REGIONAL MODELLING SYSTEM

Western Regional Model

Road Model Development Report

Údarás Náisiúnta Iompair
National Transport Authority

CONTENTS

1 Introduction 1
1.1 Background 1
1.2 Regional Modelling System Structure 3
1.2.1 National Demand Forecasting Model (NDFM) 3
1.2.2 Regional Models (RM) 3
1.2.3 Appraisal Modules 4
1.3 WRM Road Model Overview 6
1.3.1 RMS Road Model Specification 6
1.3.2 Structure of RMS Road Model 6
1.3.3 The Purpose of the Road Model 6
1.3.4 Linkages with Overall WRM Transport Model 7
1.3.5 WRM Zone System 7
1.3.6 Software 9
1.4 This Report 9

2 Road Model Development 10
2.1 Introduction 10
2.2 Road Network Development 10
2.2.1 Overview 10
2.2.2 Expansion of Galway Interim Model (GIM) 10
2.2.3 Simulation Area Coding 11
2.2.4 Buffer Area Coding 12
2.2.5 Coding of Zone Centroids 13
2.2.6 Public Transport Service Files 14
2.2.7 Vehicle Restrictions 14
2.2.8 Tolling 14
2.2.9 Speed Flow Curves 15
2.3 Assignment Model Preparation 15
2.3.1 Network Checking 15
2.3.2 Assignment Parameter Updating 15

3 Matrix Development 17
3.1 Overview 17
3.2 GIM Expansion 17
3.2.1 Introduction 17
3.2.2 Data Sources for Expansion Files 17
3.2.3 Matrix Comparison 17
3.2.4 Inclusion of RMSIT trips 19
3.2.5 Internal Goods Vehicle Trips 20
3.3 Final WRM Initial Trip Matrices 21
3.4 Prior Matrix Factoring 21
3.5 Prior Matrix Checking 22

4 Data Collation and Review 24

4.1 Supply Data ... 24
4.2 Demand Data ... 24
4.2.1 Commute and Education Matrices ... 24
4.2.2 Other Purposes ... 24
4.2.3 Goods Vehicles ... 25
4.3 Count Data ... 25
4.4 Journey Time and Queue Length Data ... 26
4.4.1 GPS-based Travel Time Data ... 26
4.4.2 Queue Length Data ... 28

5 Road Model Calibration ... 29
5.1 Introduction ... 29
5.2 Assignment Calibration Process ... 29
5.2.1 Overview ... 29
5.2.2 Calibration ... 29
5.3 Initial Generalised Cost Parameters ... 31
5.4 Initial Road Model Network Progression ... 32
5.4.1 Overview ... 32
5.4.2 Network Refinement ... 33
5.4.3 Increase in Average PCU Length (SATURN Parameter ALEX) ... 34
5.4.4 Revised Cost Base ... 34
5.4.5 Period-to-Hour Factor ... 35
5.4.6 Interim Calibration Statistics ... 35
5.5 Final Road Model Network Progression ... 35
5.5.1 Network Improvements ... 35
5.5.2 Zone Connection Review ... 35
5.5.3 Detailed Network Audit ... 36
5.6 Road Model Matrix Progression ... 41
5.6.1 Overview ... 41
5.6.2 Expanded GIM Matrices ... 42
5.6.3 Initial FDM Matrices ... 42
5.6.4 Revised FDM Matrices ... 42
5.6.5 Matrix Estimation ... 43
5.6.6 Incremental Matrix Calculation ... 43
5.6.7 Final Incremental Matrices ... 43
5.7 Final generalised cost parameters ... 44
5.8 Road Model Network Calibration ... 47
5.8.1 Overview ... 47
5.8.2 Traffic Count Locations ... 47
5.8.3 Individual link calibration criteria compliance – AM Peak ... 48
5.8.4 Screenline calibration criteria compliance – AM Peak ... 49
5.8.5 Individual Link Calibration Criteria Compliance – Inter-peak 1 ... 50
5.8.6 Screenline calibration criteria compliance – Inter-peak 1 ... 50
5.8.7 Individual Link Calibration Criteria Compliance – Inter-peak 2 ... 51
5.8.8 Screenline calibration criteria compliance – Inter-peak 2 ... 52
5.8.9 Individual Link Calibration Criteria Compliance – PM Peak ... 53
5.8.10 Screenline Calibration Criteria Compliance – PM Peak ... 53

5.9 Road Model Matrix Calibration ... 54
5.9.1 Overview ... 54
5.9.2 Calibration criteria compliance – AM Peak ... 54
5.9.3 Calibration criteria compliance – Inter-peak 1 ... 58
5.9.4 Calibration criteria compliance – Inter-peak 2 ... 62
5.9.5 Calibration criteria compliance – PM peak ... 65
5.10 Calibration summary ... 69
5.10.1 Overview ... 69
5.10.2 Traffic count observations ... 70
5.10.3 Matrix observations ... 70

6 Road Model Validation ... 71
6.1 Introduction ... 71
6.2 Assignment validation process ... 71
6.2.1 Overview ... 71
6.2.2 Validation Criteria ... 71
6.2.3 Traffic volume comparison ... 72
6.2.4 Trip length distribution ... 72
6.2.5 Journey times ... 72
6.3 Traffic volume validation ... 73
6.3.1 Overview ... 73
6.3.2 Traffic count locations ... 73
6.3.3 Validation criteria compliance – AM peak ... 73
6.3.4 Validation criteria compliance – Inter-peak 1 ... 74
6.3.5 Validation criteria compliance – Inter-peak 2 ... 75
6.3.6 Validation criteria compliance – PM peak ... 75
6.4 Trip length distribution analysis ... 76
6.4.1 Overview ... 76
6.4.2 Trip length distribution analysis ... 76
6.5 Journey time validation ... 77
6.5.1 Overview ... 77
6.5.2 Journey Time Routes ... 77
6.5.3 Validation Criteria Compliance – AM Peak ... 78
6.5.4 Validation Criteria Compliance – Inter-peak 1 ... 78
6.5.5 Validation Criteria Compliance – Inter-peak 2 ... 79
6.5.6 Validation Criteria Compliance – PM Peak ... 80
6.6 Validation summary ... 80
6.6.1 Overview ... 80
6.6.2 Traffic count observations ... 80
6.6.3 Trip Length Distribution Observations ... 81
6.6.4 Journey Time Observations ... 81
6.6.5 Validation Observation Summary ... 82

7 Conclusion and recommendations ... 83
7.1 Summary ... 83
7.2 Road Model Development ... 83
7.3 Road Model Calibration ... 83
7.4 Road Model Validation ... 86

7.5 Recommendations 86
Appendix A 88
Appendix B 89
Appendix C 90
Appendix D 91
Appendix E 92
Appendix F 93

TABLES

Table 1.1 Regional Models and their Population Centres 1
Table 2.1 WRM User Classes 11
Table 3.1 AM Peak – Road Trip Matrices – GIM Model 19
Table 3.2 AM Peak – Road Trip Matrices – Expanded WRM Matrices 20
Table 3.3 AM Peak – Road Trip Matrices –WRM Matrices to generate Costs 20
Table 3.4 Use of Prior Matrix Process 21
Table 3.5 WRM RM Initial Period to Assigned Hour Factors 22
Table 3.6 WRM RM Final “demand” Period to Assigned Hour Factors 22
Table 4.1 TomTom Journey Time Routes 27
Table 5.1 Significance of Matrix Estimation Changes 30
Table 5.2 Road Assignment Model Calibration Guidance Source 30
Table 5.3 Road Assignment Model Screenline Calibration Guidance Sources 31
Table 5.4 Initial AM Generalised Cost Values 31
Table 5.5 Initial IP1 Generalised Cost Values 31
Table 5.6 Initial IP2 Generalised Cost Values 32
Table 5.7 Initial PM Generalised Cost Values 32
Table 5.8 Pre-audit Significance of Matrix Estimation Changes, AM Peak 36
Table 5.9 Pre-audit Significance of Matrix Estimation Changes, Inter-peak 1 37
Table 5.10 Pre-audit Significance of Matrix Estimation Changes, Inter-peak 2 38
Table 5.11 Pre-audit Significance of Matrix Estimation Changes, PM Peak 39
Table 5.12 Pre-Audit Road Assignment Model Calibration 40
Table 5.13 Pre-Audit Road Assignment Model Screenline Calibration 40
Table 5.14 Final AM Generalised Cost Values 44
Table 5.15 Final IP1 Generalised Cost Values 45
Table 5.16 Final IP2 Generalised Cost Values 45
Table 5.17 Final PM Generalised Cost Values 45
Table 5.18 AM Link Flow Calibration 48
Table 5.19 AM Screenline Flow Calibration 49
Table 5.20 Inter-peak 1 Link Flow Calibration 50
Table 5.21 Inter-peak 1 Screenline Flow Calibration 50
Table 5.22 Inter-peak 2 Link Flow Calibration 51
Table 5.23 Inter-peak 2 Screenline Flow Calibration 52
Table 5.24 PM Link Flow Calibration 53
Table 5.25 PM Screenline Flow Calibration 53

Table 5.26 WRM RM AM Peak Matrix Totals 55
Table 5.27 SATME2 AM Matrix Change R2 Analysis 56
Table 5.28 AM Trip End Matrix Change R2 Analysis 57
Table 5.29 WRM RM AM Screenline Check 57
Table 5.30 Trip Length Distribution Analysis – AM 58
Table 5.31 WRM RM Inter-peak 1 Matrix Totals 58
Table 5.32 SATME2 IP1 Matrix Change R2 Analysis 60
Table 5.33 IP1 Trip End Matrix Change R2 Analysis 60
Table 5.34 WRM RM IP1 Screenline Check 61
Table 5.35 Trip Length Distribution Analysis – IP1 61
Table 5.36 WRM RM Inter-peak 2 Matrix Totals 62
Table 5.37 SATME2 IP2 Matrix Change R2 Analysis 63
Table 5.38 IP2 Trip End Matrix Change R2 Analysis 64
Table 5.39 WRM RM IP2 Screenline Check 64
Table 5.40 Trip Length Distribution Analysis – IP2 65
Table 5.41 WRM RM PM Peak Matrix Totals 65
Table 5.42 SATME2 PM Matrix Change R2 Analysis 67
Table 5.43 PM Trip End Matrix Change R2 Analysis 68
Table 5.44 WRM RM PM Screenline Check 68
Table 5.45 Trip Length Distribution Analysis – PM 69
Table 5.46 Model Calibration Status 69
Table 6.1 Road Assignment Model Screenline Validation Criteria 71
Table 6.2 Road Assignment Model Journey Time Validation Criteria 72
Table 6.3 AM Link Flow Validation 73
Table 6.4 IP1 Link Flow Validation 74
Table 6.5 IP2 Link Flow Validation 75
Table 6.6 PM Link Flow Validation 76
Table 6.7 Percentage Change in Average Trip Length 77
Table 6.8 Percentage Change in Standard Deviation of Trip Length 77
Table 6.9 Model Validation Status 80
Table 6.10 Model Validation Identified Issues 82
Table 7.1 Significance of Matrix Estimation Changes 83
Table 7.2 Road Assignment Model Calibration Guidance Source 84
Table 7.3 Road Assignment Model Screenline Calibration Guidance Sources 85

FIGURES

Figure 1.1 Regional Model Coverage ... 2
Figure 1.2 RMS Model Structure ... 5
Figure 1.3 RMS RM Structure Overview ... 6
Figure 1.4 Zone System ... 8
Figure 3.1 West Regional Model Zoning ... 18
Figure 4.1 Location of Traffic Count Data ... 26
Figure 4.2 TomTom Journey Time Routes ... 27
Figure 5.1 Road Model Matrix Development Process ... 42
Figure 5.2 Link Calibration Target Locations ... 47
Figure 5.3 Link Calibration Target Locations – County Galway and Wider Region ... 48
Figure 5.4 SATME2 AM Matrix Change GEH Analysis; 0 GEH to 0.4 GEH ... 55
Figure 5.5 SATME2 AM Matrix Change GEH Analysis; 0.4 GEH Upwards ... 56
Figure 5.6 SATME2 IP1 Matrix Change GEH Analysis; 0 GEH to 0.4 GEH ... 59
Figure 5.7 SATME2 IP1 Matrix Change GEH Analysis; 0.4 GEH Upwards ... 59
Figure 5.8 SATME2 IP2 Matrix Change GEH Analysis; 0 GEH to 0.4 GEH ... 63
Figure 5.9 SATME2 IP2 Matrix Change GEH Analysis; 0.4 GEH Upwards ... 63
Figure 5.10 SATME2 PM Matrix Change GEH Analysis; 0 GEH to 0.4 GEH ... 66
Figure 5.11 SATME2 PM Matrix Change GEH Analysis; 0.4 GEH Upwards ... 67
Figure 6.1 Link Validation Target Locations ... 73
Figure 6.2 AM Peak Journey Time Comparison ... 78
Figure 6.3 Inter-peak 1 Journey Time Comparison ... 79
Figure 6.4 Inter-peak 2 Journey Time Comparison ... 79
Figure 6.5 PM Peak Journey Time Comparison ... 80

Foreword

The NTA has developed a Regional Modelling System (RMS) for Ireland that allows for the appraisal of a wide range of potential future transport and land use alternatives. The RMS was developed as part of the Modelling Services Framework (MSF) by the National Transport Authority (NTA), SYSTRA and Jacobs Engineering Ireland.

