0.00820
Walk	AM	Car	HBW	OP	0.00317
Walk	AM	Car	HBEB	AM	0.00318
Walk	AM	Car	HBEB	OP	0.00305
Walk	AM	Car	HBEd	12hr	0.01955
Walk	AM	Car	HBPS	AM	0.02809

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Walk	AM	Car	HBRV	AM	0.02809
Walk	AM	PT	HBW	AM	0.00420
Walk	AM	PT	HBW	OP	0.00843
Walk	AM	PT	HBEB	AM	0.02265
Walk	AM	PT	HBEB	OP	0.01908
Walk	AM	PT	HBEd	12hr	0.00825
Walk	AM	PT	HBPS	AM	0.02093
Walk	AM	PT	HBRV	AM	0.02093
Walk	AM	Cycle	HBW	AM	0.00183
Walk	AM	Cycle	HBW	OP	0.00686
Walk	AM	Cycle	HBEB	AM	0.02265
Walk	AM	Cycle	HBEB	OP	0.01908
Walk	AM	Cycle	HBEd	12hr	0.00714
Walk	AM	Cycle	HBPS	AM	0.01987
Walk	AM	Cycle	HBRV	AM	0.01987
Walk	AM	Walk	HBW	AM	0.00158
Walk	AM	Walk	HBW	OP	0.00103
Walk	AM	Walk	HBEB	AM	0.02265
Walk	AM	Walk	HBEB	OP	0.01908
Walk	AM	Walk	HBEd	12hr	0.02331
Walk	AM	Walk	HBPS	AM	0.04351
Walk	AM	Walk	HBRV	AM	0.04351
Walk	IP	Car	HBW	AM	0.04194
Walk	IP	Car	HBW	IP	0.02531
Walk	IP	Car	HBW	OP	0.01443
Walk	IP	Car	HBEB	AM	0.01552
Walk	IP	Car	HBEB	IP	0.01477
Walk	IP	Car	HBEB	OP	0.00317
Walk	IP	Car	HBEd	12hr	0.02125
Walk	IP	Car	HBPS	AM	0.04226
Walk	IP	Car	HBPS	IP	0.03995
Walk	IP	Car	HBRV	AM	0.04226
Walk	IP	Car	HBRV	IP	0.03995
Walk	IP	PT	HBW	AM	0.11219
Walk	IP	PT	HBW	IP	0.03821
Walk	IP	PT	HBW	OP	0.01761
Walk	IP	PT	HBEB	AM	0.08731
Walk	IP	PT	HBEB	IP	0.05429
Walk	IP	PT	HBEB	OP	0.03109
Walk	IP	PT	HBEd	12hr	0.05078
Walk	IP	PT	HBPS	AM	0.10897
Walk	IP	PT	HBPS	IP	0.07324
Walk	IP	PT	HBRV	AM	0.10897
Walk	IP	PT	HBRV	IP	0.07324
Walk	IP	Cycle	HBW	AM	0.10130

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Walk	IP	Cycle	HBW	IP	0.01478
Walk	IP	Cycle	HBW	OP	0.02009
Walk	IP	Cycle	HBEB	AM	0.08731
Walk	IP	Cycle	HBEB	IP	0.05429
Walk	IP	Cycle	HBEB	OP	0.03109
Walk	IP	Cycle	HBEd	12hr	0.01871
Walk	IP	Cycle	HBPS	AM	0.04365
Walk	IP	Cycle	HBPS	IP	0.02904
Walk	IP	Cycle	HBRV	AM	0.04365
Walk	IP	Cycle	HBRV	IP	0.02904
Walk	IP	Walk	HBW	AM	0.10142
Walk	IP	Walk	HBW	IP	0.03970
Walk	IP	Walk	HBW	OP	0.03690
Walk	IP	Walk	HBEB	AM	0.08731
Walk	IP	Walk	HBEB	IP	0.05429
Walk	IP	Walk	HBEB	OP	0.03109
Walk	IP	Walk	HBEd	12hr	0.05061
Walk	IP	Walk	HBPS	AM	0.06421
Walk	IP	Walk	HBPS	IP	0.08541
Walk	IP	Walk	HBRV	AM	0.06421
Walk	IP	Walk	HBRV	IP	0.08541
Walk	PM	Car	HBW	AM	0.02331
Walk	PM	Car	HBW	IP	0.01620
Walk	PM	Car	HBW	OP	0.00748
Walk	PM	Car	HBW	PM	0.01305
Walk	PM	Car	HBEB	AM	0.00696
Walk	PM	Car	HBEB	IP	0.00634
Walk	PM	Car	HBEB	OP	0.00271
Walk	PM	Car	HBEB	PM	0.00415
Walk	PM	Car	HBEd	12hr	0.00864
Walk	PM	Car	HBPS	AM	0.01111
Walk	PM	Car	HBPS	IP	0.00871
Walk	PM	Car	HBPS	PM	0.01237
Walk	PM	Car	HBRV	AM	0.01111
Walk	PM	Car	HBRV	IP	0.00871
Walk	PM	Car	HBRV	PM	0.01237
Walk	PM	PT	HBW	AM	0.04233
Walk	PM	PT	HBW	IP	0.03003
Walk	PM	PT	HBW	OP	0.01749
Walk	PM	PT	HBW	PM	0.00573
Walk	PM	PT	HBEB	AM	0.02709
Walk	PM	PT	HBEB	IP	0.03443
Walk	PM	PT	HBEB	OP	0.03700
Walk	PM	PT	HBEd	12hr	0.02145
Walk	PM	PT	HBPS	AM	0.00986

NHB Mode	NHB time period	Previous HB mode	Previous HB purpose	Previous HB time period	NHB Gamma Values (NTB trip rate/HB trip rate)
Walk	PM	PT	HBPS	IP	0.01985
Walk	PM	PT	HBPS	PM	0.05513
Walk	PM	PT	HBRV	AM	0.00986
Walk	PM	PT	HBRV	IP	0.01985
Walk	PM	PT	HBRV	PM	0.05513
Walk	PM	Cycle	HBW	AM	0.03239
Walk	PM	Cycle	HBW	IP	0.00992
Walk	PM	Cycle	HBW	OP	0.00581
Walk	PM	Cycle	HBEB	AM	0.02709
Walk	PM	Cycle	HBEB	IP	0.03443
Walk	PM	Cycle	HBEB	OP	0.03700
Walk	PM	Cycle	HBEd	12hr	0.00466
Walk	PM	Cycle	HBPS	AM	0.01388
Walk	PM	Cycle	HBPS	IP	0.00610
Walk	PM	Cycle	HBPS	PM	0.01008
Walk	PM	Cycle	HBRV	AM	0.01388
Walk	PM	Cycle	HBRV	IP	0.00610
Walk	PM	Cycle	HBRV	PM	0.01008
Walk	PM	Walk	HBW	AM	0.04096
Walk	PM	Walk	HBW	IP	0.01670
Walk	PM	Walk	HBW	OP	0.00812
Walk	PM	Walk	HBW	PM	0.00541
Walk	PM	Walk	HBEB	AM	0.02709
Walk	PM	Walk	HBEB	IP	0.03443
Walk	PM	Walk	HBEB	OP	0.03700
Walk	PM	Walk	HBEd	12hr	0.00950
Walk	PM	Walk	HBPS	AM	0.00614
Walk	PM	Walk	HBPS	IP	0.01181
Walk	PM	Walk	HBPS	PM	0.02181
Walk	PM	Walk	HBRV	AM	0.00614
Walk	PM	Walk	HBRV	IP	0.01181
Walk	PM	Walk	HBRV	PM	0.02181

Appendix E. Trip Length Distribution graph comparisons with Census and NTS

E.1. Comparisons between CSRM2 2011 and Census 2011, Home-Based Work

Figure E-1 - Trip Length Distribution: all modes (HBW, vs Census)

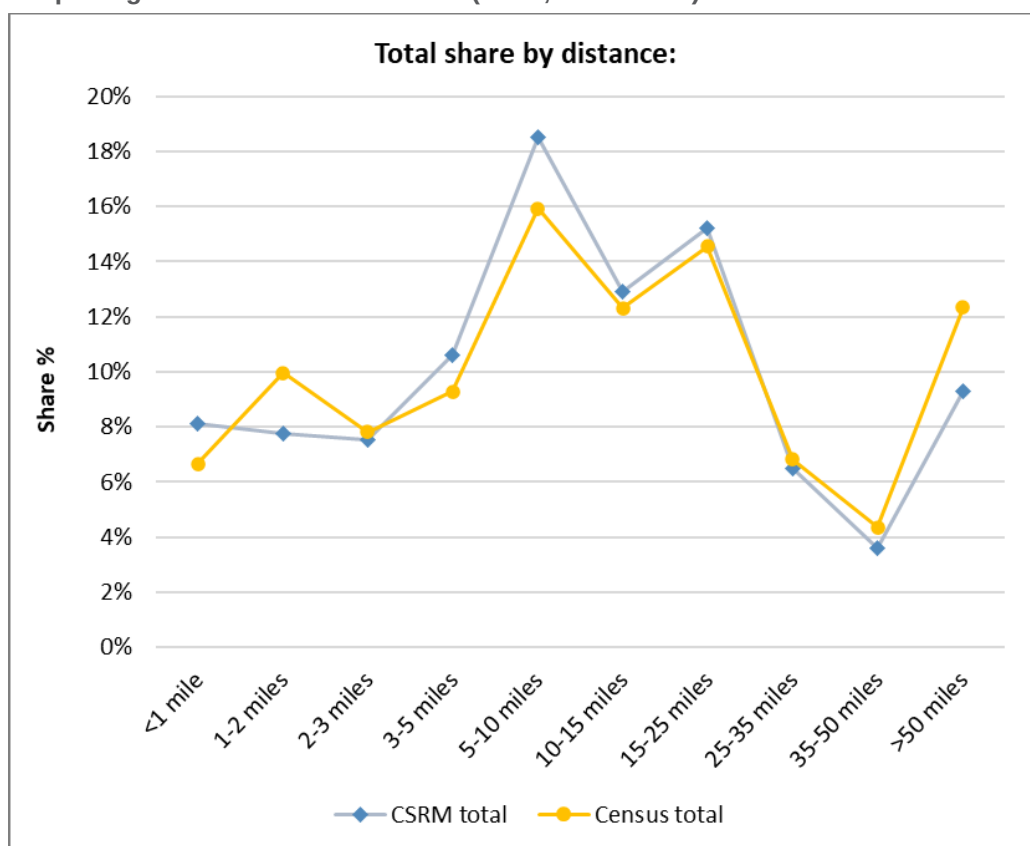


Figure E-2 - Trip Length Distribution: car (HBW, vs Census)

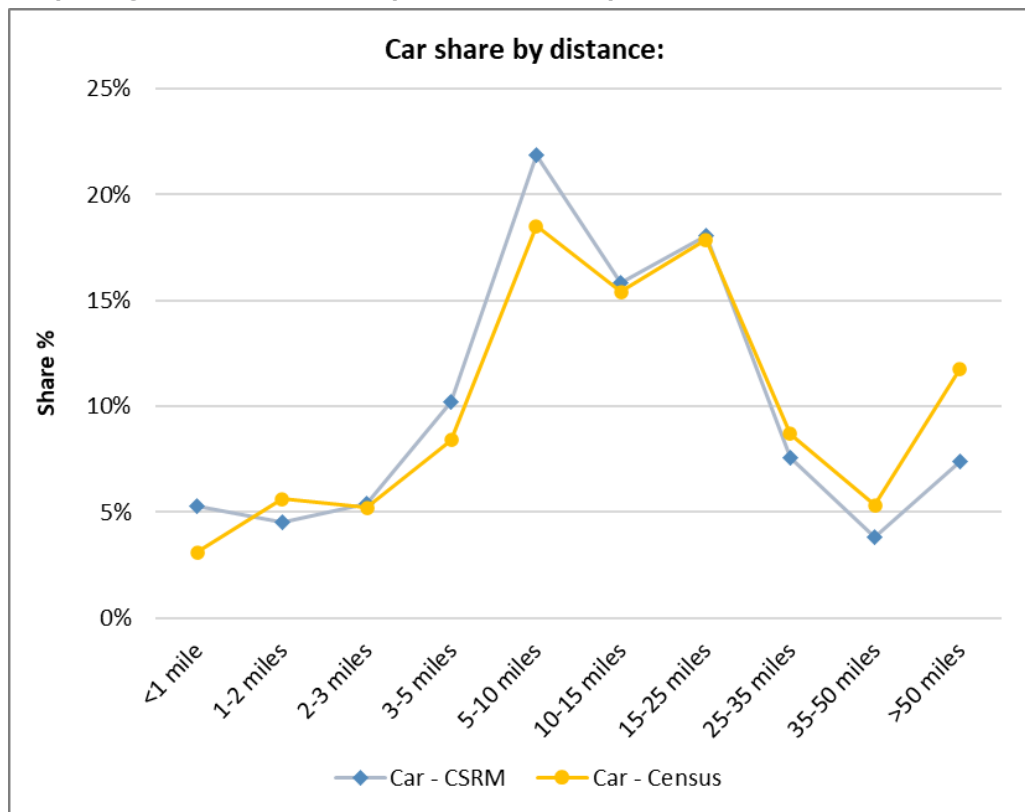


Figure E-3 - Trip Length Distribution: bus (HBW, vs Census)

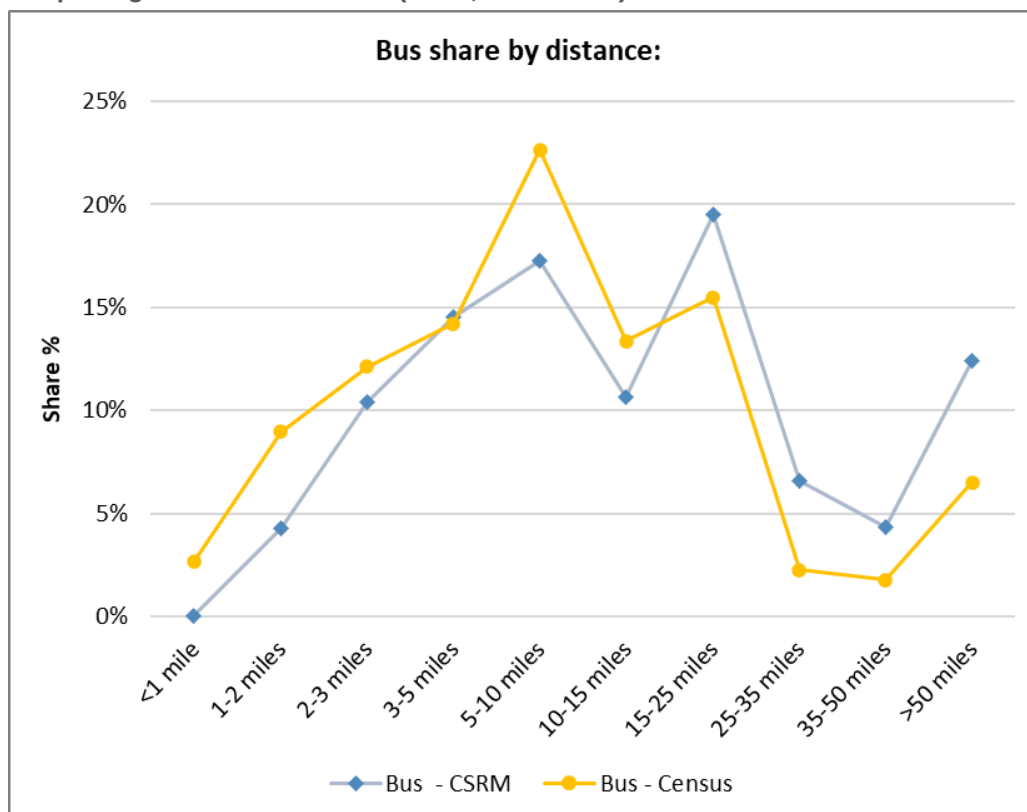


Figure E-4 - Trip Length Distribution: rail (HBW, vs Census)

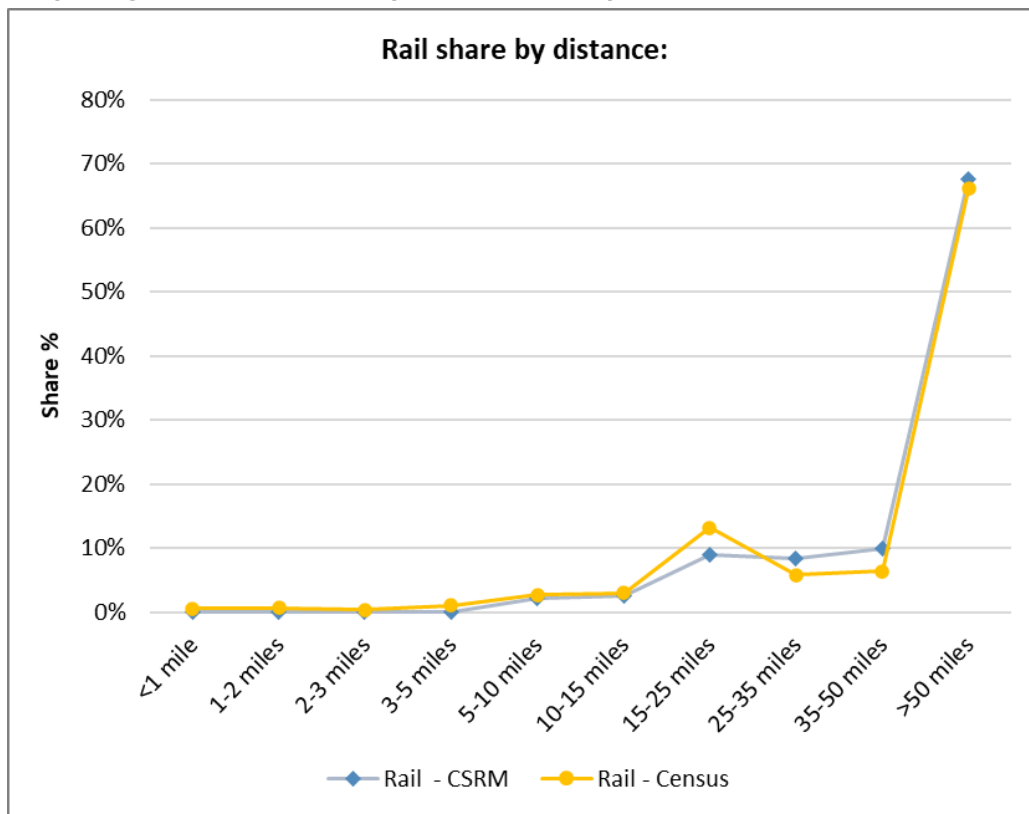


Figure E-5 - Trip Length Distribution: cycle (HBW, vs Census)

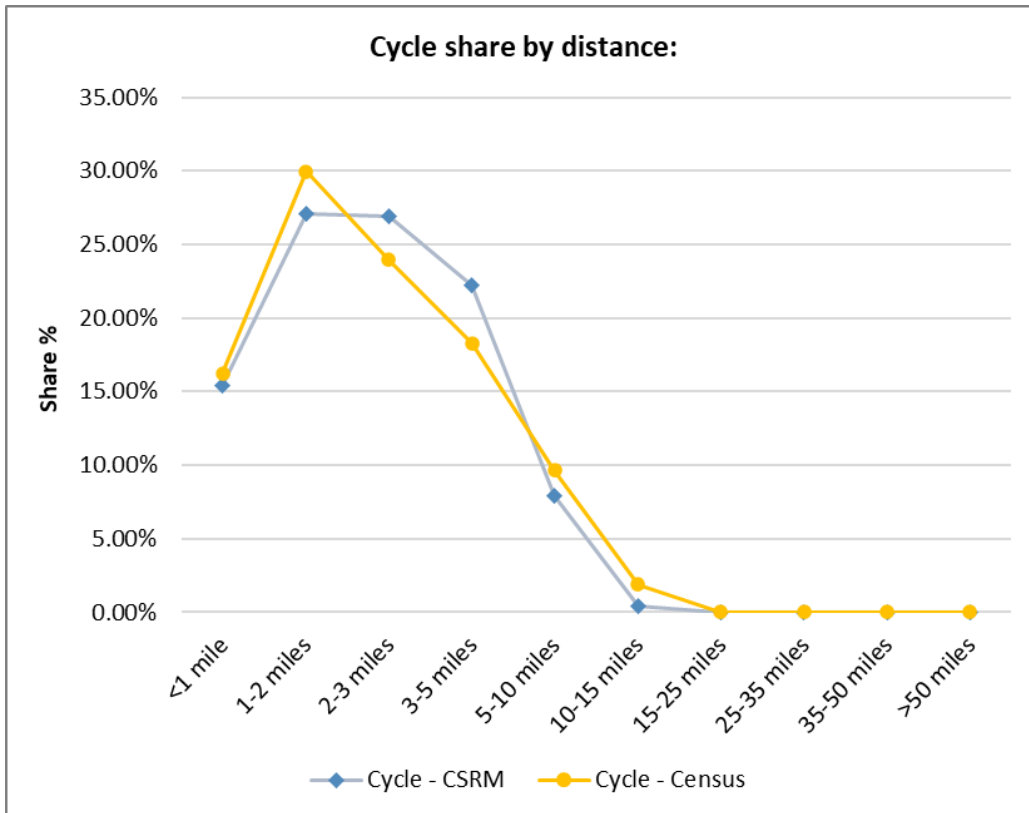
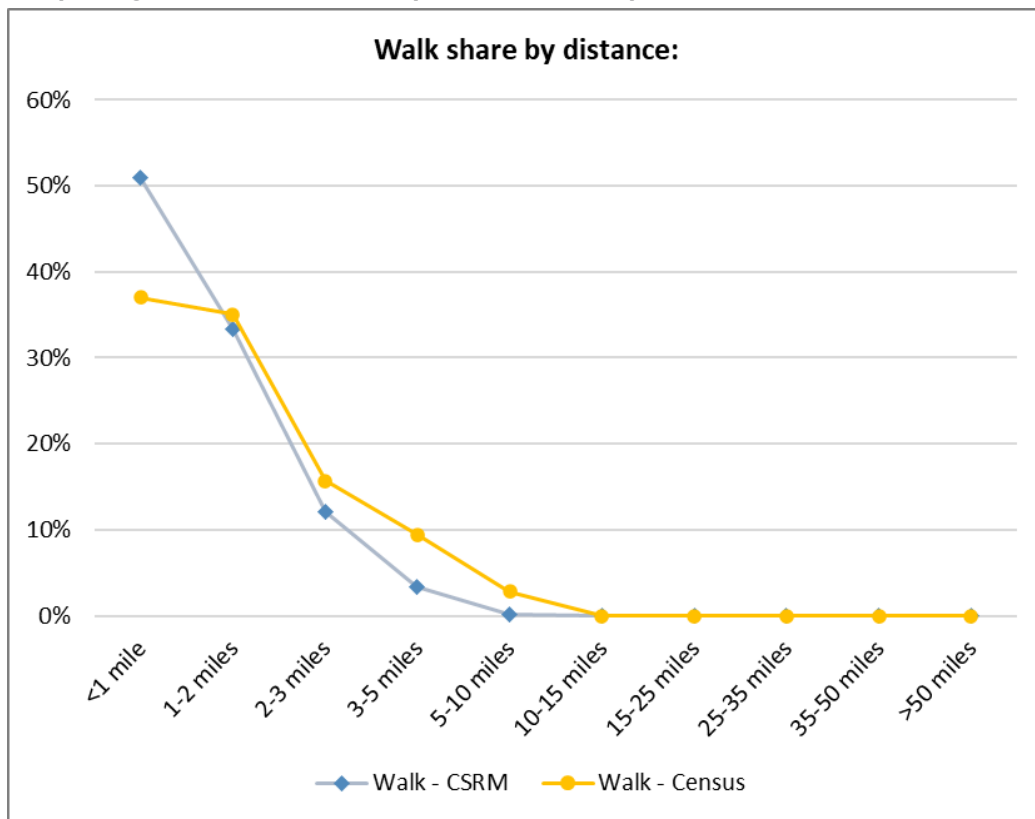


Figure E-6 - Trip Length Distribution: walk (HBW, vs Census)



E.2. Comparisons between CSRM2 2011 and NTS 2012-2014, Home-Based Work

Figure E-7 - Trip Length Distribution: all modes (HBW, vs NTS)