The National Transport Authority's (NTA) Regional Modelling System comprises the National Demand Forecasting Model, five large-scale, technically complex, detailed and multi-modal regional transport models and a suite of Appraisal Modules covering the entire national transport network of Ireland. The five regional models are focussed on the travel-to-work areas of the major population centres in Ireland, i.e. Dublin, Cork, Galway, Limerick, and Waterford.

The development of the RMS followed a detailed scoping phase informed by NTA and wider stakeholder requirements. The rigorous consultation phase ensured a comprehensive understanding of available data sources and international best practice in regional transport model development.

The five discrete models within the RMS have been developed using a common framework, tied together with the National Demand Forecasting Model. This approach used repeatable methods; ensuring substantial efficiency gains; and, for the first time, delivering consistent model outputs across the five regions.

The RMS captures all day travel demand, thus enabling more accurate modelling of mode choice behaviour and increasingly complex travel patterns, especially in urban areas where traditional nine-to-five working is decreasing. Best practice, innovative approaches were applied to the RMS demand modelling modules including car ownership; parking constraint; demand pricing; and mode and destination choice. The RMS is therefore significantly more responsive to future changes in demographics, economic activity and planning interventions than traditional models.

The models are designed to be used in the assessment of transport policies and schemes that have a local, regional and national impact and they facilitate the assessment of proposed transport schemes at both macro and micro level and are a pre-requisite to creating effective transport strategies.

1 Introduction

1.1 Background

The NTA has developed a Regional Modelling System (RMS) for the Republic of Ireland to assist in the appraisal of a wide range of potential future transport and land use options. The Regional Models (RM) are focused on the travel-to-work areas of the major population centres of Dublin, Cork, Galway, Limerick, and Waterford. The models were developed as part of the Modelling Services Framework by NTA, SYSTRA and Jacobs Engineering Ireland.

An overview of the 5 regional models is presented below in both Table 1.1 and Figure 1.1.

Table 1.1 Regional Models and their Population Centres

Model Name	Standard Abbreviation	Counties
West Regional Model	WRM	Galway, Mayo, Roscommon, Sligo, Leitrim, Donegal
East Regional Model	ERM	Dublin, Wicklow, Kildare, Meath, Louth, Wexford, Carlow, Laois, Offaly, Westmeath, Longford, Cavan, Monaghan
Mid-West Regional Model	MWRM	Limerick, Clare, Tipperary North
South East Regional Model	SERM	Waterford, Wexford, Carlow, Tipperary South
South West Regional Model	WRM	Cork and Kerry

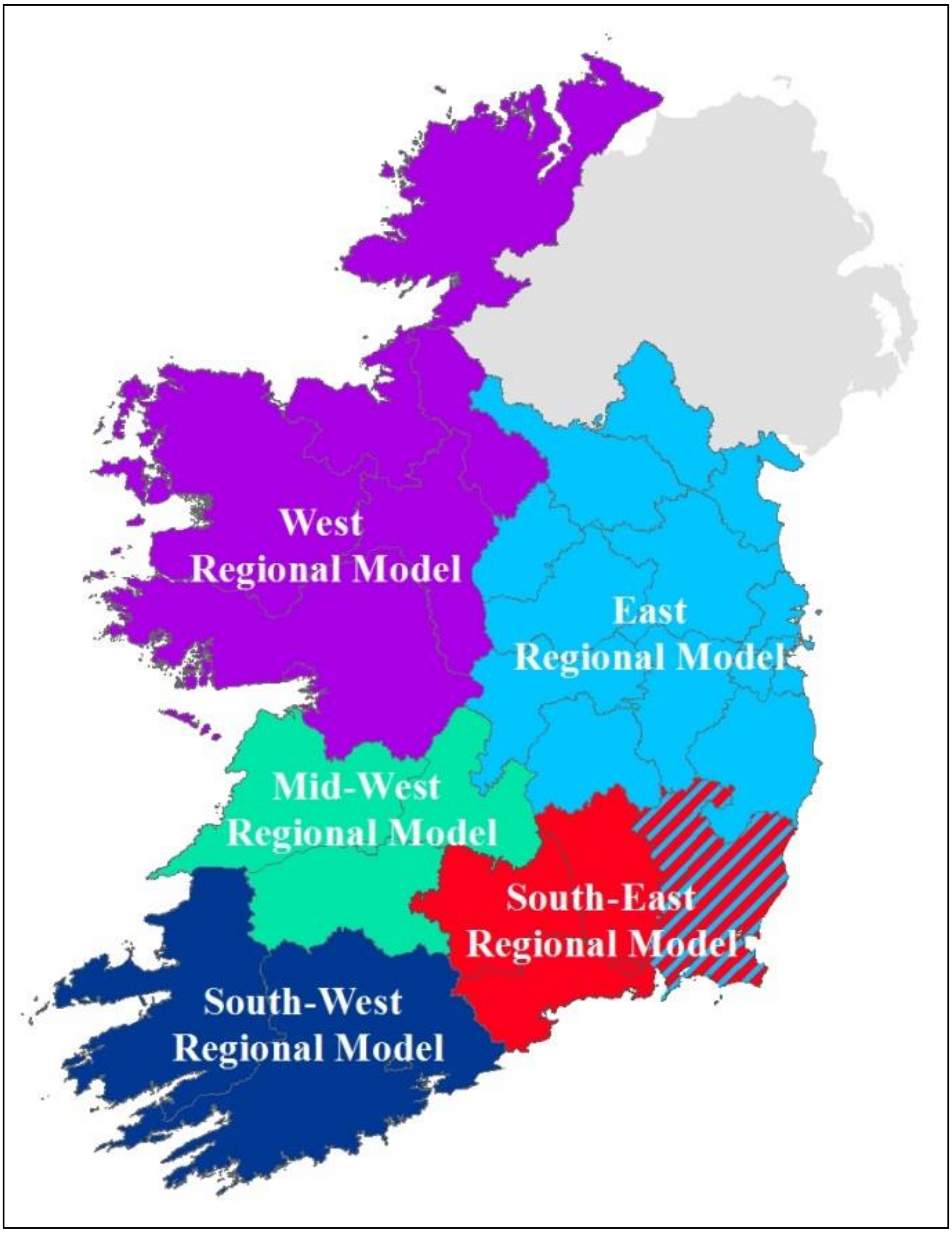

Figure 1.1 Regional Model Coverage

1.2 Regional Modelling System Structure

The Regional Modelling System is comprised of three main components, namely:

- The National Demand Forecasting Model (NDFM);
- 5 Regional Models; and
- A suite of Appraisal Modules.

The modelling approach is consistent across each of the regional models. The general structure of the ERM (and the other regional models) is shown below in Figure 1.2. The main stages of the regional modelling system are described below.

1.2.1National Demand Forecasting Model (NDFM)

The NDFM is a single, national system that provides estimates of the total quantity of daily travel demand produced by and attracted to each of the 18,488 Census Small Areas. Trip generations and attractions are related to zonal attributes such as population, number of employees and other land-use data. See the NDFM Development Report for further information.

1.2.2Regional Models (RM)

A regional model is comprised of the following key elements:

Trip End Integration

The Trip End Integration module converts the 24 hour trip ends output by the NDFM into the appropriate zone system and time period disaggregation for use in the Full Demand Model (FDM).

The Full Demand Model (FDM)

The FDM processes travel demand and outputs origin-destination travel matrices by mode and time period to the assignment models. The FDM and assignment models run iteratively until an equilibrium between travel demand and the cost of travel is achieved.

See the RMS Spec1 Full Demand Model Specification Report, RM Full Demand Model Development Report and WRM Full Demand Model Calibration Report for further information.

Assignment Models

The Road, Public Transport, and Active Modes assignment models receive the trip matrices produced by the FDM and assign them in their respective transport networks to determine route choice and the generalised cost for origin and destination pair.

The Road Model assigns FDM outputs (passenger cars) to the road network and includes capacity constraint, traffic signal delay and the impact of congestion. See the RM Spec2 Road Model Specification Report for further information.

The Public Transport Model assigns FDM outputs (person trips) to the PT network and includes the impact of capacity restraint, such as crowding on PT vehicles, on people's perceived cost of travel. The model includes public transport networks and services for all PT sub-modes that operate within the modelled area. See the RM Spec3 Public Transport Model Specification Report for further information.

Secondary Analysis

The secondary analysis application can be used to extract and summarise model results from each of the regional models.

1.2.3 Appraisal Modules

The **Appraisal Modules** can be used on any of the regional models to assess the impacts of transport plans and schemes. The following impacts can be informed by model outputs (travel costs, demands and flows):

- Economy;
- Safety;
- Environmental;
- Health; and
- Accessibility and Social Inclusion.

Further information on each of the Appraisal Modules can be found in the following reports:

- Economic Module Development Report;
- Safety Module Development Report;
- Environmental Module Development Report;
- Health Module Development Report; and
- Accessibility and Social Inclusion Module Development Report.

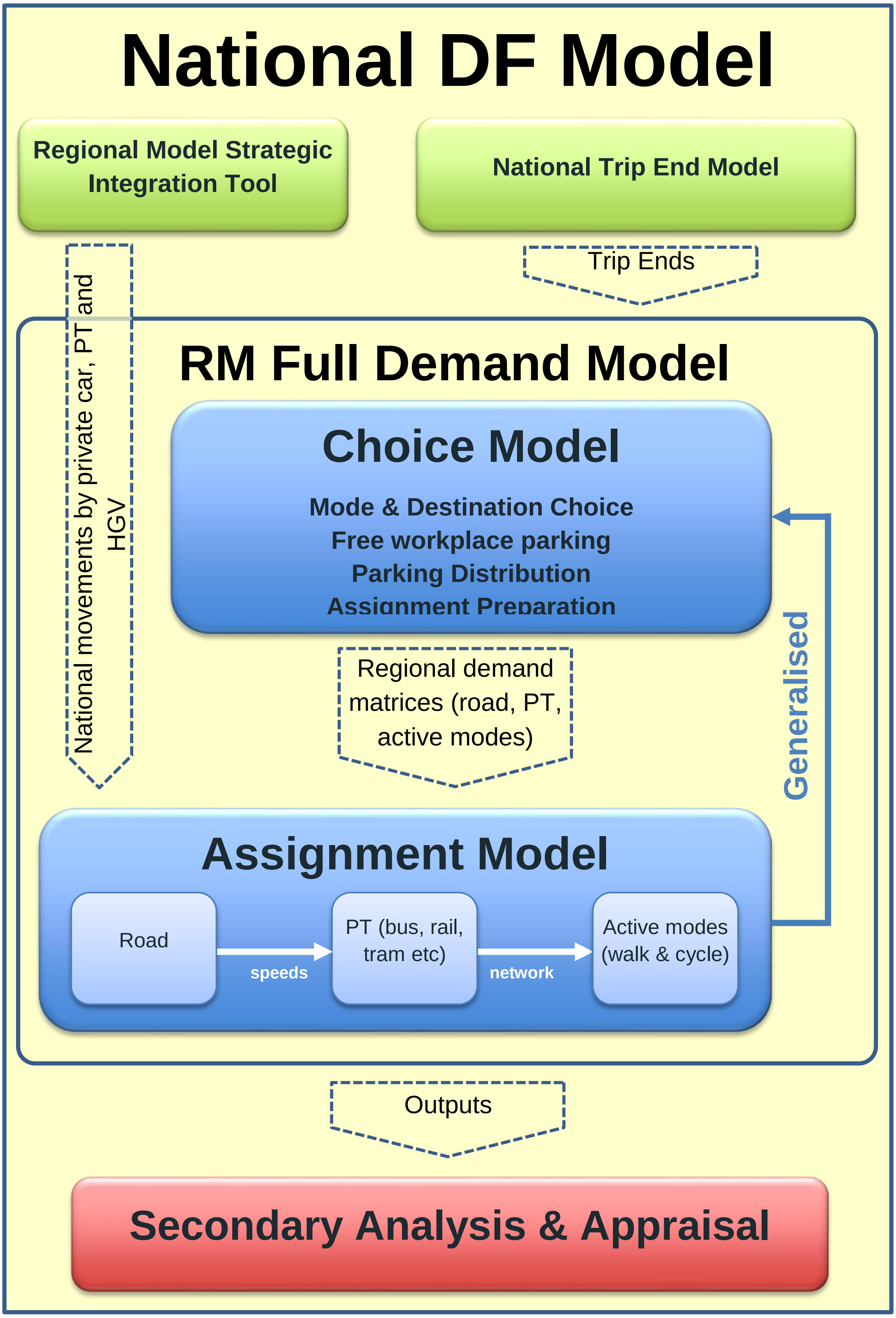

Figure 1.2 RMS Model Structure

1.3 WRM Road Model Overview

1.3.1 RMS Road Model Specification

The Regional Modelling System Road Model Specification Report was used as a guide for the development of the WRM Road Model. This specification report provides an overview with regard to:

- RMS Road Model Structure & Dimensions;
- RMS Road Network Development Approach;
- RMS Road Network Coding within SATURN;
- RMS Definition of Demand Segments for Road Model;
- RMS Road Model Assignment Methodology; and
- RMS Road Model Calibration & Validation Process.

1.3.2 Structure of RMS Road Model

Figure 1.3 provides an overview of the RMS Road Model (RM) structure. This shows the principal function of the RMS RM to represent the relationship between supply and demand through an assignment procedure and where data is an essential input to all elements of the model. This also shows the relationship with the RMS model components. The RM structure is the same for all five regional models.

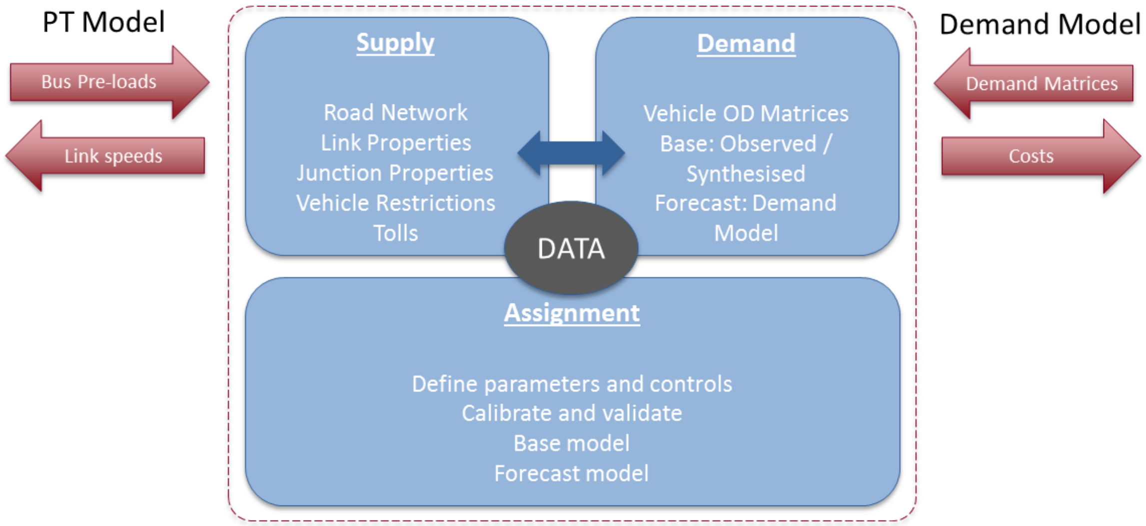

Figure 1.3 RMS RM Structure Overview

1.3.3 The Purpose of the Road Model

The purpose of the Road Model (RM) is to assign road users to routes between their origin and destination zones. The RM is sufficiently detailed to allow multiple routes between origins and destinations, and accurately model the restrictions on the available route choices.

Typical outputs from the RM that can be used directly for option development, design and appraisal include:

- vehicle flows on links;
- vehicle journey times along pre-defined routes; and
- cost of travel for economic appraisal.

1.3.4 Linkages with Overall WRM Transport Model

The development of the RM includes a number of inter-dependencies with other elements of the RMS. These linkages are discussed in later sections where relevant and can be summarised as follows.

- Inputs to the RM
  - Zone System, defining zonal boundaries for the RM;
  - Travel demand matrices provided by the FDM;
  - Pre-load bus volumes provided by the PT Model;
- Outputs from the RM
  - Provision of assigned RM network to PT Model; and
  - Provision of generalised cost skims to FDM.

1.3.5 WRM Zone System

The Road Model zone system is consistent with the zoning system specified for the overall WRM as described in the WRM Zone System Development Report. The final WRM zone system includes 693 zones and is illustrated in Figure 1.4.

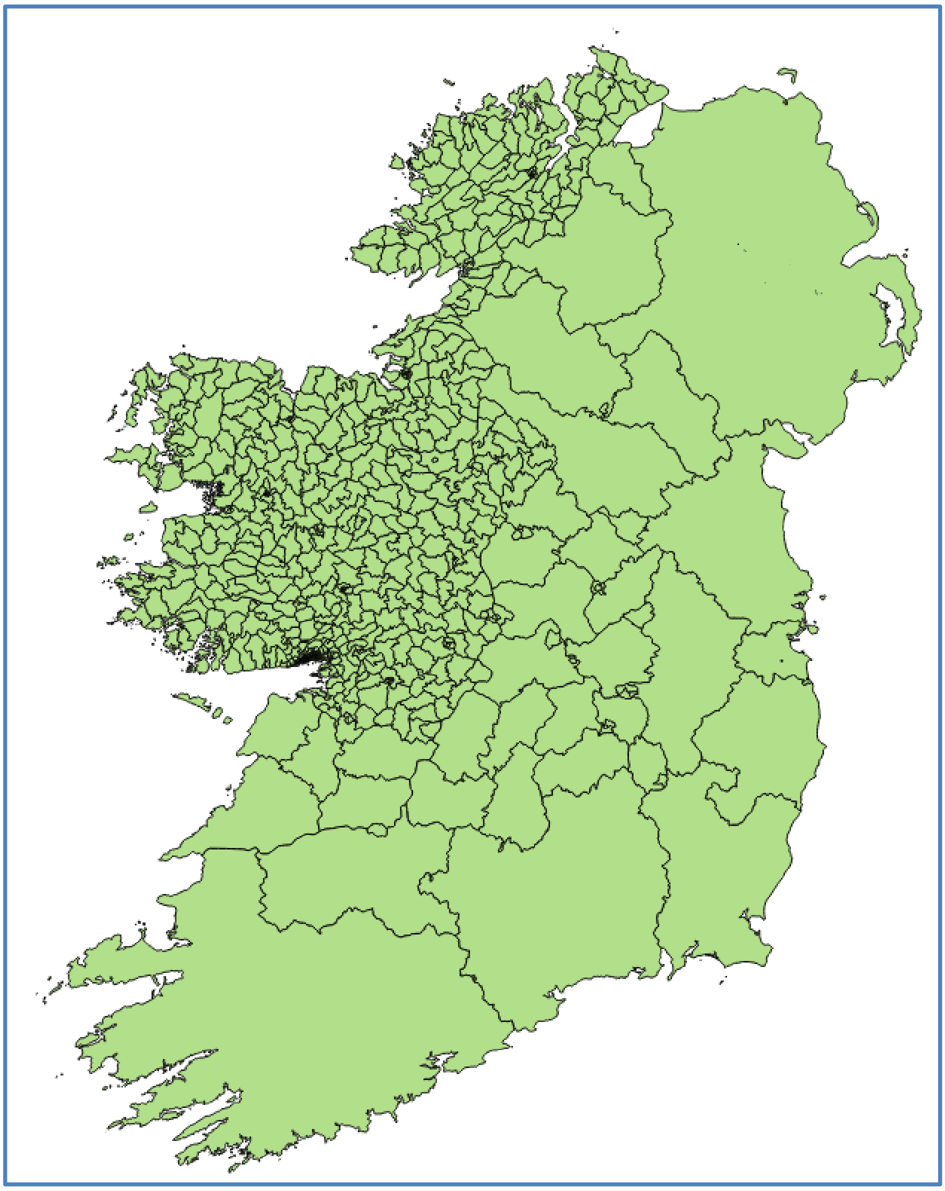

Figure 1.4 Zone System

The key zone system statistics include:

- Total zones: 749;
  - Galway City: 138
  - Galway County: 201
  - Donegal County: 108
  - Leitrim County: 27
  - Sligo County: 46
  - Roscommon County: 48
  - Mayo County: 123
  - Special Zones: 2
  - External Zones: 56

This high level of zonal detail allows the road model to be modelled to a greater degree of accuracy. Increased zonal density in urban areas such as Galway City allows for the accurate representation of walk times for users wishing to access public transport. This allows the cost of travel by PT, and associated modal split, to be calculated with greater accuracy within the model.

1.3.6 Software

All demand and Public Transport model components are implemented in Cube Voyager version 6.4. SATURN version 11.2.05 is used for the Road Model Assignment. The main Cube application includes integration modules that are responsible for running SATURN assignments and performing the necessary extractions.

1.4 This Report

This report focuses on the Development, Calibration and Validation of the Road Model component of the West Regional Model (WRM). It includes the following chapters:

- **Section 2: Road Model Development:** Provides information on the network dimensions, network development and initial assignment checks undertaken prior to calibration and validation;
- **Section 3: Matrix Development:** Outlines the hierarchy of User Classes used in the WRM Road Model and describes the process of development of travel matrices for these User Classes prior to the model calibration process;
- **Section 4: Data Collection and Review:** Outlines where the data used to calibrate and validate the WRM was sourced;
- **Section 5: Road Model Calibration:** Details the process of calibration and assignment of the Road Model;
- **Section 6: Validation:** Sets out the specification and execution of the Road Model validation process; and
- **Section 7: Conclusion and Recommendations:** Provides a summary of the development, calibration and validation of the Road Model. It also provides recommendations for future versions of the model.

2 Road Model Development

2.1 Introduction

Section Two summarises the specification of the road model development process undertaken prior to calibration and validation.

2.2 Road Network Development

2.2.1 Overview

The development of WRM road network differed from the other regional models due to the availability of the Galway Interim Model (GIM). The GIM was developed to cover the city of Galway and its environs and was used to assess the proposed Galway City Outer Bypass prior to the availability of the WRM.

The WRM model makes extensive use of the GIM, with the coding of the simulation area retained and reviewed to ensure consistency with other regions. The network has also been extended to cover the wider modelled area required for the WRM. Further details on the development of the WRM road network utilising the existing GIM is described in the following sections of this chapter.

For more information on the development of the GIM, the reader is referred to the following documents:

- MSF 016 GIM IN04 Highway Network Build (dated 07/03/2014);
- MSF 016 GIM IN05 Coding Guide (dated 07/03/2014);
- MSF 016 GIM IN07 Highway Model Checking Strategy (dated 07/03/2014); and
- MSF 040 TN1 Zone Specification Note (dated 07/03/2014).

2.2.2 Expansion of Galway Interim Model (GIM)

The road network developed for the Galway Interim Model (GIM) was the starting point for the development of the WRM. This model was fully calibrated, and utilised many of the practices implemented by the RMS process, including the derivation of generalised cost. The models share a base year of 2012, with the matrices developed from the same data sources with the exception of goods vehicles.

The network was expanded to cater for the increase in the number of zones from 288 to 749, and to fully align with the RMS architecture. This network was version V0 and was the foundation on which all future network versions were based.

The GIM model's time periods differed to those specified for the RMS. While the AM Peak definitions were consistent, an average Inter-peak hour, representing the period from 1000 to 1600 was used and no PM Peak time period was specified.

The introduction of the PM Peak required additional coding, principally for traffic signals within the simulation model. An assumption was made that the signal times for the PM Peak could be adequately represented by the existing AM Peak coding, at least initially. Changes were made to the coded cycle and phase definitions during model calibration.

With the disaggregation of the Inter-peak period into two distinct assignment periods, 1000 – 1300 and 1300 – 1600, it was assumed that the current Inter-peak traffic signal coding would be suitable for both the Inter-peak 1 and Inter-peak 2 time periods.

The user classes within the WRM assignment model have been updated for consistency with the ERM model.**Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.** Table 2.1 below lists the updated WRM user classes and their links to the original six GIM model user classes:

Table 2.1 WRM User Classes

WRM User Class	WRM UC Description	GIM User Class	GIM UC Description
1	Taxi	3	NA[1]
2	Employers Business (EMP B)	3	EMPLOYERS BUSINESS
3	Commuting (COM)	1	WORK
4	Education (EDU)	2	EDUCATION
5	Others	4	OTHERS
6	Light Goods Vehicles	5	LGV
7	OGV1	6	OGV
8	OGV2 Permitted	6	OGV
9	OGV2 Not Permitted	6	OGV

The revised user class specification required an updating of the generalised cost equations which were derived for the GIM. The corresponding generalised costs from the GIM were applied to the revised user classes within the WRM. Further details are provided in Section 5.3 later in this report.

2.2.3 Simulation Area Coding

The WRM model network was built to utilise the maximum amount of information from the GIM. The GIM network development followed the same processes as subsequently used for the other regional models. Thus, the approach was to retain

[1] Taxi demand was not modelled as a separate user class in the GIM. Counts used in the GIM road model calibration would have included taxis and, as such, there demand was accounted for in this way.

and review the simulation area coding, while replacing the buffer area coding to enable its extension to connect all zones within the defined zoning system.

The review of the simulation modelling identified a few minor issues in coding, which were subsequently addressed prior to progressing with network calibration. These changes are detailed below:

- Bus lane added on both approaches to Node 50622 as per Google Maps (2010);
- Bus lane added to Node 53383 from approach 50930 as per Google Maps (2010);
- Node 50528 re-coded so arms were in correct order and with correct turn saturations;
- Node 50413 was signalised as per Google Maps (2011);
- Extended the flared approach at node 50862 from 6pcu to 8pcu;
- Removed second lane from Node 52842, and replaced it with a 2pcu flare;
- The nodes making up the R336 / R864 roundabout (50652, 50651, 52814, 52813, 52812 and 52940) recoded to match coding guide;
- Node 50650 was signalised to represent the pedestrian crossing;
- Node 50649 was deleted and Nodes 53059 and 50648 recoded accordingly;
- Added an AM-specific ban to link 50731 – 50734 as traffic appears to be banned until 11am (was previously just an HGV ban);
- Added second lane at Node 50721 from approach 50722 as per Google Maps (2014);
- Added second lane at Node 53386 from approach 50725 as per Google Maps (2014);
- Removed Zone 137 connection to 53271, and reconnected to 52233 instead; and
- Added turn saturation capacity at multiple external nodes (not all external nodes have a capacity).

2.2.4 Buffer Area Coding

The buffer network was derived from the HERE[2] maps data using a dissolving process developed for the ERM model and documented as a repeatable method.