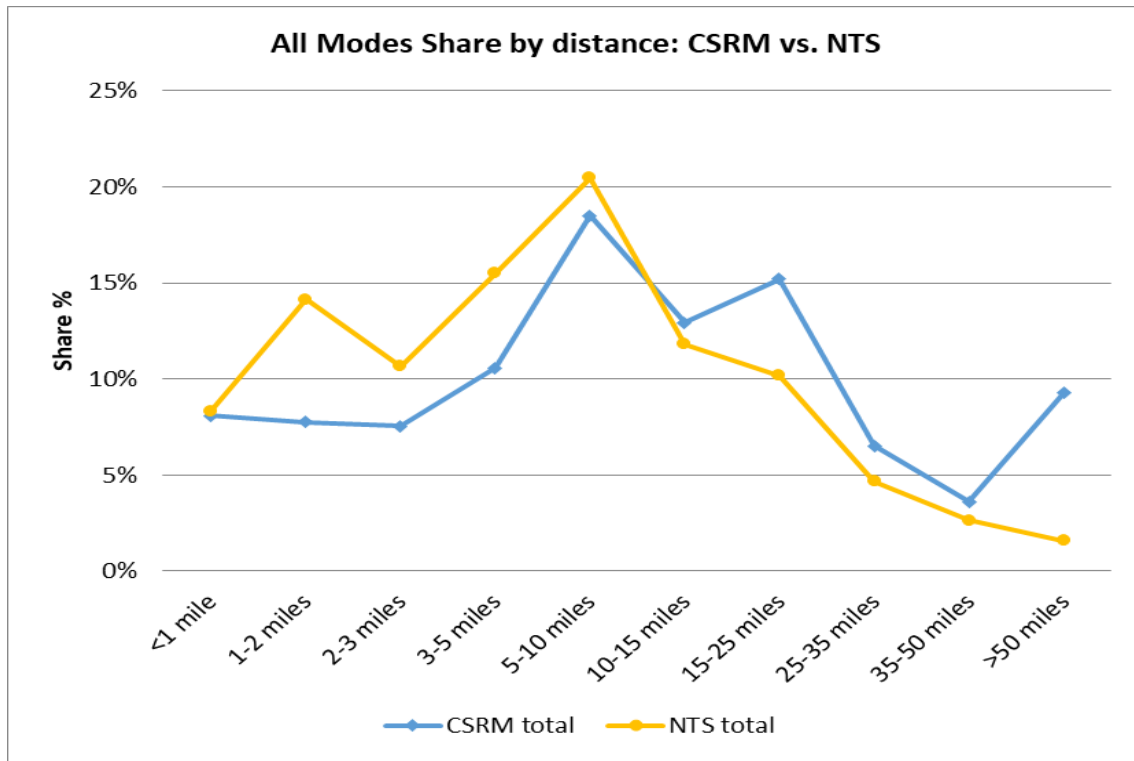


Figure E-8 - Trip Length Distribution: car (HBW, vs NTS)

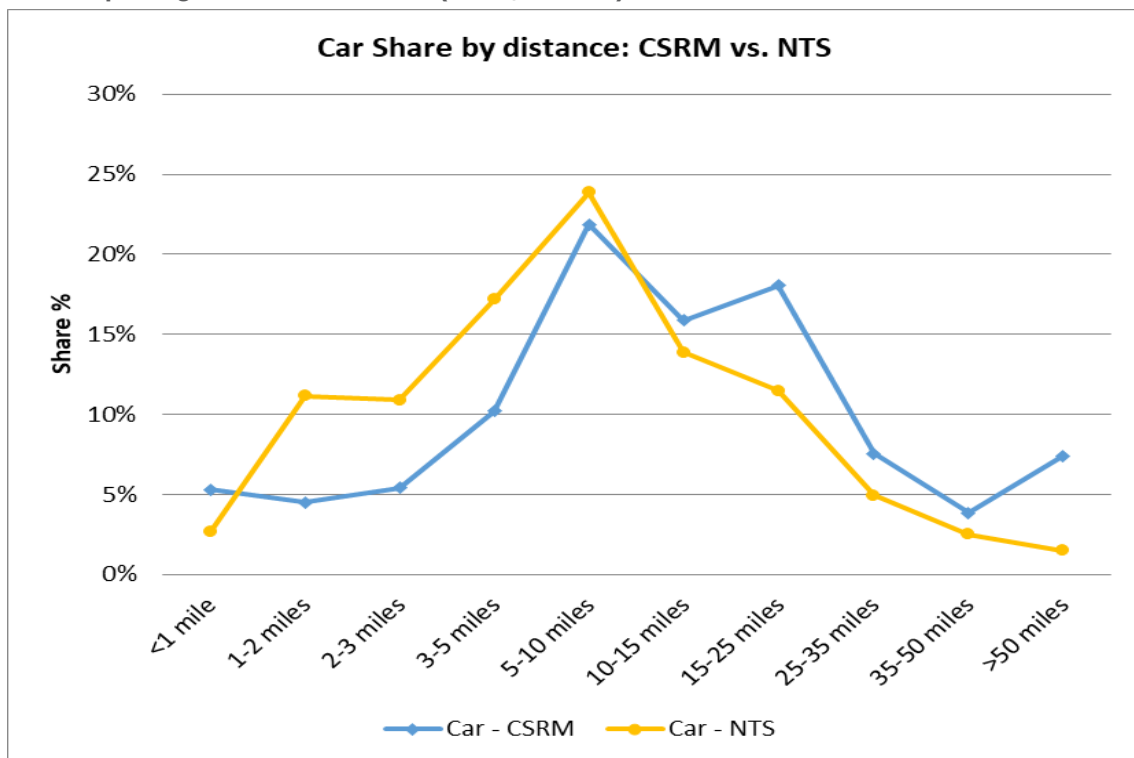


Figure E-9 - Trip Length Distribution: bus (HBW, vs NTS)

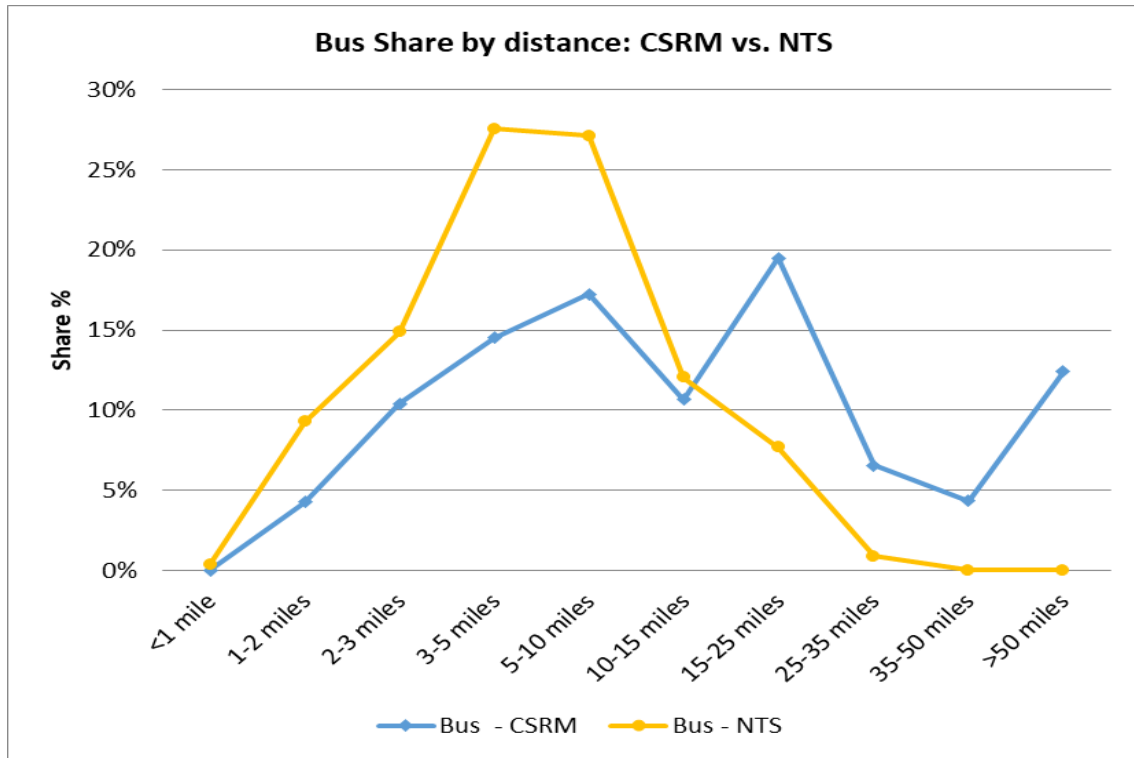


Figure E-10 - Trip Length Distribution: rail (HBW, vs NTS)

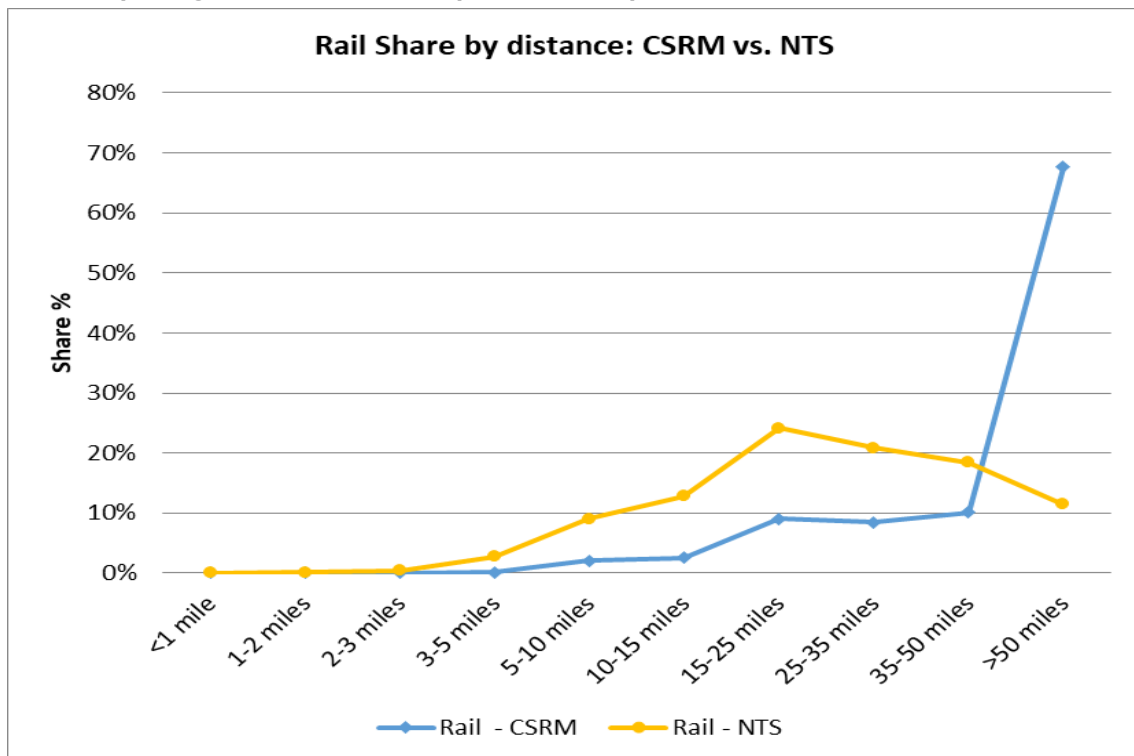


Figure E-11 - Trip Length Distribution: cycle (HBW, vs NTS)