The method required the identification of a subset of HERE links and the points at the end of a link to be retained as a SATURN node representing either a junction, bus stop, zone connector or shape node. Bus stop nodes were extracted from the

[2] HERE Maps (http://maps.here.com), originally Navigation Technologies Corporation (NavTeq) provides mapping, location businesses, satellite navigation and other services under one brand.

GTFS database and overlaid in GIS to ensure that there was sufficient network coverage.

The subset of links was derived through a three stage process:

- By taking links which are function classes 1- 4 which fall within a polygon representing the area to be modelled. ArcMap was used to facilitate this stage;
- Using the bus stops shapefile, identify manually any additional links required to ensure sufficient network coverage for the public transport network; and
- Using the zone centroid location, identify manually any additional links required to ensure sufficient network coverage to limit non-external zone centroid length to a maximum of 3km.

The nodes which were retained were identified by three stages:

- Excel was used to process the selected links to identify the meeting of 3 or more links and the end points where the route stopped at the end of route or the boundary of the modelled area;
- The nodes in the GIM were mapped to the end of link reference ID ‘Nodes’ in the HERE data set and these were selected; and
- The provisional zoning system was interrogated to create a set of points representing each of the zones. This was used to identify the nearest ‘Node’ and these nodes were included in the list nodes fed into the dissolving process.

The dissolving process takes the selected HERE links and the set of nodes identified through the above process. These are then processed using the dissolver to provide a set of links with a number of parameters including length. The dissolving process was developed for an earlier model and forms part of the repeatable methods process. A further spreadsheet was used to derive SATURN coding based on the data saved into the ‘newLinks’ tab.

The resulting Saturn coding provided a buffer network for the study area. This was then manually stitched to the existing SATURN simulation area from the reviewed GIM model. The stitching process is specific to the WRM to facilitate the coding recently prepared for the Galway Interim Model as this will reduce the time required during the calibration stage.

The stitching process was carried out to join the two data sets together this involved matching nodes from the data sets and coding a link to ensure continuity over the network. This process ensured that there were no overlapping or duplicate links.

2.2.5 Coding of Zone Centroids

The zone centroid locations were plotted in ArcMap and centroid connectors were assigned to the nearest buffer nodes using ArcMap. This procedure was appropriate for zones in the zone range 268 to 691, which represent the bulk of the buffer zones in the extended demand model area. Zones prior to zone 268 retained their GIM model coding, while the remaining two demand model zones represent the Port of Galway and Galway Airport. These were manually coded as additional zones within the simulation area.

The external zones, ranging from zone 694 to 745, were coded in a consistent manner to the other buffer area zones, with the maximum distance constraint relaxed. The exception to these rules were the zones representing Northern Ireland (746 to 749) that have multiple zone centroids connected.

2.2.6 Public Transport Service Files

The public transport lines files generated as part of the Public Transport Model Development task were converted into a SATURN pre-load file using a spreadsheet-based macro, which assigns a timetabled volume of buses to turns and links in the SATURN model. This file is referenced at the network build stage, and buses are pre-loaded on to the SATURN network before general traffic is assigned.

Where a bus lane exists, the buses will utilise the bus lane and not be affected by link congestion. If no bus lane is present, buses will use regular road space at a rate of one-bus equals' three passenger car units (PCU) and will be impacted by link congestion. Other road users will subsequently be impacted by the presence of the bus on the regular road space.

2.2.7 Vehicle Restrictions

Bus lanes are fully represented within the road model. Bus-only links have been coded as general traffic links, but with all assigned user classes banned with the exception of taxis. Where taxis are not permitted to use a bus only link, these links have been coded as a bus-only link in SATURN.

Galway City Council bans vehicles whose length exceeds twelve metres from many residential areas in the WRM area. Inclusion of the vehicle ban has been included in the road model with the use of turn penalties for the affected user classes.

2.2.8 Tolling

There is only one tolled road within the WRM modelled area as of 2012. This is:

- Toll Plazas on the M6 / N6 between Galway and Ballinasloe;

Tolling levels were extracted from the Transport Infrastructure Ireland (TII) tolling information website[3].

The tolling levels are in 2012 prices, but are then factored to a cost base of 2011 to remain consistent with the calculated values of time.

2.2.9 Speed Flow Curves

Initial speed flow curves and mid-link capacities were specified in “SA TN11 Regional Model Coding Guide” and implemented in the development of the supply networks. Speed flow curves are applied to all the buffer links in the WRM modelled area.

During the network calibration and validation stage, some amendments to the speed flow relationships were made. These amendments included changing the capacity index of the curve applied on an individual link or making changes to the shape (as defined by the power value), free-flow speed, speed at capacity or capacity per lane for a specific curve, which would be replicated across all links in the network with similar characteristics. Where a more significant change is deemed necessary, it is likely to be more appropriate to adopt an alternative speed flow relationship, for example after checking speed limit or road cross section.

Speed flow curves are not currently applied in the simulation area within Galway City Centre. Combining speed flow curves with simulated junction coding within congested urban areas can have the effect of double counting the delay experienced by traffic as they are delayed by the capacity of the link and the capacity of the junction. In an urban environment, delays are typically caused by junction capacity and not by link capacity.

Although speed flow curves are not currently applied in the simulation area within Galway City Centre, it may be necessary to add speed flow curves on some corridors with few junctions in future iterations of the model development, where it is shown to be necessary to incorporate a speed flow curve to improve journey time validation.

2.3 Assignment Model Preparation

2.3.1 Network Checking

A comprehensive set of network checks was undertaken before commencing calibration. These included:

- range of checks including saturation flows, free flow speeds, flares, etc;
- spot checking of junction coding;

[3] http://www. tii.ie/roads-tolling/tolling-information/toll-locations-and-charges/

- check that the right types of junctions are coded;
- check that all zones are connected;
- coded link distances versus crow-fly distance; and
- observed traffic volumes versus coded and calculated capacity in SATURN.

2.3.2 Assignment Parameter Updating

The calculated vehicle operating cost (Price Per Kilometre, PPK) component takes the average simulated network speed as an input variable. Whilst updating the model to newer versions of the network and newer versions of the matrix it is possible that the average network speed changes. Although changes in network speed will have a small impact on the calculated generalised cost components, it is prudent to update the costs to reflect network performance on a regular basis during model development.

The calculated value of time (Price Per Minute, PPM) component does not change with the average simulated network speed and will be fixed for all assignments.

Although it is possible to adjust the PPK and PPM values to improve calibration of the road model, this is generally not undertaken as this may introduce inconsistency with future year values of PPK and PPM, which will have been calculated using the method used to calculate the base values.

3 Matrix Development

3.1 Overview

Similar to the road network development outlined previously, the development of the prior WRM road model matrices benefited from the availability of GIM. The GIM was calibrated and validated in line with TII guidelines and, therefore, provided a good starting position for the WRM. The following sections of this chapter provide an overview of the process used to expand the calibrated GIM road matrices in line with the new WRM zone system (outlined in Figure 1.4 previously).

3.2 GIM Expansion

3.2.1 Introduction

The matrix expansion process undertook the following procedures:

- Source 24-hour production-attraction (PA) matrices and final estimated assignment model matrices from GIM archives;
- Factor 24-hour PA matrices to hourly time period OD matrices by mode and journey purpose using GIM parameters;
- Factor the AM and IP assignment matrices from GIM to proportion out to the additional user classes required for the WRM;
- Combine the factored PA matrices from 2 to obtain WRM user class matrices for the IP2 and PM time periods;
- Expand from the 288 to 749 zoning system through a matrix expansion file described subsequently in section 3.2.2; and
- Compress GIM and WRM matrices for comparison purposes.

3.2.2 Data Sources for Expansion Files

A matrix expansion file is a list of zone equivalences between two zoning systems used to either compress a large matrix, or expand a smaller matrix, to the required zoning system. The zone equivalence list was created in GIS using 'point in polygon' queries to establish which 'small' WRM zones are within the 'larger' GIM zones.

For expansion, additional information is required to enable the factoring of cells as, unlike compression, the process is not a simple sum. Expansion factors were calculated by comparing a summation of POWSCAR data for the final WRM zone system and the GIM zone system.

3.2.3 Matrix Comparison

A sector system was developed for the analysis of the GIM expansion process, with equivalence lists compiled for both the GIM and WRM zoning systems. This allows for a direct matrix comparison between the GIM matrices and the expanded

WRM matrices. For brevity this was performed for all vehicle trips and all public transport trips for the AM Peak and Inter-peak periods.

The 4-sector system employed is based on the simulation, buffer, inner-external and outer-external areas of the zoning system, as shown in Figure 3.1, overleaf.

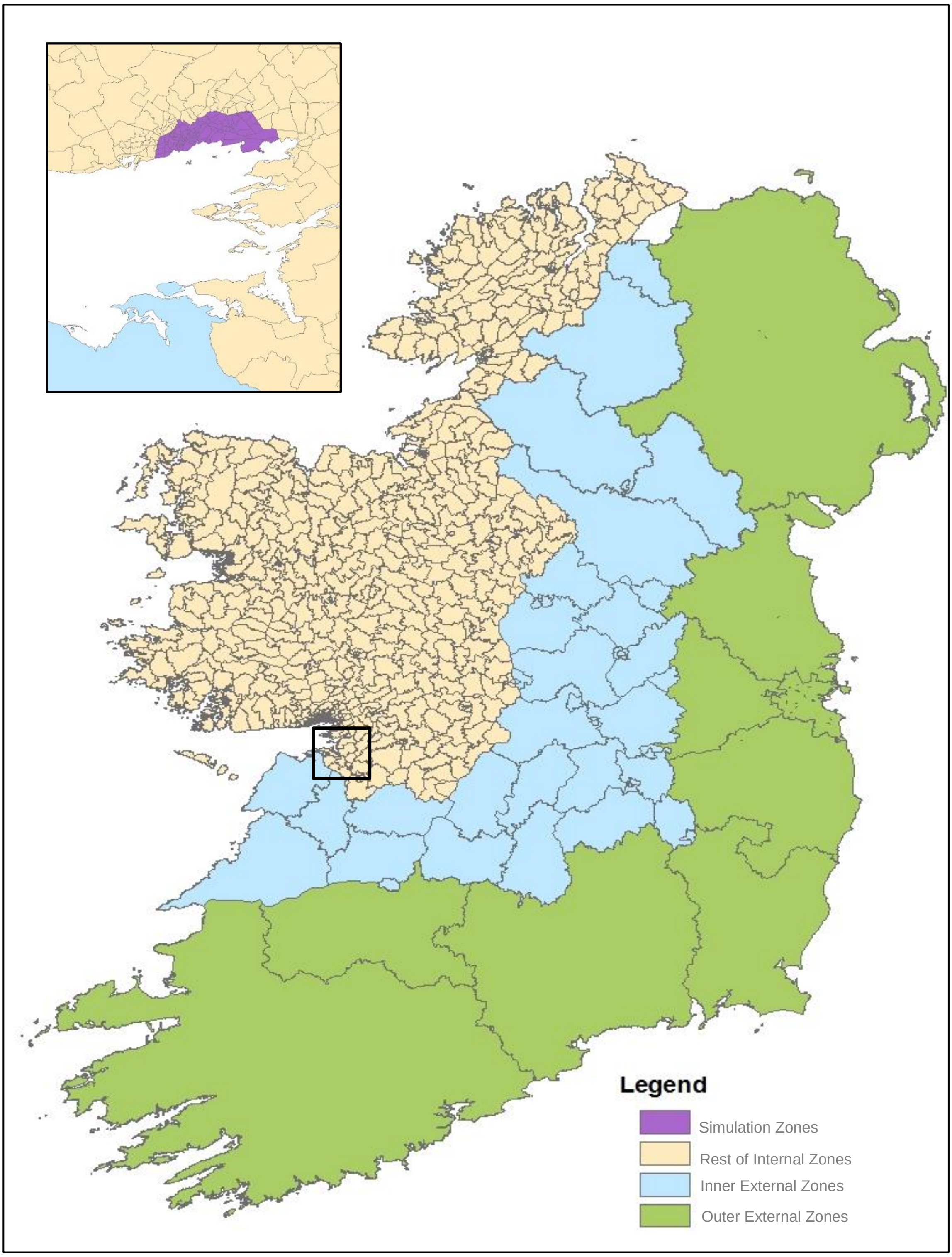

Figure 3.1 West Regional Model Zoning

The following two tables provide a comparison between the AM Peak road trip matrices for the GIM and expanded WRM models. As can be seen, the matrices are nearly identical when compressed to a common sector system. The differences can be explained by the rounding of expansion factors within the process. The differences are insignificant given that the expanded matrices are being used solely to generate initial costs for subsequent demand model calibration.

Table 3.1 AM Peak – Road Trip Matrices – GIM Model

Area	Galway Simulation Area	Rest of Internal Zones	Inner External	Outer External	Total
Galway Simulation Area	2,909	2,605	38	66	5,617
Rest of Internal Zones	8,106	10,676	443	567	19,792
Inner External	79	249	20	0	349
Outer External	157	238	0	0	395
Total	11,250	13,768	501	632	26,152

3.2.4 Inclusion of RMSIT trips

The next stage of the process was to infill trip demand in the zones outside the GIM demand model area (where trip data is available) based on RMSIT[4] data. This approach was required to enable preliminary assignments using the estimated trip data and hence provide initial costs for subsequent model development purposes.

The RMSIT process was used to obtain external and goods vehicle trips by modelled time period in OD format. These trips replaced those in the expanded WRM matrices, again ensuring that trips internal to the GIM demand model area were not changed.

The changes to the matrices are shown in the tables below for all road trips for the AM Peak. As can be seen, only the external trips are changed indicating that only the RMSIT matrices have been included. Furthermore, the RMSIT trips are exclusively from Inner External zones, reflecting the location of the RMSIT route zones and consequent loading points within the WRM.

[4] Regional Model System Integration Tool, which provides estimates of inter-regional trip demand – see MSF 5.3 IN01 RMS-IT Development Report v2 5 20151116 for further details.

Table 3.2 AM Peak – Road Trip Matrices – Expanded WRM Matrices

Area	Galway Simulation Area	Rest of Internal Zones	Inner External	Outer External	Total
Galway Simulation Area	2,921	2,602	40	64	5626
Rest of Internal Zones	8,132	10,641	449	560	19,782
Inner External	89	256	20	0	365
Outer External	148	231	0	0	378
Total	11,289	13,729	509	624	26,152

Table 3.3 AM Peak – Road Trip Matrices –WRM Matrices to generate Costs

Area	Galway Simulation Area	Rest of Internal Zones	Inner External	Outer External	Total
Galway Simulation Area	2921	2602	301	0	5824
Rest of Internal Zones	8132	10641	1548	0	20320
Inner External	301	1548	168	0	2017
Outer External	0	0	0	0	0
Total	11354	14790	2017	0	28160

3.2.5 Internal Goods Vehicle Trips

The final stage of the process involved using the Prior Matrix process to calculate matrices of goods vehicles for LGV, OGV1 and OGV2 for the “Rest of Internal zones” to “Rest of Internal zones” part of the matrix as illustrated below in Table 3.4**Error! Reference source not found.**.

The prior matrix process is documented in “FDM Scope12 Base Year Matrix Building”. This process can be applied to any model area with appropriate updating of zoning systems and road travel costs from the initial GIM expanded matrix assignment.

It was preferable to use the Prior Matrix process for goods vehicles, rather than the GIM expanded matrices, because the latter were derived from a small number of movements (the process entails expanding a small number of zones to a large number of zones based on population proportions), and are hence less reliable.

Table 3.4 Use of Prior Matrix Process

Area	Galway Simulation Area	Rest of Internal Zones	Inner External	Outer External
Galway Simulation Area	GIM	**PRIORS**	RMSIT	RMSIT
Rest of Internal Zones	**PRIORS**	**PRIORS**	RMSIT	RMSIT
Inner External	RMSIT	RMSIT	RMSIT	RMSIT
Outer External	RMSIT	RMSIT	RMSIT	RMSIT

3.3 Final WRM Initial Trip Matrices

Upon completion of the goods vehicle processing stage, the matrices were compiled and assigned to the road network to provide initial costs for use in the demand model calibration. Section 5.6 provides a detailed overview of the development of the WRM Road matrices through calibration and improvement of the Full Demand Model (FDM).

3.4 Prior Matrix Factoring

The prior matrices (referred to in 3.2 above) represent travel demand over a three-hour period, such as 0700 – 1000. However, for assignment in the Road Model, SATURN requires a travel demand matrix that represents a single hour. Several methodologies are available to factor the three-hour travel demand matrix to a single hour, using a Period-to-Hour (PtH) factor.

Two common approaches to deriving this PtH factor are to divide the total matrix by the number of hours it represents in order to provide an average hourly travel demand matrix, or to factor the matrix to a specific hour, for example 0800 – 0900, using observed traffic count data.

A third methodology is to represent the “peak everywhere” by applying a single factor, derived from various data sources, with the aim of representing the worst traffic conditions at each point in the network simultaneously. Automatic Traffic Count (ATC) data was used to derive factors for the WRM in order to best represent the traffic conditions within Galway. The method used for this is consistent with the method used for ERM, which is discussed further in the “FDM Scope3 Modelling Time of Travel” report. This factor represents the “flow” PtH factor, and the factors calculated from the ATC data are outlined in Table 3.5. These factors were applied to interim versions of the road model.

Table 3.5 WRM RM Initial Period to Assigned Hour Factors

Time Period	Period to Hour Factor
AM Peak (0700 – 1000)	0.389
Inter-peak 1 (1000 – 1300)	0.333
Inter-peak 2 (1300 – 1600)	0.333
PM Peak (1600 – 1900)	0.363
Off Peak (1900 – 0700)	0.083

The “demand” PtH factor is based on the Household Travel Diary and represents the proportion of all trips which take place within the peak hour, without regard to journey purpose. The “flow” PtH factors are generally lower than the “demand” factors as trips are travelling between a variety of origins and destinations and therefore pass the fixed observation points at different times. The result is that the flow profile is spread more evenly throughout the period compared to the demand profile.

The flow PtH factors were applied to all counts and, initially, to the assignment matrices. It was later recognised that, due to the way SATURN assigns trips to the network, the true PtH factor required to convert the 3-hour demand matrices into 1-hour assignment matrices is somewhere between the two factors. In practice, there is no straightforward way to determine mathematically what the factor should be, prior to model calibration.

An iterative process was therefore required to vary the PtH factor within the upper and lower limits formed by the demand and flow PtH factors, until the overall level of demand matched the observed flows. The final “demand” PtH factors used in the WRM are outlined in Table 3.6**Error! Reference source not found.**.

Table 3.6 WRM RM Final “demand” Period to Assigned Hour Factors

Time Period	Period to Hour Factor
AM Peak (0700 – 1000)	0.47
Inter-peak 1 (1000 – 1300)	0.35
Inter-peak 2 (1300 – 1600)	0.45
PM Peak (1600 – 1900)	0.48
Off Peak (1900 – 0700)	0.08

3.5 Prior Matrix Checking

Comprehensive checks of the matrices were undertaken before commencing calibration. These checks included:

- comparing matrix trip ends against NTEM outputs;
- checking trip length distribution against observed data;

- checking implied time period splits by sector-pair;
- checking implied purpose splits by sector pair; and
- comparing sectored matrices with total screen-line and cordon flows where possible.

These checks revealed no significant issues with the prior matrices. These matrices were then assigned to the latest version of the road model.

4 Data Collation and Review

4.1 Supply Data

As described in the "RM Spec2 Road Model Specification Report", road link specification is based on the HERE GIS layer for the Republic of Ireland. The HERE data includes a number of data fields including: link lengths; road class; speed category; single / dual carriageway; and urban / rural characteristics.

This was used to create the initial road network. The simulation area was then coded with reference to the agreed coding guide.

Based on guidelines established for ERM and described in "SA TN11 Regional Model Coding Guide", superfluous network detail was removed from the WRM road network (the development of the WRM road network pre-dated the finalisation of the ERM guidance).

Traffic signal stages and timings were developed for Galway City from:

- Split Cycle Offset Optimization Technique (SCOOT) database where available;
- Microprocessor Optimised Vehicle Actuation (MOVA);
- Proportional green time split based on observed traffic count if not available from SCOOTS or MOVA; and
- Estimated if no other information was available.

4.2 Demand Data

4.2.1 Commute and Education Matrices

The POWSCAR[5] dataset provides a comprehensive set of production-attraction[6] matrices for commute and education purposes. POWSCAR does not include data on how frequently (e.g. how many times a week) a journey is made.

Outputs of the National Trip End Model (NTEM), which has been calibrated using the National Household Travel Survey 2012 (NHTS) travel diary data, provided origin and destination trip ends for each modelled time period for all other journey purposes and to corroborate with POWSCAR.

4.2.2 Other Purposes

The sample sizes of the NHTS 2012 are too small to be used directly to construct matrices for individual zone to zone trip volumes (there are approximately 9,000 records for WRM). However, the NHTS can be used to estimate broader sector to

[5] Place of Work, School, or College Census of Anonymised Records, part of the 2011 Census of Ireland

[6] Based on Census Small Area spatial disaggregation

sector totals, mode share, time of day profiles and time of day return factors. Trip ends were obtained from NTEM, as described in NDFM Development Report. Mode choice and distribution models were calibrated to match the NHTS 2012 data. These models were applied to create the base year prior matrices for the WRM for purposes other than commute and education.

4.2.3 Goods Vehicles

Goods vehicles are comprised of the following classes of vehicles:

- Light Goods Vehicles (LGVs): up to 3.5 tonnes gross weight, for example transit vans.
- Other Goods Vehicles 1 (OGV1): rigid vehicles over 3.5 tonnes gross weight with two or three axles, for example tractors (without trailers) or box vans.
- Other Goods Vehicles 2 (OGV2): rigid vehicles with four or more axles, and all articulated vehicles.

For the purposes of the regional models, these three classes were divided into two groupings with different trip characteristics, bulk goods and non-bulk goods.

Bulk Goods Trips are defined as trips between locations such as ports, airports, quarries, major industrial sites, supermarkets and distribution centres. These trips will be made regardless of the cost of travel. As with ERM, they have been assumed to be made mainly by OGV2, with a proportion of OGV1. Bulk Goods Trips have been derived from RMSIT, with the local distribution of trips to destinations other than ports, airports and similar locations with a single corresponding RMSIT centroid based on NACE survey data relating to industrial activities. A 70/30 split was used to disaggregate the Bulk Goods matrices between OGV1 and OGV2.

More information on the goods vehicle matrices and their derivation is available in “FDM Scope12 Base Year Matrix Building”.

Non-Bulk Goods Trip Ends were estimated using linear regression based on factors estimated for ERM. The same synthetic process as for the ‘Other Purposes’ (Section 4.2.2) was used to create a non-bulk goods matrix, which was disaggregated between LGVs and OGV1 using a 84/16 split.

More detail on the goods vehicles matrices is given in WRM TO9 TN01 Base Year Matrix Building.

4.3 Count Data

There are between 6,000 and 7,000 road traffic survey data records nationwide, including manual classified counts, automatic traffic counts (ATC) and SCATS data, which were collated under the Data Collection task. The data was collated in 2014 and represents data from January 2009 to December 2014.

Figure 4.1 indicates the location of the collated traffic count data.

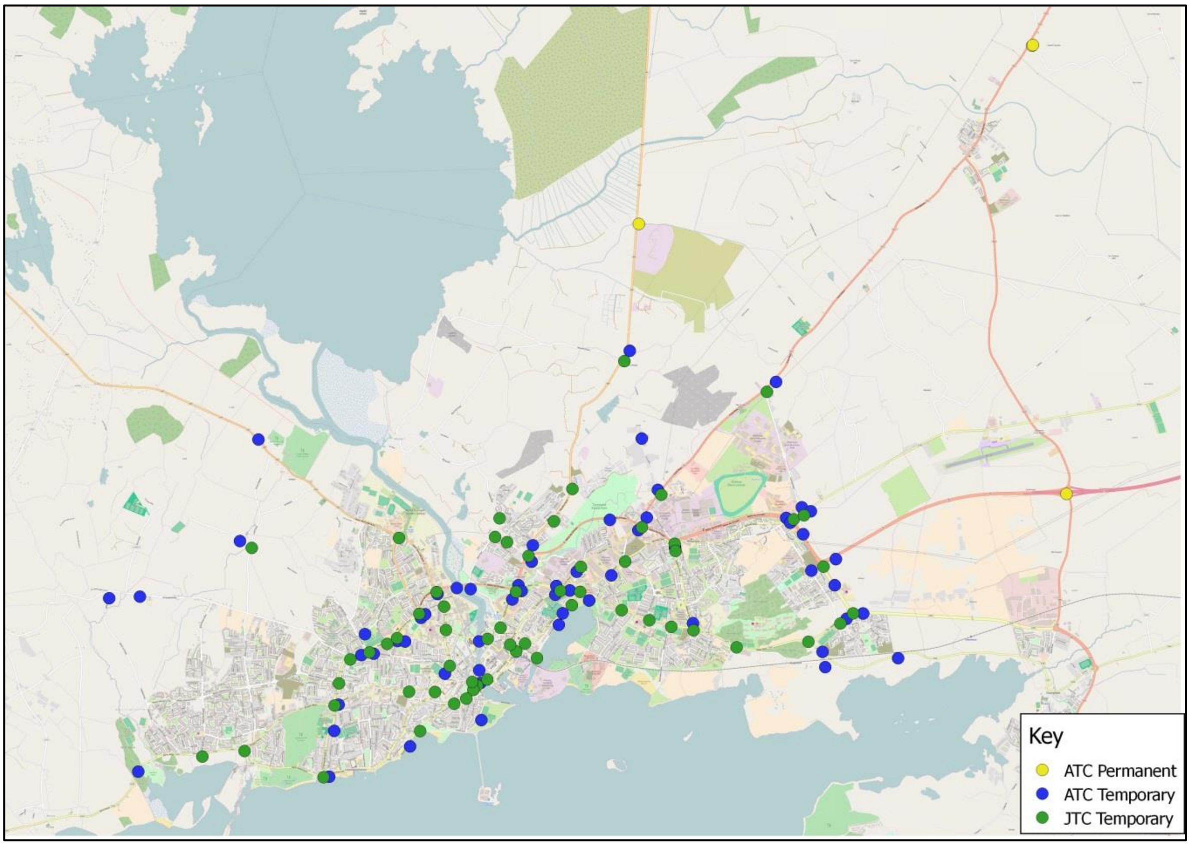

Figure 4.1 Location of Traffic Count Data

4.4 Journey Time and Queue Length Data

4.4.1 GPS-based Travel Time Data

The NTA purchased a license from TomTom[7] for their travel time product Custom Area Analysis (CAA). This product provides average travel time data on every road link within a given area over a specified time period. Details of the data acquisition and data processing are discussed in “MSF 011 TomTom Data Portal Guide” and “MSF 011 TomTom Data Extraction and Processing”.