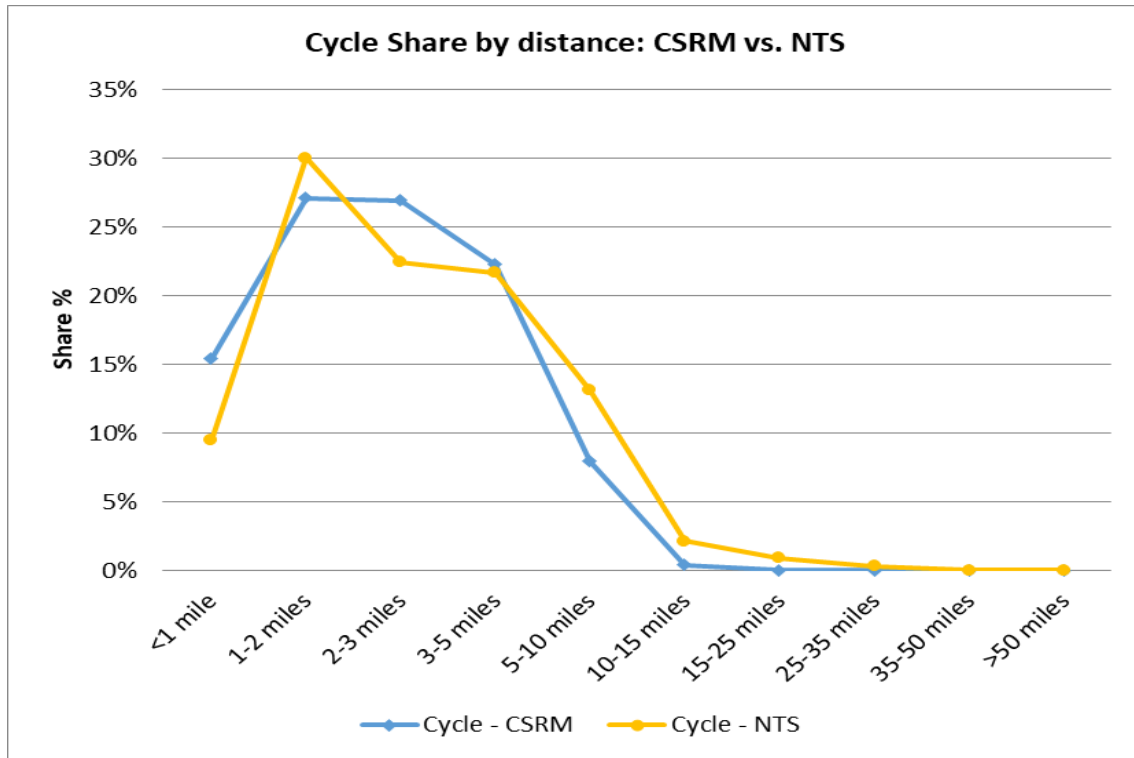
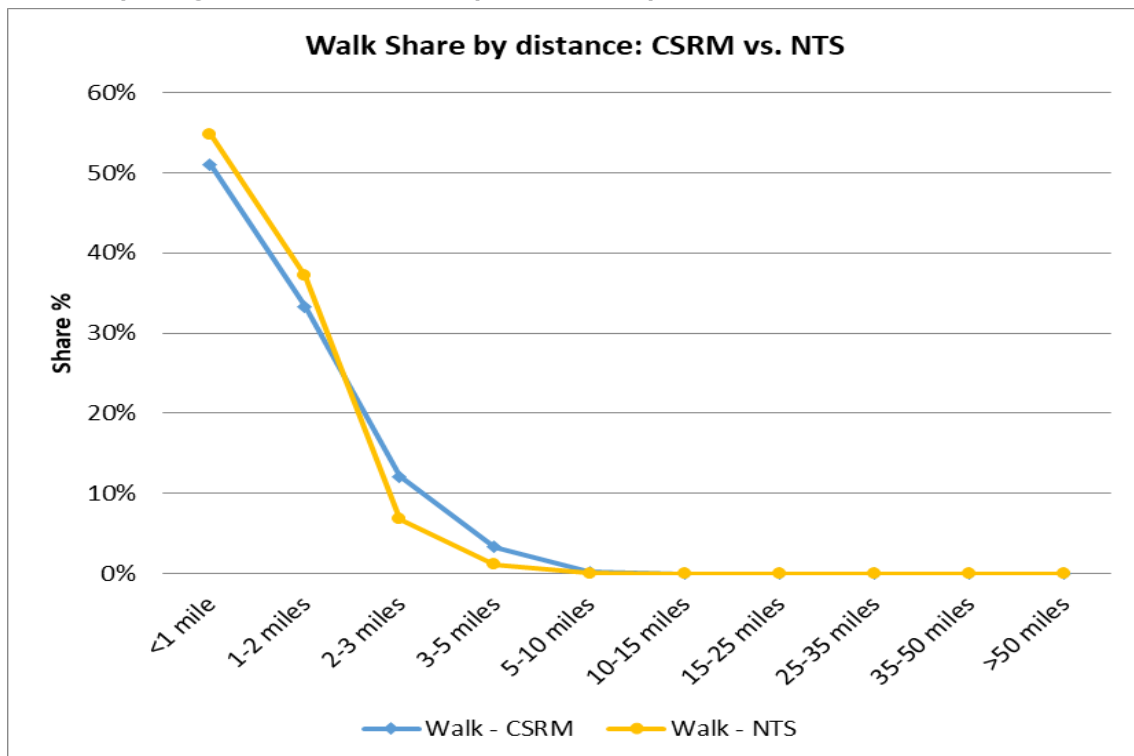


Figure E-12 - Trip Length Distribution: walk (HBW, vs NTS)



E.3. Comparisons between CSRM2 2011 and NTS 2012-14, Employer's Business

Figure E-13 - Trip Length Distribution: all modes (EB, vs NTS)

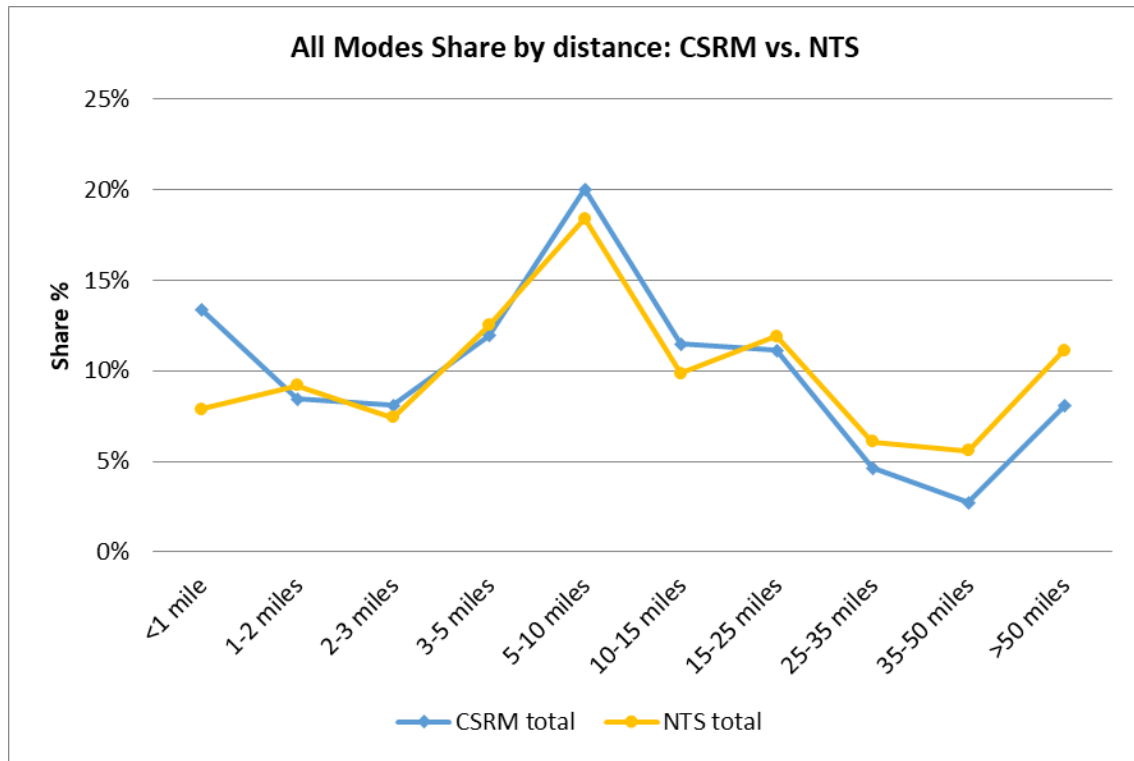


Figure E-14 - Trip Length Distribution: car (EB, vs NTS)

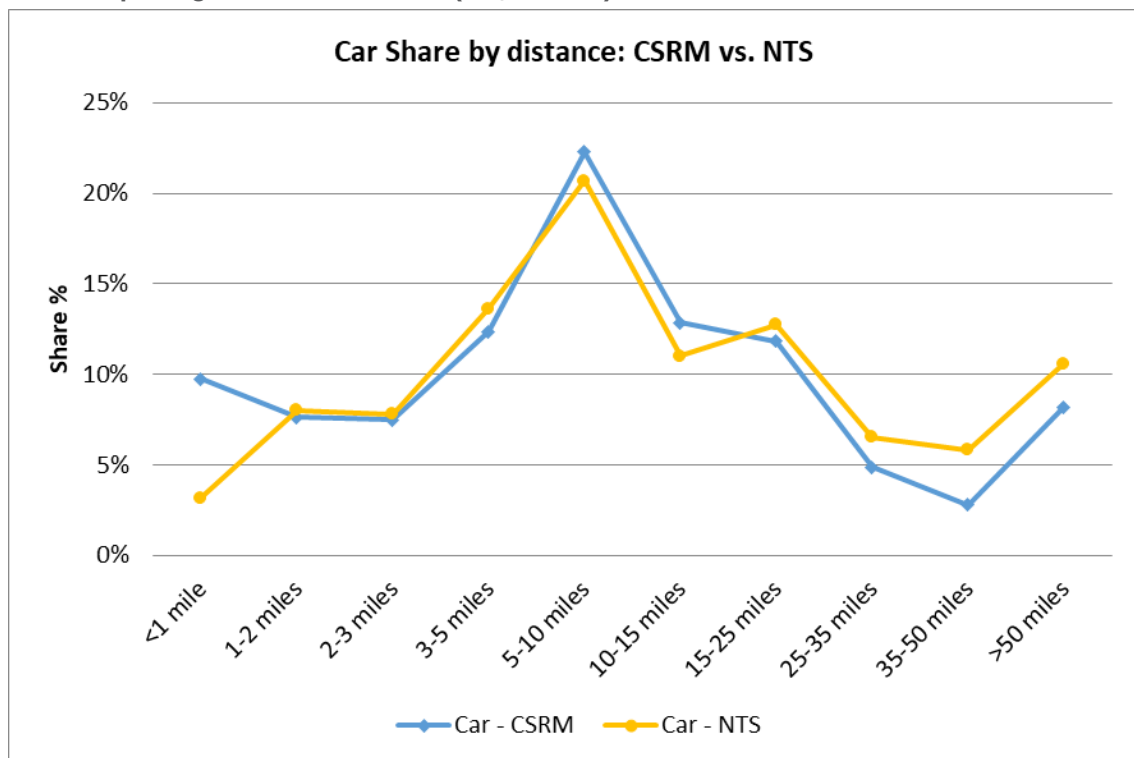


Figure E-15 - Trip Length Distribution: bus (EB, vs NTS)

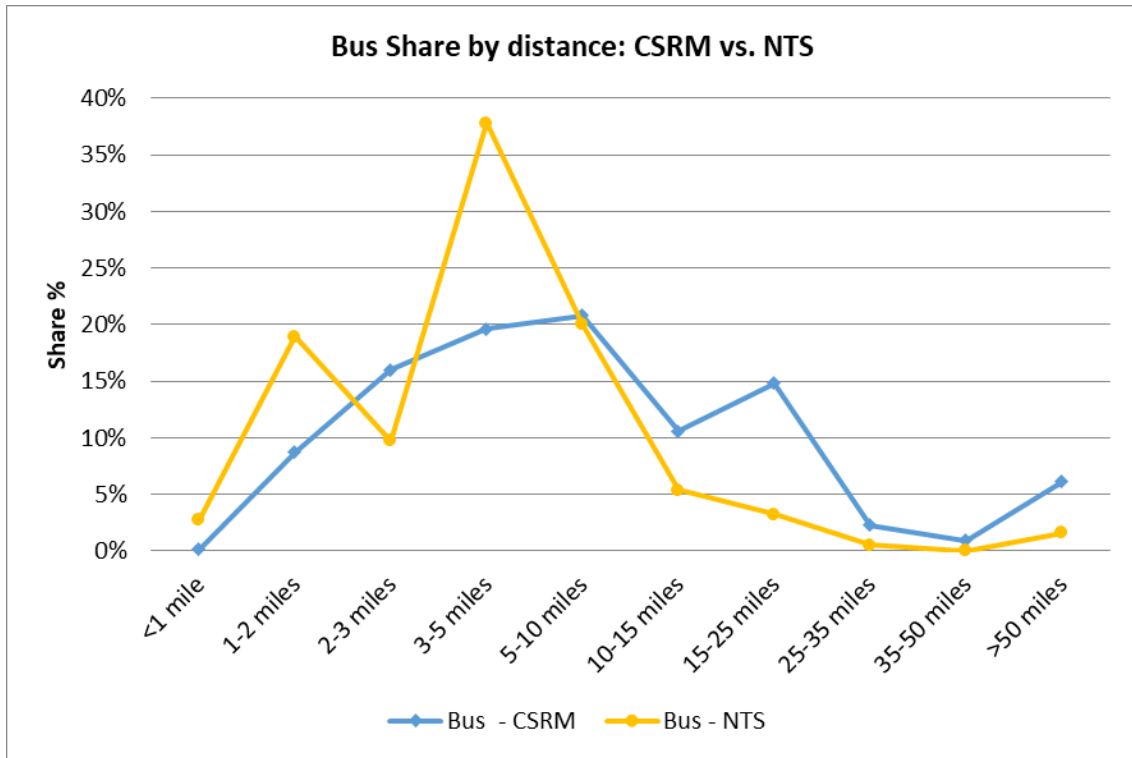


Figure E-16 - Trip Length Distribution: rail (EB, vs NTS)