In total, 12 routes in both the inbound and outbound directions were specified for comparison, and these are detailed in

[7] http://trafficstats.tomtom.com

Figure 4.2 and Table 4.1, overleaf. Due to a large unobserved gap in TomTom data, Route 4b outbound was split into two sections resulting in a total of 25 individual journey routes reported.

The inbound and outbound direction for all routes is available and extracted in the AM (08:00 – 09:00), Lunch Time (13:00 – 14:00), School Run (14:00 – 15:00) period, PM peak period (17:00 – 18:00).

Figure 4.2   TomTom Journey Time Routes

Table 4.1 TomTom Journey Time Routes

Route	Description
1	Silverstrand to Galway
2	N59 to Galway
3	Western Distributor Road
4a	R338 to N6
4b	N6 to City Centre
5	R339 to City Centre
6	Letteragh to Salthill
7	N17 / R336 to City Centre
8	N84 to City Centre
9	Coolough Road to City Centre
10	Galway Airport to Ballybane
11	Thornpark to City Centre

Data is available at an hourly average level between 0700 and 1900, and at an average level for 1900 – 0700. The average travel times between 1900 and 0700 are split into two datasets, with a "quiet" off-peak covering 0100 – 0400 and the remainder of the off-peak (1900 – 0100 and 0400 – 0700) forming a second dataset, with smaller variability and uncertainty.

Data was averaged over the neutral 2012 months of February, March, April, May, October and November, excluding weekends, public and school holidays within these months. This resulted in 112 days' worth of observations, which were averaged to form the TomTom travel time dataset. This is significantly in excess of what could normally be achieved through moving car observer type surveys. This data was used to validate the final WRM road model.

4.4.2 Queue Length Data

Where available, queue length data was used to confirm that queuing occurs at the correct locations in the model network. However, owing to potential ambiguity regarding the definition of a queue in a survey and the definition of a queue within SATURN, no attempt was made to match the observed queue length in anything other than general terms.

5 Road Model Calibration

5.1 Introduction

This chapter sets out the specification and execution of the model calibration process. This includes the incorporation and application of matrix estimation.

5.2 Assignment Calibration Process

5.2.1 Overview

The assignment calibration process was undertaken for the assignment of the WRM RM and matrices through comparisons of model flows against observed traffic counts at:

- Individual links (i.e. link counts); and
- Across defined screenlines.

5.2.2 Calibration

Calibration is the process of adjusting the WRM RM to ensure that it provides robust estimates of road traffic assignment and generalised cost before integrating it into the wider demand model. This is typically achieved in iteration with the validation of the model against independent data.

The UK's Department for Transport's Transport Analysis Guidance (TAG) unit M3-1 advises that the assignment model may be recalibrated by one or more of the following means:

- Remedial action at specific junctions where data supports such as;
    - Increase or reduction in turn saturation capacity;
    - Adjustment to signal timings;
    - Adjustment to cruise speeds;
- Adjustments to the matrix through matrix estimation as a last resort;

TAG indicates that the above suggestions are generally in the order in which they should be considered. However, this is not an exact order of priority but a broad hierarchy that should be followed. In all cases, any adjustments must remain plausible and should be based on a sound evidence base.

Calibration is broadly split into two components; matrix calibration and network calibration. Matrix calibration ensures the correct total volume of traffic is bound for certain areas with the use of sector analysis, while network calibration ensures the correct traffic volumes on distinct links (roads) within the modelled area. Table 5.1 outlines the matrix estimation change calibration criteria, as specified in TAG Unit M3-1, Section 8.3, Table 5.

Table 5.1 Significance of Matrix Estimation Changes

Measure	Significance Criteria
Matrix zonal cell value	Slope within 0.98 and 1.02; Intercept near zero; R^2 in excess of 0.95.
Matrix zonal trip ends	Slope within 0.99 and 1.01; Intercept near zero; R^2 in excess of 0.98.
Trip length distribution	Means within 5%; Standard Deviation within 5%.
Sector to sector level matrices	Differences within 5%

The comparison of the modelled vehicle flows also makes use of the GEH[8] summary statistic. This statistic is more tolerant of large percentage differences at lower flows. When comparing observed and modelled counts, focus on either absolute differences or percentage differences alone can be misleading when there is a wide range of observed flows. For example, a difference of 50 PCUs is more significant on a link with an observed flow of 100 PCUs than on one with and observed flow of 1,000 PCUs, while a 10 per cent discrepancy on an observed flow of 100 vehicles is less important than a 10 per cent mismatch on an observe d flow of 1,000 PCUs.

The GEH Statistic is defined as:

$$GEH = \sqrt{\frac{(M-C)^2}{(M+C)/2}}$$

Where, GEH is the Statistic, M is the Modelled Flow and C is the Observed Count.

Table 5.2 outlines the link calibration criteria as set out in TAG Unit M3-1, Section 3.2, Table 2.

Table 5.2 Road Assignment Model Calibration Guidance Source

Criteria	Acceptability Guideline
Individual flows within 100 veh/h of counts for flows less than 700 veh/h	> 85% of cases
Individual flows within 15% of counts for flows from 700 to 2,700 veh/h	> 85% of cases
Individual flows within 400 veh/h of counts for	> 85% of cases

[8] Developed by Geoffrey E. Havers (GEH)

flows more than 2,700 veh/h	
GEH < 5 for individual flows	> 85% of cases

Table 5.3 outlines the screenline calibration criteria as set out in TAG Unit M3-1, Section 3.2, Table 3.1.

Table 5.3 Road Assignment Model Screenline Calibration Guidance Sources

Criteria	Acceptability Guideline
Differences between modelled flows and counts should be less than 5% of the counts	All or nearly all screenlines

5.3 Initial Generalised Cost Parameters

Initial generalised cost parameters applied were taken from the initial generalised cost parameters applied to the Galway Interim Model (see Section 2.2.2 previously). The initial generalised cost parameters are set out in the following four tables, with IP2 mirroring the initial costs of IP1 as there was no IP2 assignment undertaken at this stage. The generalised cost parameters have a base year of 2011 to remain consistent with the other model components and input values.

Table 5.4 Initial AM Generalised Cost Values

User Class	Cents Per Minute	Cents Per Kilometre
UC1 – Taxi	60.13	18.78
UC2 – Car Employers Business	60.13	18.78
UC3 – Car Commute	21.52	9.82
UC4 – Car Education	36.39	9.82
UC5 – Car Other	21.16	9.82
UC6 – LGV	43.34	13.38
UC7 – OGV1	46.08	30.52
UC8 – OGV2 Permit Holder	44.40	55.86
UC9 – OGV2 (Other)	44.40	55.86

Table 5.5 Initial IP1 Generalised Cost Values

User Class	Cents Per Minute	Cents Per Kilometre
UC1 – Taxi	70.39	17.80
UC2 – Car Employers Business	70.39	17.80
UC3 – Car Commute	20.74	9.38
UC4 – Car Education	42.66	9.38

UC5 – Car Other	38.41	9.38
UC6 – LGV	45.91	13.68
UC7 – OGV1	47.87	29.84
UC8 – OGV2 Permit Holder	46.55	54.79
UC9 – OGV2 (Other)	46.55	54.79

Table 5.6 Initial IP2 Generalised Cost Values

User Class	Cents Per Minute	Cents Per Kilometre
UC1 – Taxi	70.39	17.80
UC2 – Car Employers Business	70.39	17.80
UC3 – Car Commute	20.74	9.38
UC4 – Car Education	42.66	9.38
UC5 – Car Other	38.41	9.38
UC6 – LGV	45.91	13.68
UC7 – OGV1	47.87	29.84
UC8 – OGV2 Permit Holder	46.55	54.79
UC9 – OGV2 (Other)	46.55	54.79

Table 5.7 Initial PM Generalised Cost Values

User Class	Cents Per Minute	Cents Per Kilometre
UC1 – Taxi	60.13	18.40
UC2 – Car Employers Business	60.13	18.40
UC3 – Car Commute	21.52	9.65
UC4 – Car Education	36.39	9.65
UC5 – Car Other	21.16	9.65
UC6 – LGV	43.34	13.16
UC7 – OGV1	46.08	29.80
UC8 – OGV2 Permit Holder	44.40	54.55
UC9 – OGV2 (Other)	44.40	54.55

5.4 Initial Road Model Network Progression

5.4.1 Overview

As noted previously in Section 2.2, the GIM was used as the basis for development of the WRM road network. Throughout the network development process, a number checks and alterations were made to provide a better representation of road costs and improve the overall road calibration.

Initially, the developed WRM network was reviewed and refined including updates to signal timings, junction capacities, observed count data, parameter values etc., and these are described in the following sections. Also presented, is a review of the interim GIM calibration and validation highlighting its appropriateness for use in developing the WRM road network.

5.4.2 Network Refinement

Network version V1 was the first "major change" network, which included model changes to accommodate all model issues identified by a high level review of the preliminary assignments.

Junction turning counts and capacity checks were undertaken to identify the junctions with counts lower than the modelled capacity. The network coding for these junctions was reviewed and it was discovered that several junctions had unwarranted flares at priority or signalised junctions that were artificially inflating the available capacity. For this purpose, flares and lane allocation were checked and the capacity was reduced by removing or changing flares on lanes where necessary.

A review of all signalised junctions led to the signal times at many junctions being altered. During the GIM, only AM and IP1 signal times were obtained from Galway Council, and thus the PM signals were a copy of the AM signals. PM signals were reviewed where SATURN indicated potential issues (delays, queues, route choice). For all signalised junctions in all peaks, signal timings and signals stages were reviewed. Where appropriate, green time adjustments were undertaken. If this was not possible overall cycle time was increased. For some junctions, signal phases were rearranged. In addition, several pedestrian crossing points with dedicated traffic signals were included to better match observed travel times, and to improve traffic route choice.

A review of all regional roads was also undertaken to check that the capacity, geometry and speed flow curves are consistent throughout the model.

Volume to capacity (V/C) and delay checks were carried out against the link capacity in the buffer area and turn saturation capacity was added at multiple external nodes as not all external nodes have a capacity. A review of centroid connectors was also carried out to check they are connected to the zones correctly and in an appropriate location. This was carried out in order to facilitate the proposed Galway City Centre traffic restrictions, and partly to better reflect the true major access from a zone. Exploded roundabout checks were undertaken in order to match the coding guide and bus lane coding for the Galway City area was reviewed.

A review of the observed data was undertaken to ensure that the count data was processed correctly and it was paired to the relevant nodes by direction and time period. A screenline at Bundoran was removed as it only contained two counts and was considered to provide no significant information on model performance. The removed counts were included as part of the individual count data. During calibration a number of manual classified counts, which were undertaken within Galway City, were included in the matrix estimation process. These had previously been excluded due to a lack of detailed classification of traffic. To overcome this issue, observed Car, LGV and HGV ratios were taken from accompanying ATCs and applied globally to the MCCs.

Finally, a stress test was undertaken where 110% of the original matrix was assigned to the network and compared to the original network. Checks to identify any junctions that were now over capacity as a result of assigning the larger matrix were undertaken. Based on the outcome of these checks, all junctions along the N6 were reviewed and coding amended where necessary.

5.4.3 Increase in Average PCU Length (SATURN Parameter ALEX)

The average PCU length parameter in SATURN, ALEX, was set to the default value of 5.75m as used in the current version of the GDA model, and remained consistent at this level during the network development tasks. Further analysis by the NTA, including visual reviews of several aerial / satellite photographs suggested that the average PCU length has increased in recent years and is closer to 5.95m in length. The ALEX parameter was subsequently revised to 5.95m based on this recent research.

The increase in the average PCU length within SATURN reduces the stacking capacity of links, which in turn will increase the length of any queue, potentially beyond the end of a link, and can affect the link speeds as a result. This change had the effect of slowing down the modelled journey times, which was consistent with comparisons between the observed and modelled journey times.

5.4.4 Revised Cost Base

The Common Appraisal Framework (CAF) provides the largest proportion of information used during the derivation of the generalised cost assignment parameters; value of time (VoT) and vehicle operating cost (VOC). At the commencement of the initial network development, the latest available information from the CAF provided costs with a base year of 2002. During the development of the road network, a draft version of the CAF was circulated which provided generalised cost parameters with a base cost year of 2011. A summary of all variables used during the development of the WRM and their sources is presented in the “FDM Scope18 Regional Transport Model Exogenous Variables” report.

5.4.5 Period-to-Hour Factor

As outlined in Section 3.4, the PtH factors were adjusted during the development of the final model. These factors had the impact of varying the overall travel demand (matrix size) of the targeted time period prior to any adjustment. The factors tended to increase during development, which in turn highlighted additional areas of the model that required review.

5.4.6 Interim Calibration Statistics

This section provides a brief calibration summary of the Galway Interim Model. Further information on the performance of the Galway Interim Model (GIM) is located in the “MSF 016 GIM TN06 Base Model Assignment Calibration Validation”.

The report states that 82 per cent of link flows and 83 per cent of turn flows satisfy the calibration criteria in the AM peak. Of the journey times in the AM peak, 79 per cent of routes satisfy the validation criteria, with 88 per cent in the Inter-peak. Of the remaining routes, all are within 31 per cent of the observed time.

Three alternative highway matrix estimation runs were undertaken, with differing parameters to establish whether a different balance could be found between reducing the impact of matrix estimation on the prior matrix and calibrating and validating well against the counts. Although the alternatives improved the model in some ways, it was often to the detriment of other areas of the model such that, on balance, no overall improvement was found.

The summary and conclusions within the report indicate that the road model has shown to calibrate and validate well against observed data, which demonstrates that there are no serious issues with the model. The GIM was used to assess the Galway City Outer Bypass and public transport alternatives to the Bypass.

5.5 Final Road Model Network Progression

5.5.1 Network Improvements

Following the use of the WRM for the Galway Integrated Transport Strategy, a number of updates were identified for the final SATURN road network. The major considerations during network development and detailed audit are outlined in the following sections.

5.5.2 Zone Connection Review

Several of the proposed transport interventions being considered as part of the Galway Integrated Transport Strategy included revisions to City Centre access arrangements. A complete review of City Centre zone centroid connectors was undertaken to ensure that access would not be affected by the proposed changes. The access point for three zones were changed as part of this review.

5.5.3 Detailed Network Audit

A detailed network audit was completed after all major changes had been applied to the model. The headline statistics prior to the detailed audit are outlined in the following six tables.

Table 5.8 Pre-audit Significance of Matrix Estimation Changes, AM Peak

Measure	Significance Criteria	UC1	UC2	UC3	UC4	UC5	UC6	UC7	UC8	UC9
Matrix zonal cell value	Slope within 0.98 and 1.02;	0.99	0.99	0.94	0.98	0.98	0.82	1.01	1.17	0.00
	Intercept near zero;	0.00	0.00	0.00	0.00	-0.01	0.00	0.01	0.01	0.00
	R^2 in excess of 0.95.	0.97	0.98	0.93	0.99	0.98	0.44	0.32	0.43	1.00
Matrix zonal trip ends	Slope within 0.99 and 1.01;	0.96	0.84	0.86	0.89	0.91	0.61	1.23	1.37	0.00
	Intercept near zero;	0.06	0.50	3.08	0.04	4.83	0.58	0.21	0.13	0.00
	R^2 in excess of 0.98.	0.92	0.85	0.90	0.93	0.93	0.64	0.78	0.76	1.00
Trip Length Distribution	Means within 5%;	-5%	-6%	-3%	-8%	-2%	-45%	-22%	-29%	-
	Standard Deviation within 5%.	-4%	0%	2%	-8%	1%	-37%	6%	7%	-

Table 5.9 Pre-audit Significance of Matrix Estimation Changes, Inter-peak 1

Measure	Significance Criteria	UC1	UC2	UC3	UC4	UC5	UC6	UC7	UC8	UC9
Matrix zonal cell value	Slope within 0.98 and 1.02;	1.00	0.99	0.57	0.97	0.81	0.39	0.95	1.03	0.00
	Intercept near zero;	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00
	R^2 in excess of 0.95.	0.95	0.89	0.53	0.91	0.80	0.17	0.65	0.75	1.00
Matrix zonal trip ends	Slope within 0.99 and 1.01;	1.03	0.94	0.10	0.89	0.74	0.57	0.98	1.03	0.00
	Intercept near zero;	0.11	0.34	6.66	0.01	5.46	0.76	0.19	0.15	0.00
	R^2 in excess of 0.98.	0.93	0.70	0.05	0.80	0.56	0.63	0.89	0.91	1.00
Trip Length Distribution	Means within 5%;	-7%	-8%	-28%	-38%	-23%	-31%	-11%	-18%	-
	Standard Deviation within 5%.	-6%	-1%	-13%	-24%	-28%	-27%	11%	17%	-

Table 5.10 Pre-audit Significance of Matrix Estimation Changes, Inter-peak 2

Measure	Significance Criteria	UC1	UC2	UC3	UC4	UC5	UC6	UC7	UC8	UC9
Matrix zonal cell value	Slope within 0.98 and 1.02;	1.00	1.00	0.98	0.99	0.99	0.31	0.90	0.89	0.00
	Intercept near zero;	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
	R^2 in excess of 0.95.	0.96	0.87	0.93	0.99	0.98	0.15	0.70	0.63	1.00
Matrix zonal trip ends	Slope within 0.99 and 1.01;	1.05	1.28	0.99	0.89	0.95	0.48	0.94	0.89	0.00
	Intercept near zero;	0.12	-0.77	0.58	0.17	7.07	0.89	0.04	0.06	0.00
	R^2 in excess of 0.98.	0.91	0.68	0.92	0.88	0.93	0.59	0.91	0.84	1.00
Trip Length Distribution	Means within 5%;	-5%	-6%	-4%	-4%	-3%	-24%	-2%	-7%	-
	Standard Deviation within 5%.	-5%	-3%	0%	-5%	-1%	-23%	5%	7%	-

Table 5.11 Pre-audit Significance of Matrix Estimation Changes, PM Peak

Measure	Significance Criteria	UC1	UC2	UC3	UC4	UC5	UC6	UC7	UC8	UC9
Matrix zonal cell value	Slope within 0.98 and 1.02;	1.00	1.00	0.96	0.95	0.99	0.63	0.84	0.91	0.00
	Intercept near zero;	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00
	R^2 in excess of 0.95.	0.97	0.77	0.92	0.88	0.98	0.33	0.35	0.38	1.00
Matrix zonal trip ends	Slope within 0.99 and 1.01;	1.02	1.40	0.90	0.68	0.93	0.56	1.08	1.21	0.00
	Intercept near zero;	0.11	-1.83	4.03	0.23	6.44	0.60	0.11	0.05	0.00
	R^2 in excess of 0.98.	0.93	0.38	0.93	0.74	0.93	0.60	0.83	0.83	1.00
Trip Length Distribution	Means within 5%;	-4%	-5%	-4%	-9%	-3%	-41%	-13%	-20%	-
	Standard Deviation within 5%.	-3%	-3%	0%	-7%	-1%	-36%	5%	3%	-

It should be noted that there was no observed data available to derive the prior goods vehicle matrices. These were developed synthetically, and hence were unlikely to accurately represent the true patterns of travel of heavy goods vehicles. As a result of this, matrix estimation was required to make large changes to the LGV, OGV1 and OGV2 matrices across all time periods.

For the remaining user classes the differences between pre- and post-matrix estimation matrices either exceeded or was close to exceeding the recommended criteria, with several exceptions. In the AM Peak and Inter-peak 2 periods, both the slope and R^2 values either exceed or are close to exceeding close to the recommended criteria. In the Inter-peak 1 period, Car Commute (UC3) and Car Other (UC5) fail to meet the recommended criteria by a significant margin. In the Pm Peak, although the slope values are near the recommended criteria, the R2 values are further away, especially for Car Employers Business (UC2) and Car Education (UC4). Overall, this indicates that the changes made during matrix estimation were larger than desired.

To address this, the XAMAX parameter in SATURN was reduced and trip end constraints were applied. The XAMAX parameter is discussed more fully in Section 5.9.1, however in summary it defines a maximum (or minimum) adjustment factor during Matrix Estimation. A lower value restricts the magnitude of the changes that can be made at a cell level during Matrix Estimation, while the trip end constraints were applied to further reduce the significance of the changes made during Matrix Estimation.

Table 5.12 Pre-Audit Road Assignment Model Calibration

Measure	Significance Criteria	AM Peak	Inter-peak 1	Inter-peak 2	PM Peak
Individual flows within 100 veh/h of counts for flows less than 700 veh/h within 15% of counts for flows from 700 to 2,700 veh/h within 400 veh/h of counts for flows more than 2,700 veh/h	> 85% of cases	94% (213)	94% (214)	94% (213)	94% (214)
GEH < 5 for individual flows	> 85% of cases	91% (206)	89% (203)	92% (208)	90% (205)

Table 5.13 Pre-Audit Road Assignment Model Screenline Calibration

Measure	Significance Criteria	AM Peak	Inter-peak 1	Inter-peak 2	PM Peak
Differences between modelled flows and counts should be less than 5% of the counts	> 85% of cases	72 %	72%	72%	72%

Table 5.13 indicates that the road assignment model, pre-audit, generally falls short of the recommended criteria in each time period, although it does meet the more relaxed criteria typically used for models of this size outlined in Section 5.2.2.

Table 5.10 shows a similar pattern across the model screenlines, with the pre-audit stage model falling short of the criteria in each time period.

However, reducing the XAMAX parameter and applying trip end constraints during matrix estimation to reduce the significance of matrix changes was anticipated to reduce the level of flow calibration achieved. The reason for this is that by restricting the matrix adjustments permitted during matrix estimation, the matrix estimation process may no longer make a significant enough change to the prior matrices to meet the flow calibration criteria at as many locations.

To address this, an audit of the road model network coding was undertaken, which considered whether the coding could be improved at specific locations to improve the level of calibration pre-matrix estimation.

A number of changes were made to the road network, including amending coded signal times at a small number of locations to more accurately reflect pedestrian facilities. In general, the junctions that were amended were those where pedestrian movements are walk-with but there is either a late-start or early cut-off on one or more movements to allow pedestrians to cross one arm, although at some locations, a full pedestrian stage was added by extending the last inter-green period. Several dedicated pedestrian crossings were also added to the road model in order to more accurately reflect the delay along some routes. It was also noted that at some locations, local rerouting was occurring, minimising delays at some junctions. This was corrected where possible through the adjustment of junction coding, and a small decrease was applied to the coded free flow speed on links where the alternative road was noted to be of a significantly lower standard than the main route and unlikely to carry the assigned flow at the coded speed.

The audit also noted that the junction turning count dataset had not been fully utilised during matrix estimation as the traffic counts were not fully classified. Observed vehicle splits were calculated from neighbouring ATC data, and additional traffic count data was included in the matrix estimation dataset in order to adjust the traffic volumes at key locations.

5.6 Road Model Matrix Progression

5.6.1 Overview

For the WRM, four distinct versions of the prior matrices were produced, and each of these were assigned in order to provide updated network costs for further refinement of the Full Demand Model (FDM). The four versions of the matrices are numbered in Figure 5.1 below, which illustrates the process involved in developing the final road model matrices for the WRM. Note that not all of the steps that were undertaken are shown on this diagram.

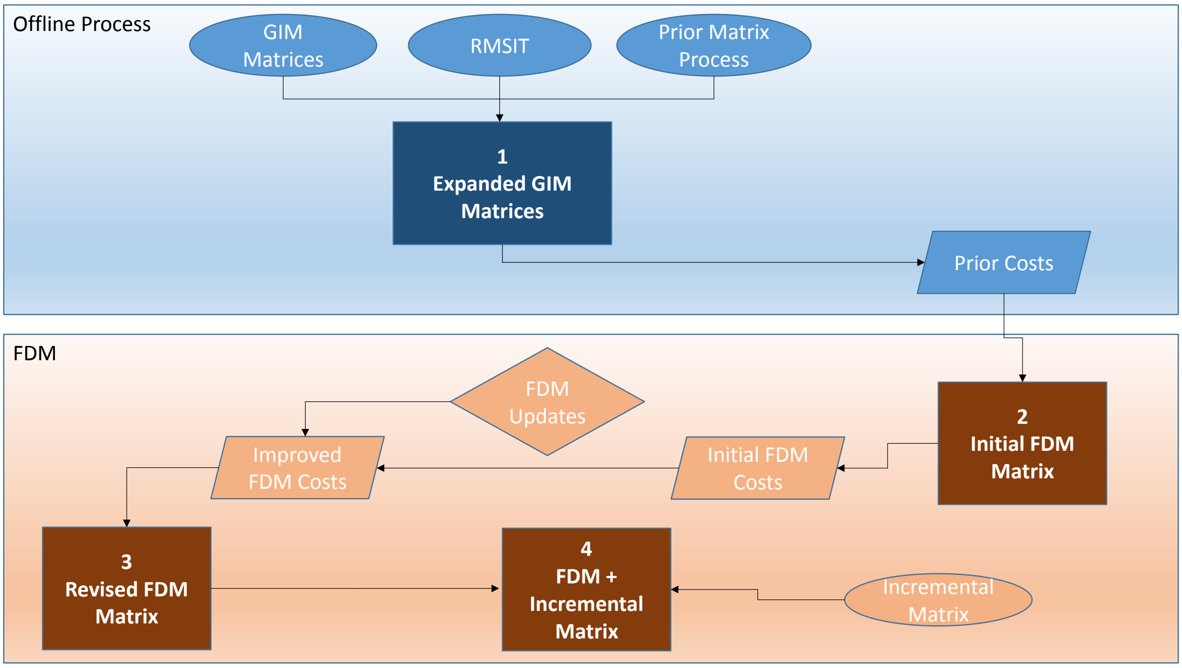

Figure 5.1 Road Model Matrix Development Process

5.6.2 Expanded GIM Matrices

As noted in Chapter 3 previously, the initial WRM matrices were developed through an expansion of the GIM matrices with information on external demand provided by RMSIT. The prior matrix development process, developed for the ERM, was utilised to generate initial goods vehicle matrices. These matrices were assigned to the road network and cost skims were extracted for input into the FDM.