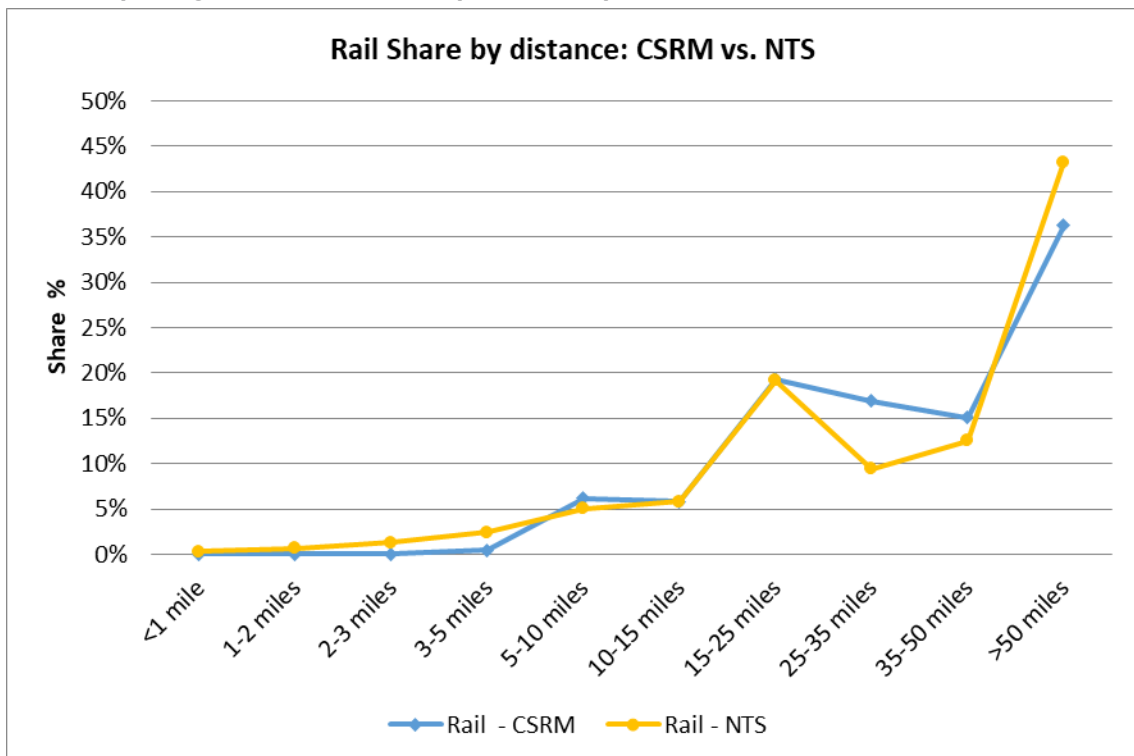


Figure E-17 - Trip Length Distribution: cycle (EB, vs NTS)

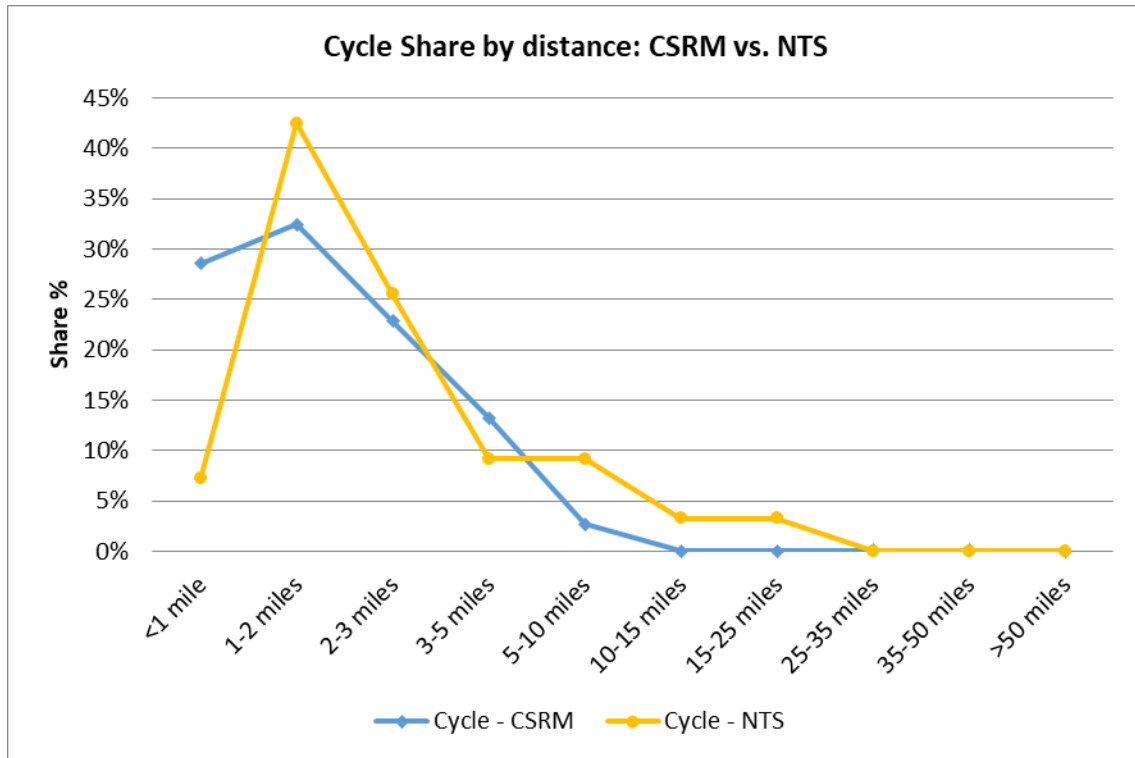
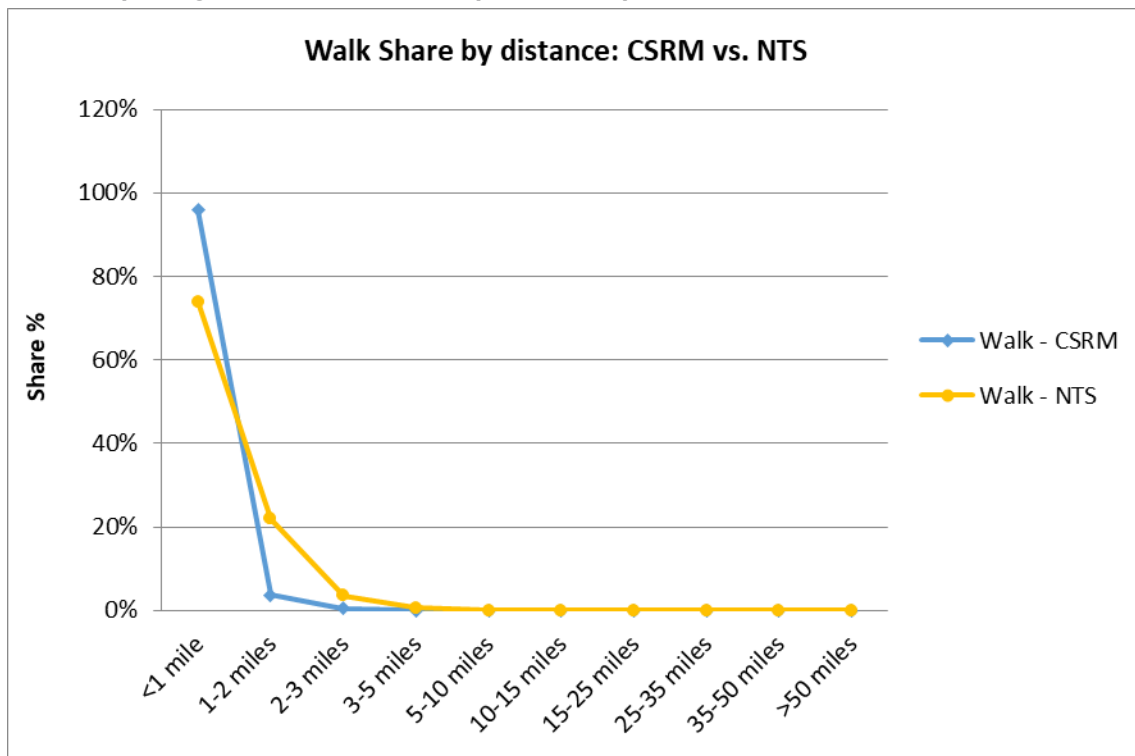


Figure E-18 - Trip Length Distribution: walk (EB, vs NTS)



E.4. Comparisons between CSRM2 2011 and NTS 2012-2014, Education

Figure E-19 - Trip Length Distribution: all modes (Edu, vs NTS)

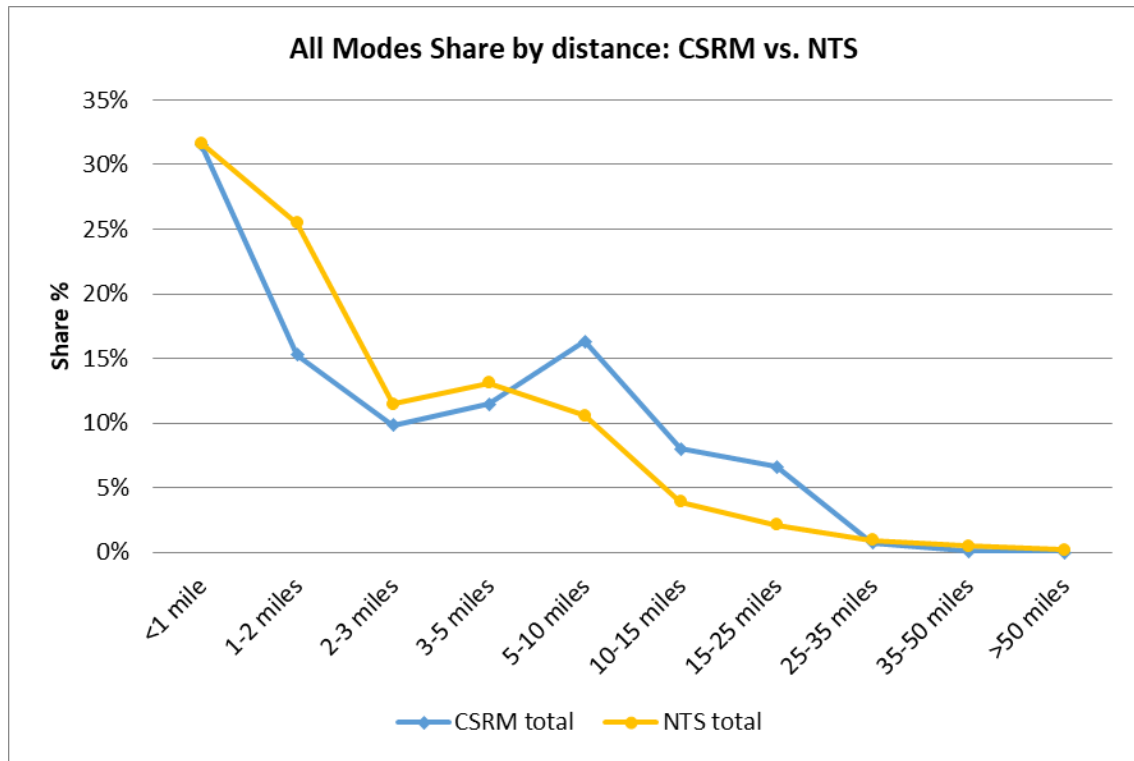


Figure E-20 - Trip Length Distribution: car (Edu, vs NTS)

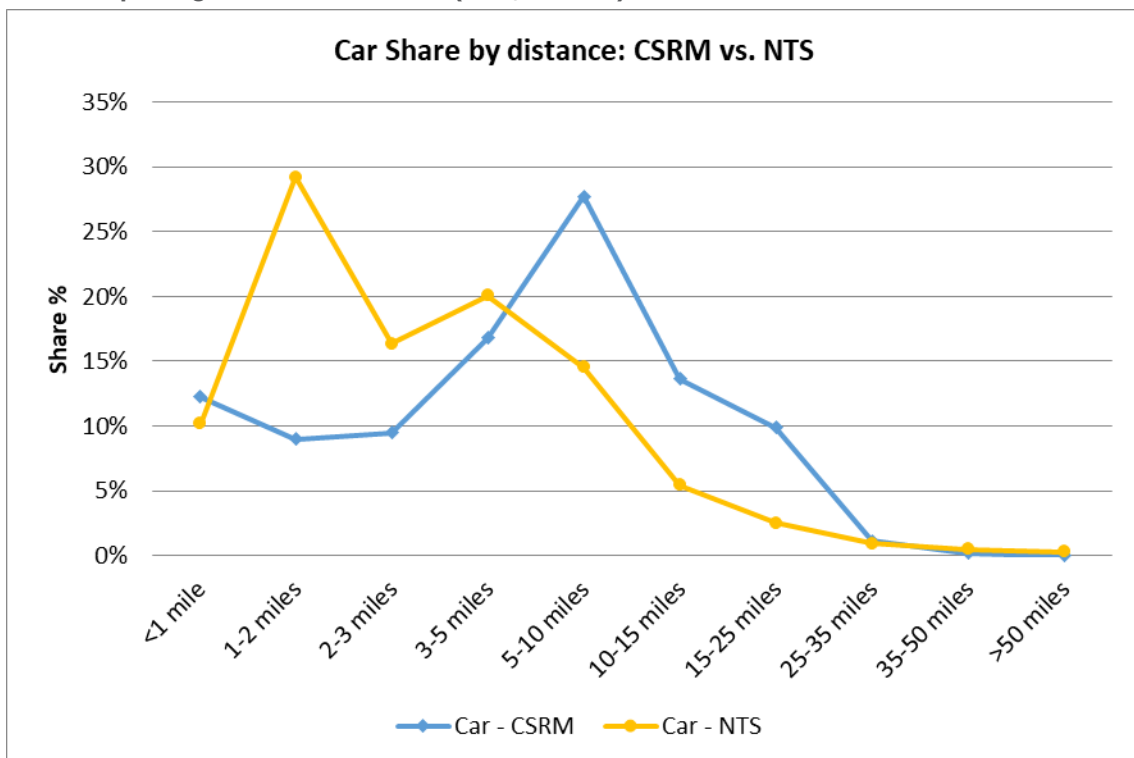


Figure E-21 - Trip Length Distribution: bus (Edu, vs NTS)

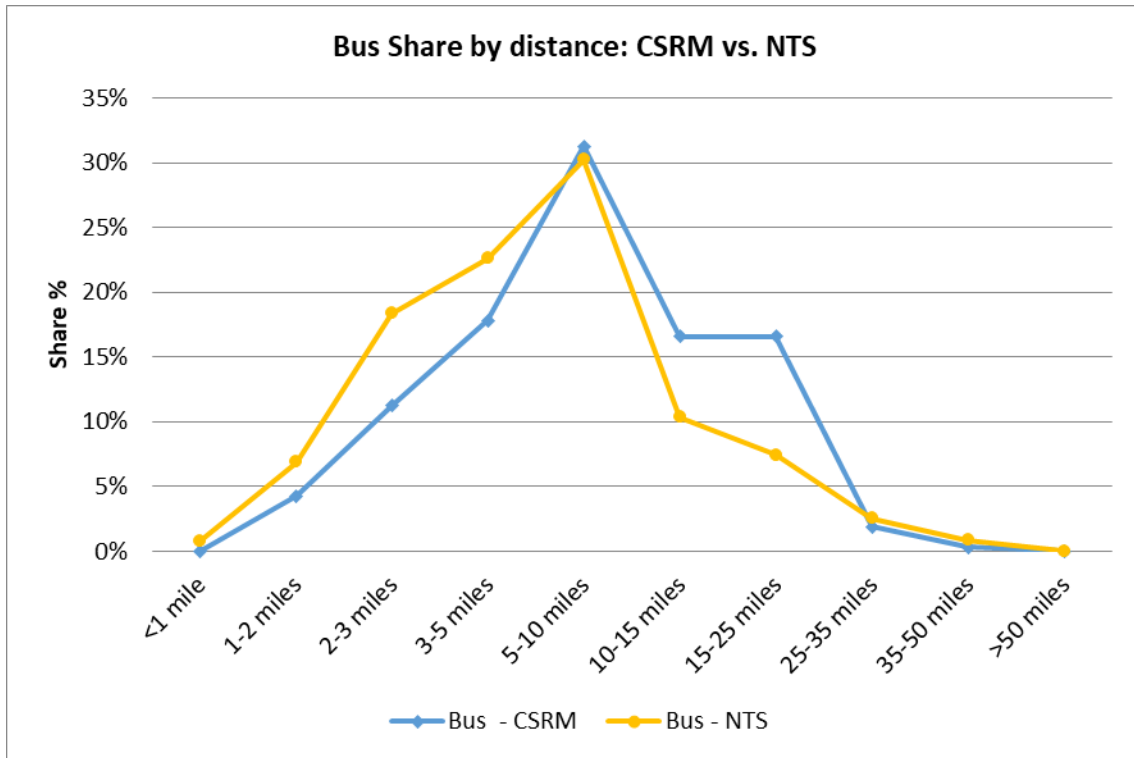


Figure E-22 - Trip Length Distribution: rail (Edu, vs NTS)

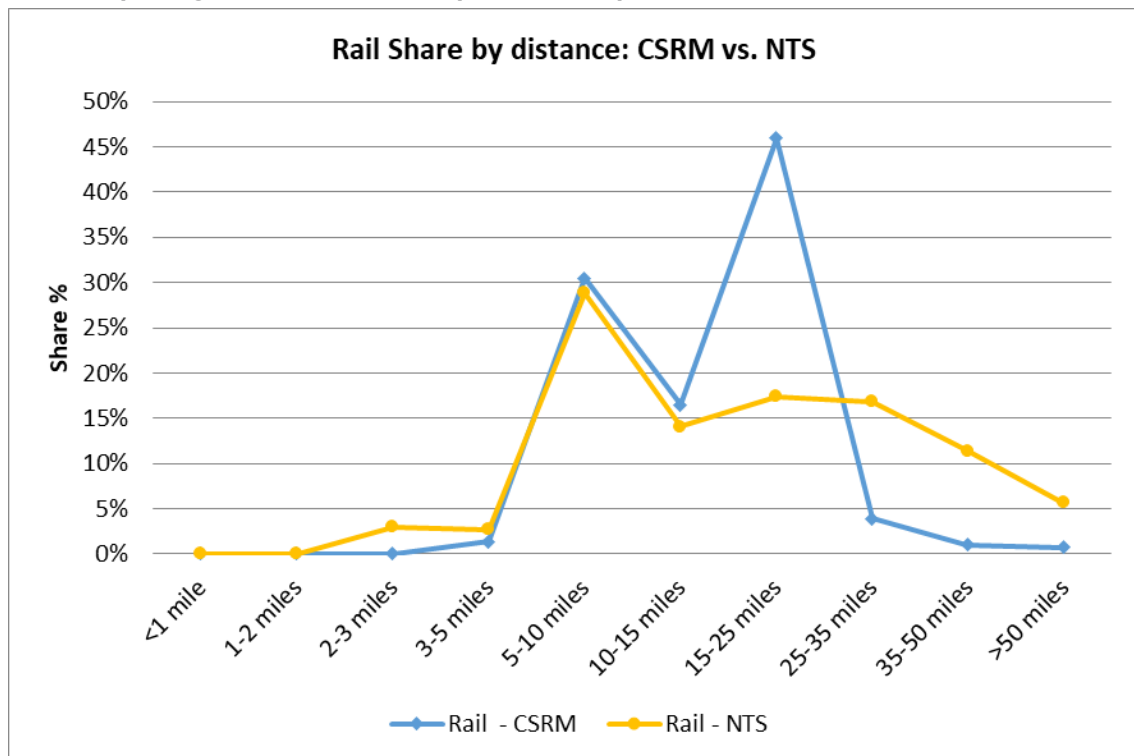


Figure E-23 - Trip Length Distribution: cycle (Edu, vs NTS)

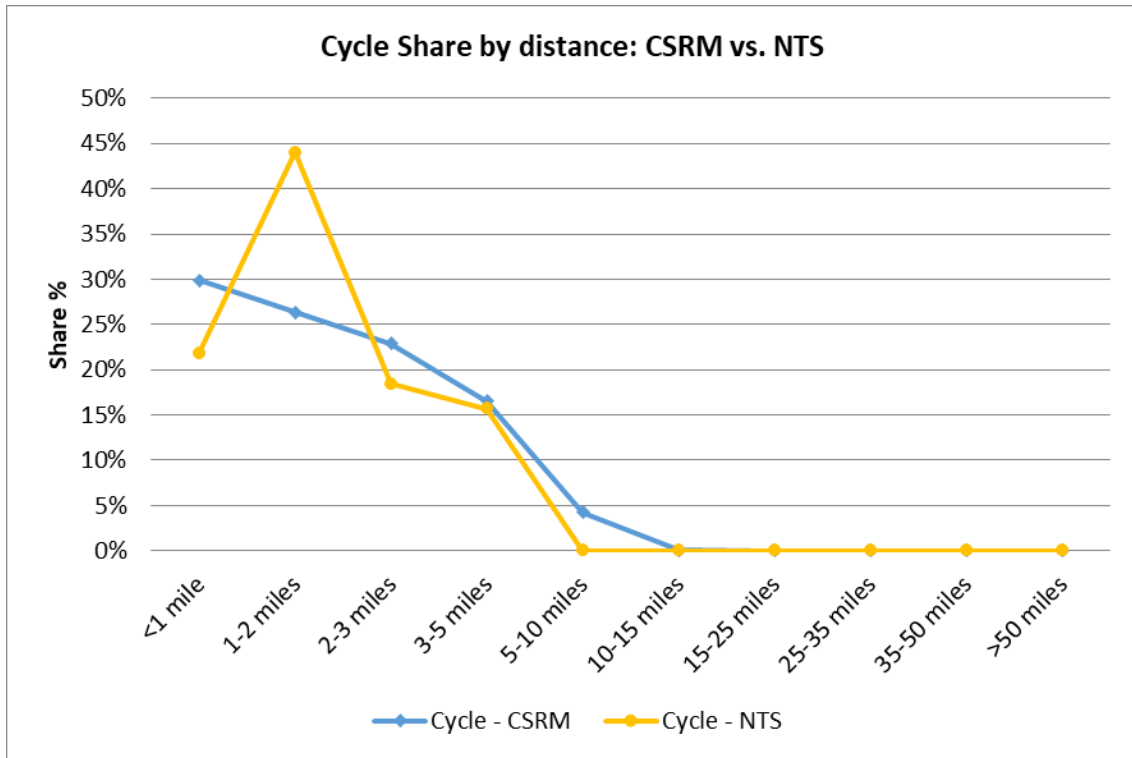
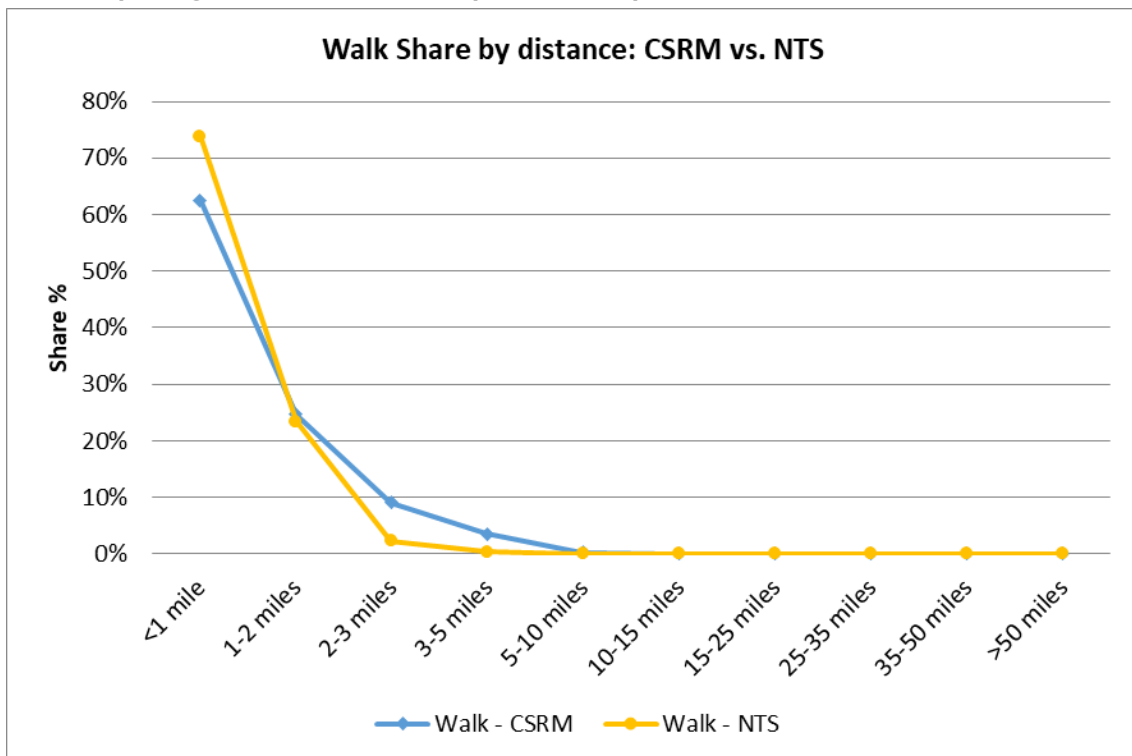


Figure E-24 - Trip Length Distribution: walk (Edu, vs NTS)



E.5. Comparisons between CSRM2 2011 and NTS 2012-2014, Discretionary Purposes

Figure E-25 - Trip Length Distribution: all modes (Other, vs NTS)

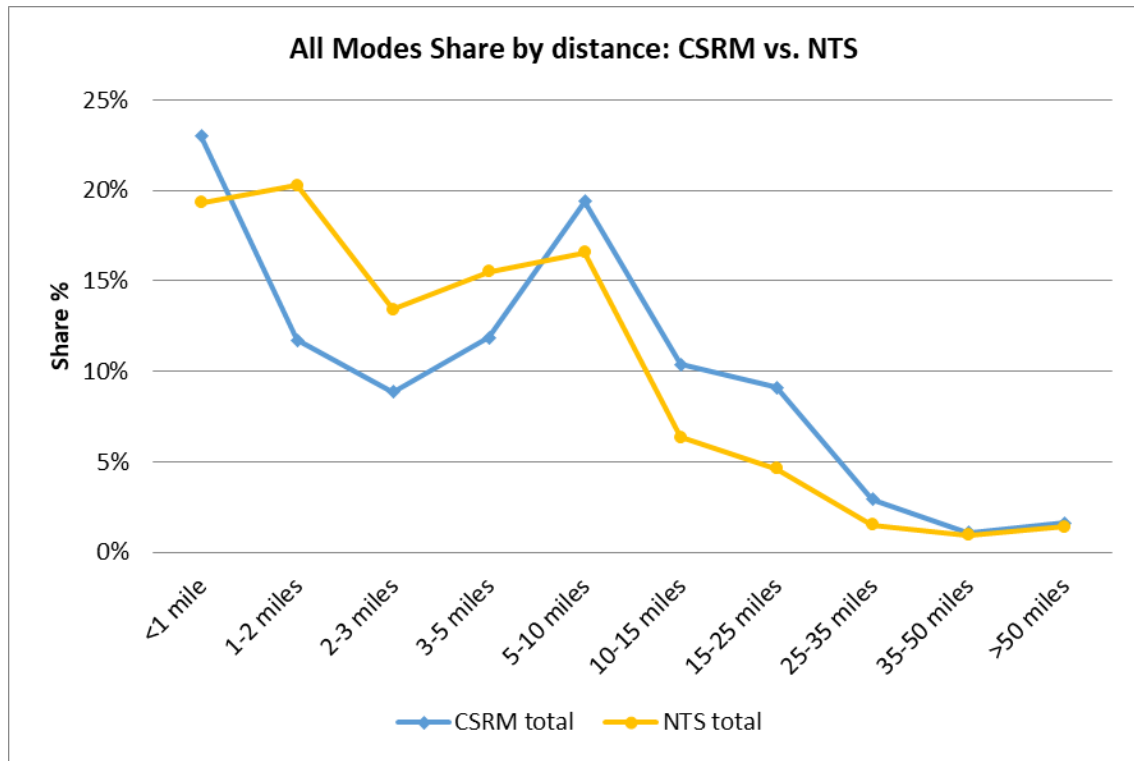


Figure E-26 - Trip Length Distribution: car (Other, vs NTS)

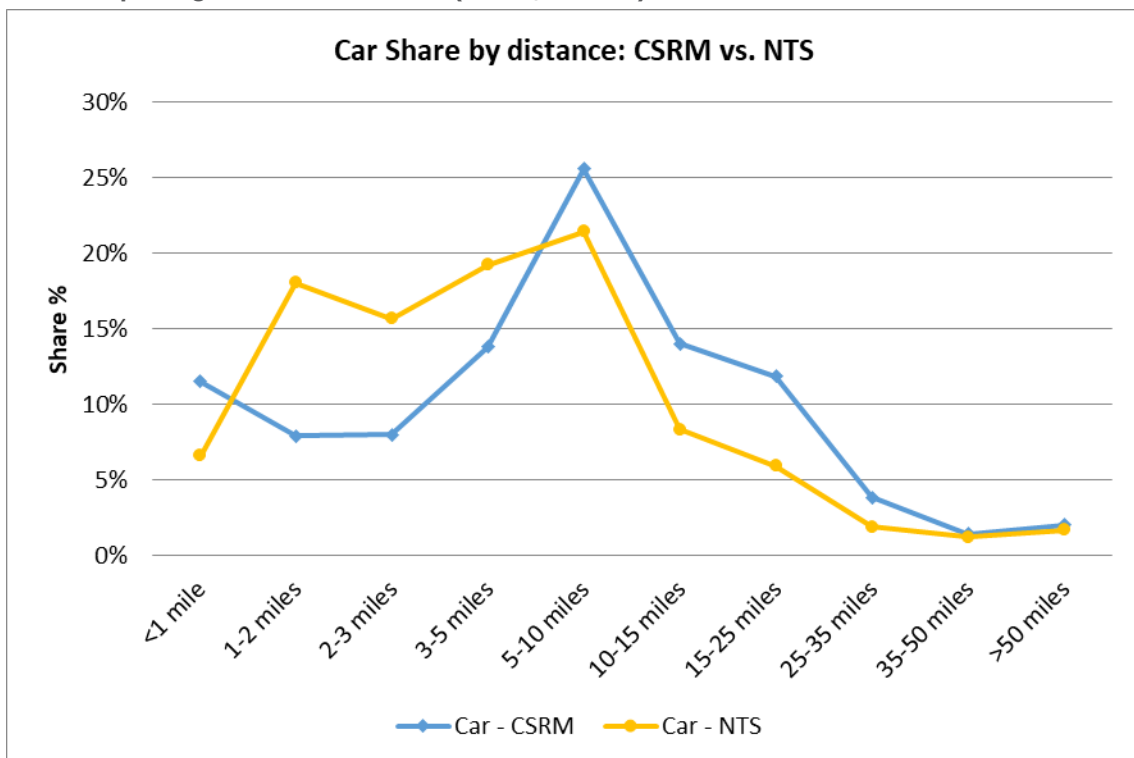


Figure E-27 - Trip Length Distribution: bus (Other, vs NTS)

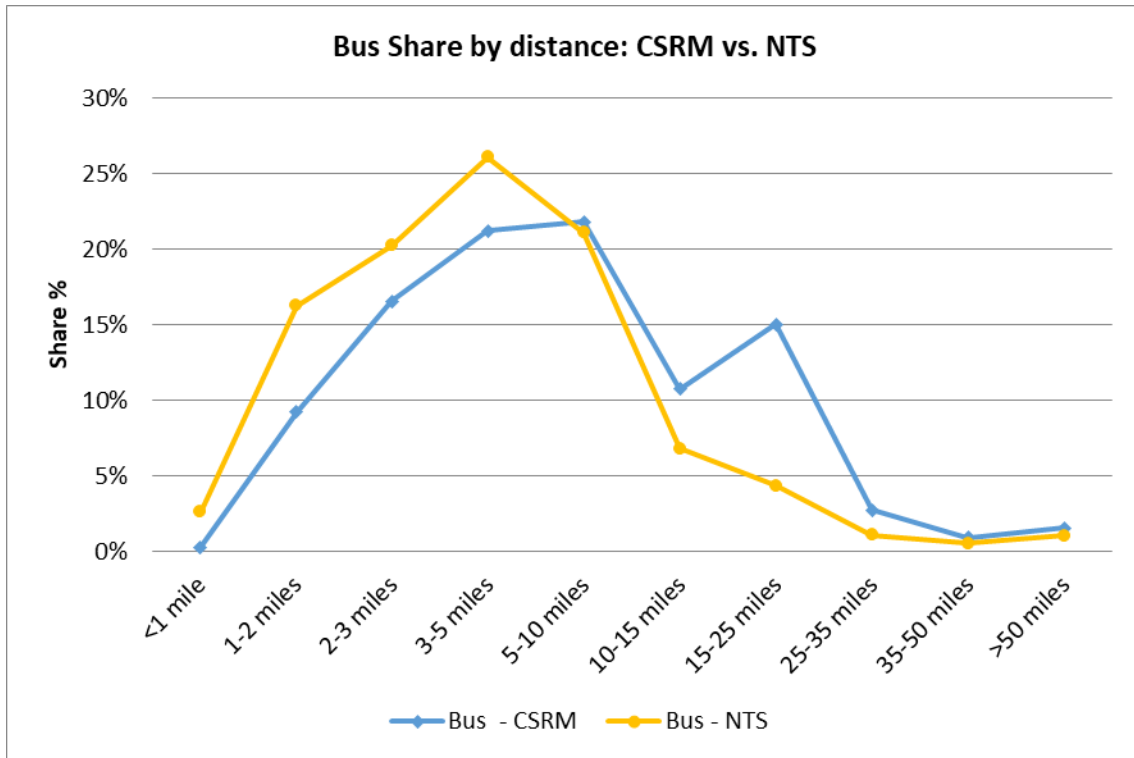


Figure E-28 - Trip Length Distribution: rail (Other, vs NTS)

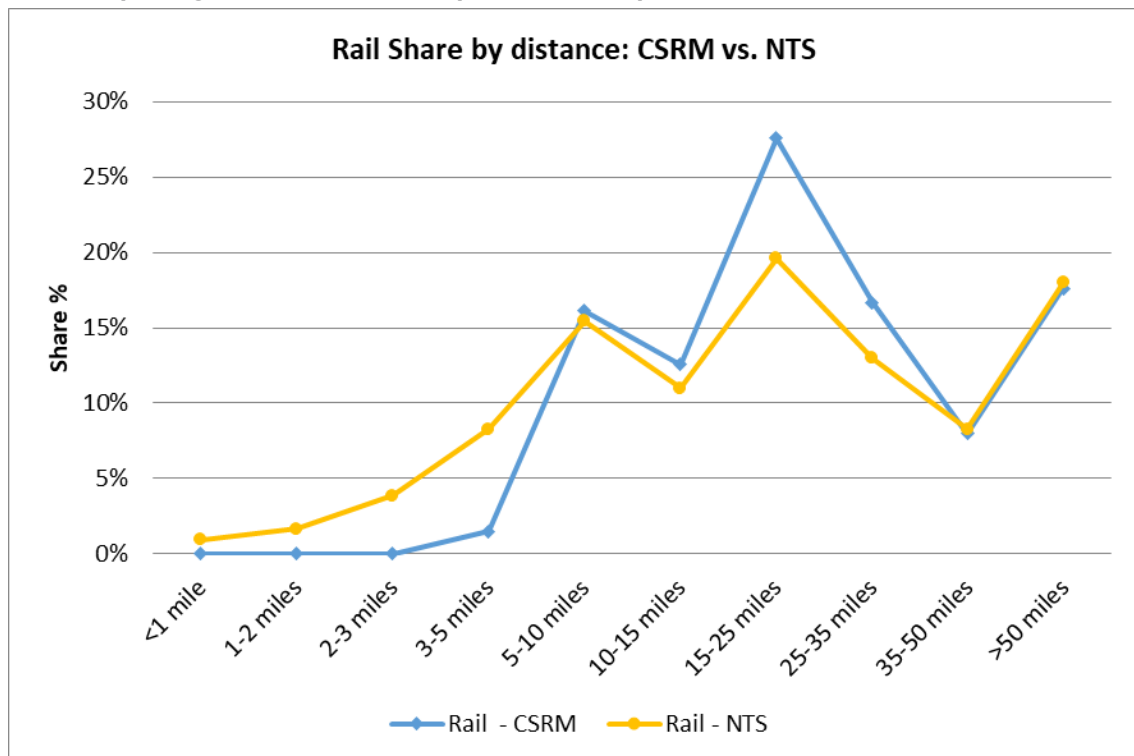


Figure E-29 - Trip Length Distribution: cycle (Other, vs NTS)

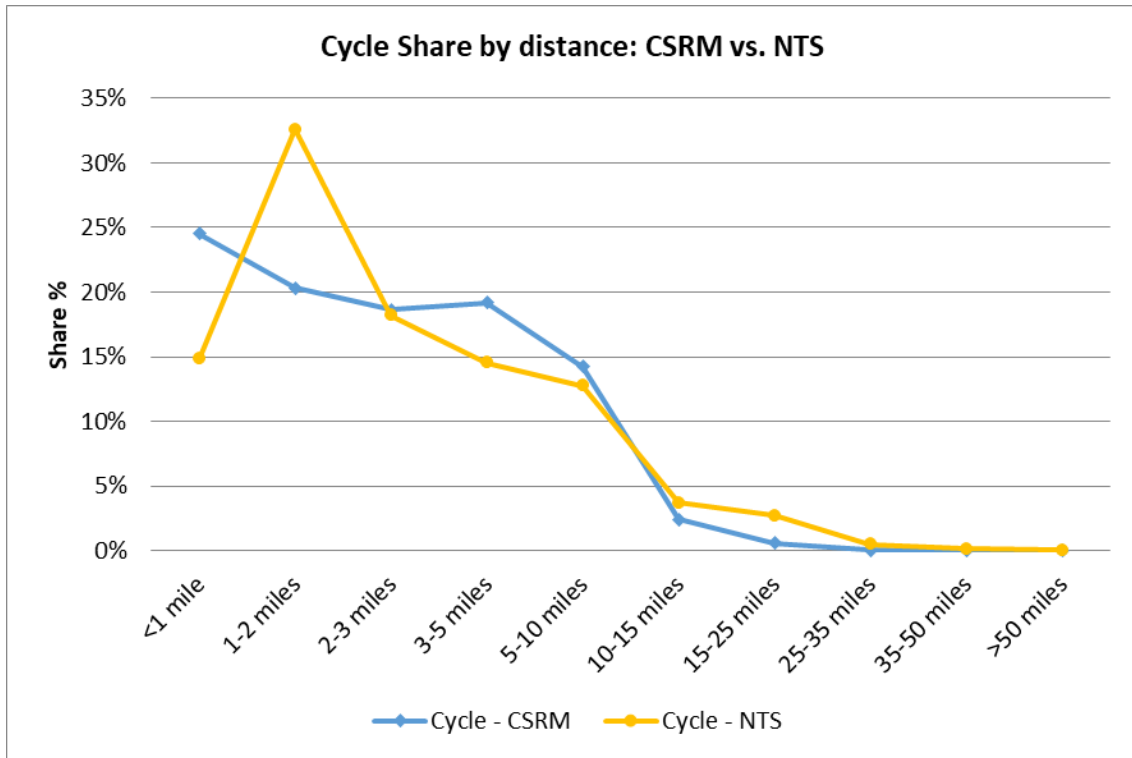
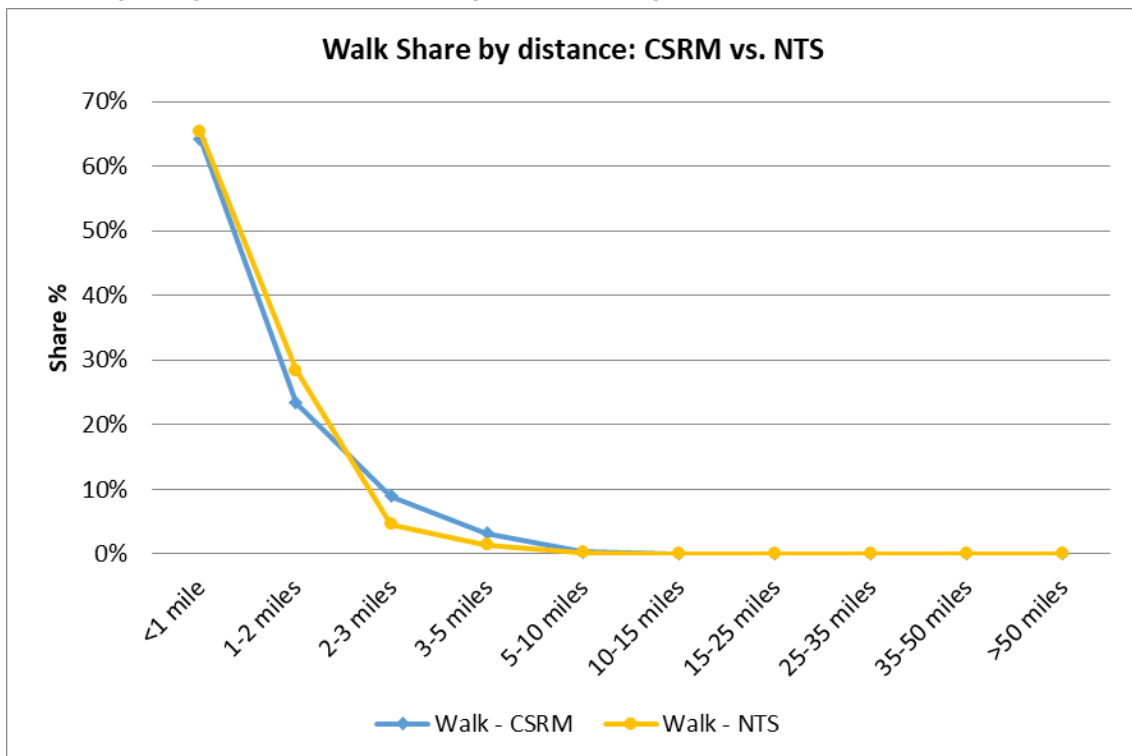


Figure E-30 - Trip Length Distribution: walk (Other, vs NTS)



Appendix F. Additional Model Definitions

F.1. Flow Type Definitions

Table F-1 - Flow Type Definitions in CSRM2 F-series

Flow ID	Description
1	AM, commuting, walk (all income groups)
2	AM, commuting, cycle (all income groups)
3	AM, commuting, car – from home, high income
4	AM, commuting, car – to home, high income
5	AM, commuting, rail (no car), high income
6	AM, commuting, bus, high income
7	AM, commuting, guided bus, high income
10	AM, commuting, rail – P&R at local stations – from home, high income
11	AM, commuting, rail – P&R at Cambridge central station – from home, high income
12	AM, commuting, rail – P&R at Huntingdon station – from home, high income
13	AM, commuting, rail – P&R at Ely station – from home, high income
14	AM, commuting, rail – P&R at St Neots station – from home, high income
15	AM, commuting, rail – P&R at Cambridge North station – from home, high income
16	AM, commuting, rail – P&R at Royston station – from home, high income
18	AM, commuting, rail – P&R at Whittlesford station – from home, high income
20	AM, commuting, bus P&R – Milton – from home, high income
21	AM, commuting, bus P&R – Newmarket Road – from home, high income
22	AM, commuting, bus P&R – Babraham Road – from home, high income
23	AM, commuting, bus P&R – Trumpington – from home, high income
24	AM, commuting, bus P&R – Madingley Road – from home, high income
30	AM, commuting, bus P&R – St Ives – from home, high income
31	AM, commuting, bus P&R – Longstanton – from home, high income
39	AM, commuting, rail – P&R at local stations – to home, high income
40	AM, commuting, rail – P&R at Cambridge central station – to home, high income
41	AM, commuting, rail – P&R at Huntingdon station – to home, high income
42	AM, commuting, rail – P&R at Ely station – to home, high income
43	AM, commuting, rail – P&R at St Neots station – to home, high income
44	AM, commuting, rail – P&R at Cambridge North station – to home, high income
45	AM, commuting, rail – P&R at Royston station – to home, high income
47	AM, commuting, rail – P&R at Whittlesford station – to home, high income
53 - 97	AM, commuting – as 3 - 45 above, but middle income group
103 - 147	AM, commuting – as 3 - 45 above, but low income group

Flow ID	Description
149	AM, commuting, bus P&R – Milton – to home, high income
150	AM, commuting, bus P&R – Newmarket Road – to home, high income
151	AM, commuting, bus P&R – Babraham Road – to home, high income
152	AM, commuting, bus P&R – Trumpington – to home, high income
153	AM, commuting, bus P&R – Madingley Road – to home, high income
159	AM, commuting, bus P&R – St Ives – to home, high income
160	AM, commuting, bus P&R – Longstanton – to home, high income
166 - 177	AM, commuting, bus P&R to home – as 159 - 160 above, but middle income group
183 - 194	AM, commuting, bus P&R to home – as 159 - 160 above, but low income group
201 - 394	AM – as 101 - 194 above, but employer's business instead of commuting
401 - 594	AM – as 101 - 194 above, but education instead of commuting
601 - 794	AM – as 101 - 194 above, but discretionary purposes instead of commuting
1001 - 1794	As 101 - 794 above, but IP instead of AM
2001 - 2794	As 101 - 794 above, but PM instead of AM
3001 – 3794	Off peak: only implemented for 'car from home' following the pattern for other periods above (i.e. 3003, 3053, 3103, etc.)

F.2. User Mode Definitions

Table F-2 - User Mode Definitions in CSRM2 F-series 2015 and 2019

User Mode ID	Description
1	AM walk
2	AM cycle
3	AM rail, no car
4	AM car
5	AM bus
6	AM guided bus
9	AM rail – P&R at Cambridge central station, from home
10	AM rail – P&R at Huntingdon station, from home
11	AM rail – P&R at Ely station, from home
12	AM rail – P&R at St Neots station, from home
13	AM rail – P&R at local stations, from home
14	AM rail – P&R at Cambridge North station, from home
15	AM rail – P&R at Royston station, from home
17	AM rail – P&R at Whittlesford station, from home
19	AM bus P&R – Milton, from home
20	AM bus P&R – Newmarket Road, from home
21	AM bus P&R – Babraham Road, from home

User Mode ID	Description
22	AM bus P&R – Trumpington, from home
23	AM bus P&R – Madingley Road, from home
24	AM bus P&R – St Ives, from home
25	AM bus P&R – Longstanton, from home
38	AM rail – P&R at Cambridge central station, to home
39	AM rail – P&R at Huntingdon station, to home
40	AM rail – P&R at Ely station, to home
41	AM rail – P&R at St Neots station, to home
42	AM rail – P&R at local stations, to home
43	AM rail – P&R at Cambridge North station, to home
44	AM rail – P&R at Royston station, to home
46	AM rail – P&R at Whittlesford station, to home
48	AM bus P&R – Milton, to home
49	AM bus P&R – Newmarket Road, to home
50	AM bus P&R – Babraham Road, to home
51	AM bus P&R – Trumpington, to home
52	AM bus P&R – Madingley Road, to home
53	AM bus P&R – St Ives, to home
54	AM bus P&R – Longstanton, to home
65	AM P&A – Milton, from home
66	AM P&A – Newmarket Road, from home
67	AM P&A – Babraham Road, from home
68	AM P&A – Trumpington, from home
69	AM P&A – Madingley Road, from home
70	AM P&A – St Ives, from home
71	AM P&A – Longstanton, from home
82	AM P&A – Milton, to home
83	AM P&A – Newmarket Road, to home
84	AM P&A – Babraham Road, to home
85	AM P&A – Trumpington, to home
86	AM P&A – Madingley Road, to home
87	AM P&A – St Ives, to home
88	AM P&A – Longstanton, to home
101 - 188	As 1 - 88 but for IP instead of AM
201 - 288	As 1 - 88 but for PM instead of AM

Nicola Price
Atkins Limited
5 Wellbrook Court
Girton Road
Cambridge
CB3 0NA

Tel: +44 (0)1223 276002
Fax: +44 (0)1223 277529