5.6.3 Initial FDM Matrices

The initial calibration of the FDM used the costs extracted from the initial WRM matrix assignment. One loop of the FDM was run to create road matrices for all time periods, and these were assigned and costs skimmed. These costs were then used to recalibrate the FDM. Once this had been completed, one loop of the re-calibrated FDM was run to create road matrices, and these were assigned. A check of the assigned demand at the 24-hour level with observed data for each of the screenlines showed that the demand from the FDM was low compared to observed flows on the network.

5.6.4 Revised FDM Matrices

The WRM FDM has been developed through a series of iterations where a number of alterations have been made including parameter estimation, scripting updates, assumption reviews etc. Further information on the WRM FDM development and calibration is provided in the “WRM Demand Model Calibration Report” and the ”RM Demand Model Development Report”, which should be read in conjunction with this report.

The revised FDM matrices have been created from the final calibrated WRM FDM, and have been taken forward for matrix estimation and development of the final incremental matrices.

5.6.5 Matrix Estimation

Matrix estimation was undertaken on the final prior matrices using SATME2. SATME2 uses observed traffic count data and assigned road model paths to adjust the matrix. A maximum (or minimum) adjustment factor is defined by the SATURN parameter XAMAX. Traffic passing a particular point in the network where a traffic count is located can be factored by any number that lies between XAMAX and 1 / XAMAX. XAMAX has been set to 2 for cars, and 1000 (essentially unlimited) for goods vehicles due to the low confidence in the prior goods matrices. In this case, cars can be adjusted by a factor between 0.5 and 2. Goods vehicles can be adjusted by a factor between 0.001 and 1000.

Further matrix estimation controls included applying a trip end constraint to the adjustments of + / - 10 per cent for all zone trip ends for cars (user classes 1 – 5).

SATME2 and the assignment module, SATALL, were run iteratively with the assigned paths and costs from the latest road assignment informing the next iteration of SATME2. The input prior matrices do not change between successive iterations.

5.6.6 Incremental Matrix Calculation

The incremental matrix reflects those parts of the full travel behaviour pattern which have not been estimated by the demand model. This would include factors like:

- the choice of a school which gets particularly good exam results over another local school; or
- the choice of a journey by tram or train rather than bus which is made because the user can work more reliably on a tram or a train.

The incremental matrix includes all of these varied, hard to predict, behaviour patterns. In the base model it is used to adjust the matrices which are directly output from the demand model to match the calibrated base matrices and so produce a calibrated base network following assignment. In the future model it is intended to improve the predictive power of the model by adding in a contribution from the more unpredictable parts of the travel demand.

5.6.7 Final Incremental Matrices

Two types of incremental matrix are in use in the model:

- Additive incrementals, where the incremental matrices (whose values may be positive, negative, or a mix of the two) are added on to the matrices output by the demand model; and
- Multiplicative incrementals, where the incremental matrices are used to factor the matrices output by the demand model.

There is no reason in principal why each incremental could not be a mix of additive and multiplicative values but at present the model uses additive incrementals for the road and public transport matrices and multiplicative incrementals for the active modes. This is because the calibrated base matrices are considered to be much better defined in the road and public transport networks than is the case in the active modes model.

The additive incrementals are calculated by taking the best direct demand model output and finding the difference between this and the best calibrated base matrix on a cell by cell basis. The incremental matrix produced is added on to the best direct demand model output such that the final assignment output matches the calibrated base (in the base case).

As there is no detailed calibration of the active modes component the multiplicative incrementals used are calculated by working out the factor which will adjust the assignment matrices to give the best overall fit to the total observed flow on any observed screenline. For example if 100 trips were observed and the model with no incremental applied gave a value of 120 trips on that screenline then the incremental matrix would be set to a value of 100/120 in every cell such that once the incremental is applied the assignment model would mimic the 100 observed trips closely.

The final assignment matrices including the incremental adjustments are what the network calibration and validation assessments are based on. In relation to road travel, the incremental matrix only applies to car user classes; for goods vehicles the matrix estimated matrix was input directly as an updated version of the input internal goods matrix.

During the incremental process the ratio of the estimated “Taxi” user class to the estimated “Car Other” user class was calculated and applied to generate future “Taxi” matrices. Further details of the incremental process are presented in the “RM Spec1 Full Demand Model Specification Report”.

5.7 Final generalised cost parameters

The road assignment model was calibrated and subsequently validated using the generalised cost parameters set out in the following tables.

Table 5.14 Final AM Generalised Cost Values

User Class	Cents Per Minute	Cents Per Kilometre
UC1 – Taxi	60.13	19.71
UC2 – Car Employers Business	60.13	19.71
UC3 – Car Commute	21.52	10.26
UC4 – Car Education	36.39	10.26
UC5 – Car Other	21.16	10.26

UC6 – LGV	43.34	13.97
UC7 – OGV1	46.08	32.27
UC8 – OGV2 Permit Holder	44.40	59.08
UC9 – OGV2 (Other)	44.40	59.08

Table 5.15 Final IP1 Generalised Cost Values

User Class	Cents Per Minute	Cents Per Kilometre
UC1 – Taxi	70.39	18.82
UC2 – Car Employers Business	70.39	18.82
UC3 – Car Commute	20.74	9.84
UC4 – Car Education	42.66	9.84
UC5 – Car Other	38.41	9.84
UC6 – LGV	45.91	14.26
UC7 – OGV1	47.87	31.82
UC8 – OGV2 Permit Holder	46.55	58.44
UC9 – OGV2 (Other)	46.55	58.44

Table 5.16 Final IP2 Generalised Cost Values

User Class	Cents Per Minute	Cents Per Kilometre
UC1 – Taxi	70.39	19.19
UC2 – Car Employers Business	70.39	19.19
UC3 – Car Commute	20.74	10.01
UC4 – Car Education	42.66	10.01
UC5 – Car Other	38.41	10.01
UC6 – LGV	45.91	14.48
UC7 – OGV1	47.87	32.53
UC8 – OGV2 Permit Holder	46.55	59.74
UC9 – OGV2 (Other)	46.55	59.74

Table 5.17 Final PM Generalised Cost Values

User Class	Cents Per Minute	Cents Per Kilometre
UC1 – Taxi	60.13	19.51
UC2 – Car Employers Business	60.13	19.51
UC3 – Car Commute	21.52	10.16
UC4 – Car Education	36.39	10.16
UC5 – Car Other	21.16	10.16
UC6 – LGV	43.34	13.84

UC7 – OGV1	46.08	31.89
UC8 – OGV2 Permit Holder	44.40	58.36
UC9 – OGV2 (Other)	44.40	58.36

5.8 Road Model Network Calibration

5.8.1 Overview

This section details the calibration process and the level of calibration for the road assignment model across the four assigned peak periods. In total, 272 observations have been used in the SATME2 procedure and a total of 82 observations form part of the strategic screenlines.

Although TAG suggests that GEH values should be less than 5 for 85 per cent of cases, for a model of this size and complexity a range of standards suggest that it is common for larger GEH values to be accepted as showing a robust level of calibration when considered in full with the intended model application and other performance indicators. Acceptable models typically achieve criterion in the following ranges:

- GEH < 5 for 65 per cent of all sites;
- GEH < 7 for 75 per cent of all sites; and
- GEH < 10 for 95 per cent of all sites.

5.8.2 Traffic Count Locations

Detailed maps showing the location of all traffic counts used during calibration are illustrated in Figure 5.2 and Figure 5.3, overleaf.

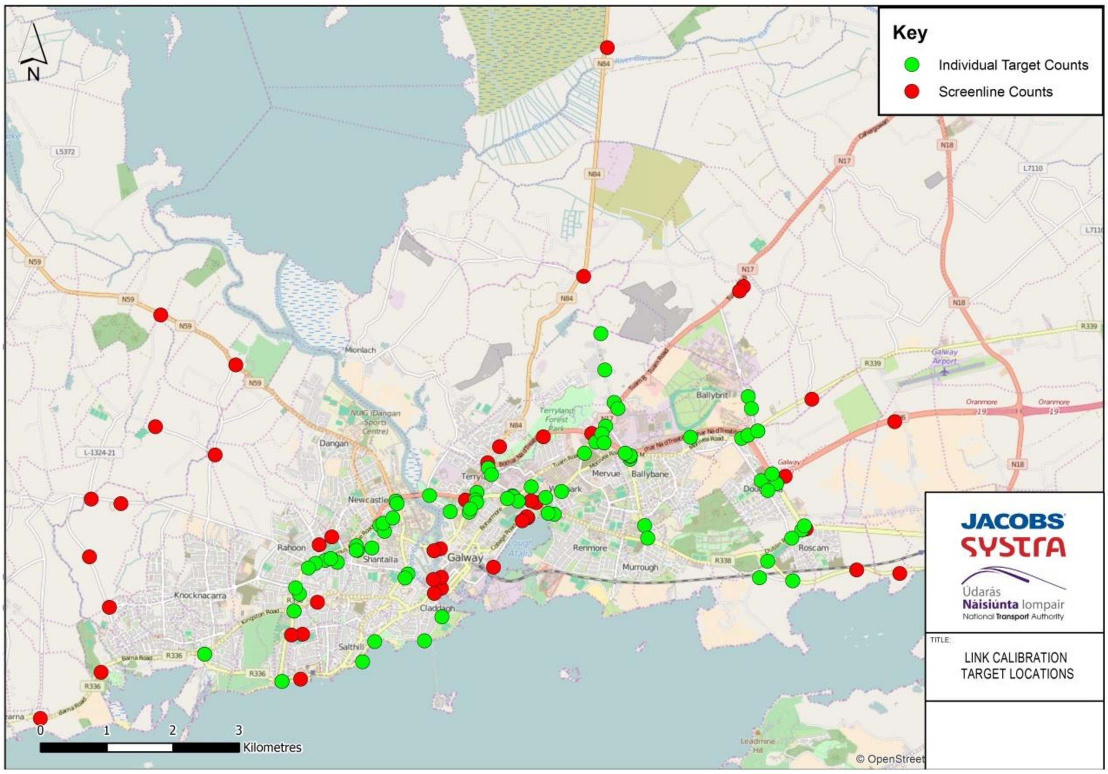

Figure 5.2 Link Calibration Target Locations

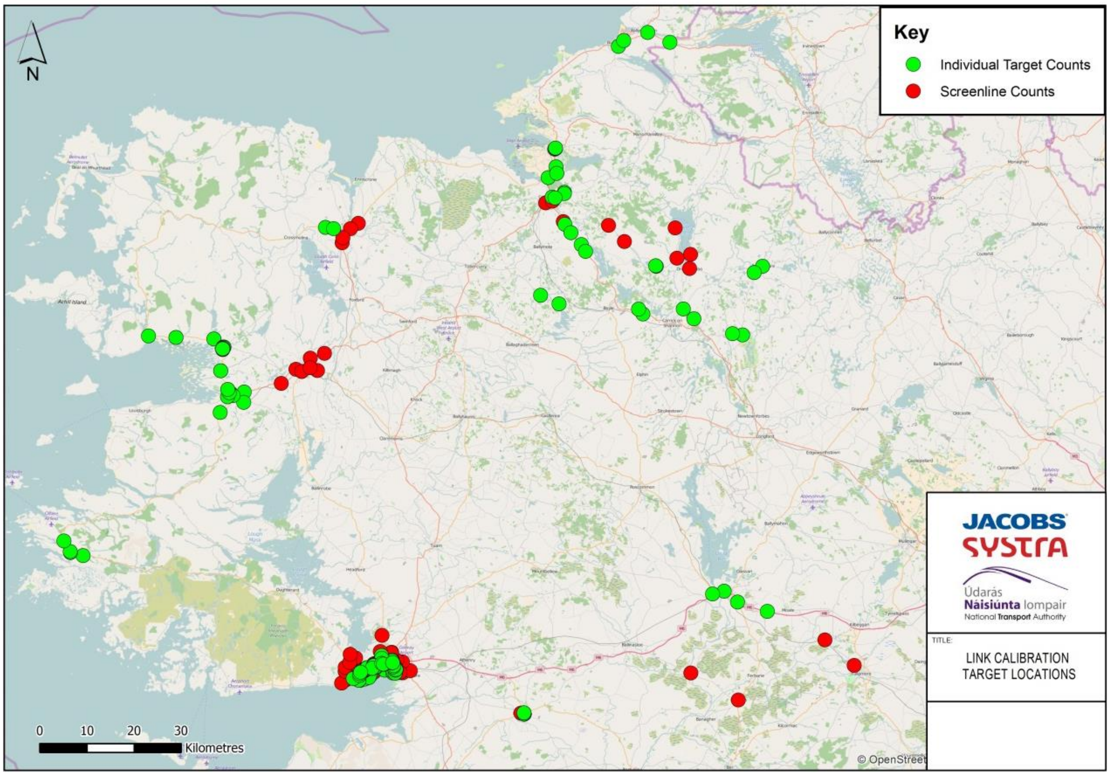

Figure 5.3 Link Calibration Target Locations – County Galway and Wider Region

5.8.3 Individual link calibration criteria compliance – AM Peak

There are a total of 272 individual link traffic counts used during the AM peak road model network calibration. Table 5.18 details the individual link count acceptability criteria.

Table 5.18 AM Link Flow Calibration

Criteria	Acceptability Guideline	Model Statistics
Link Flow	> 85% of cases	87% (236)
GEH < 5 for individual flows	> 65% of cases	80% (217)
GEH < 7 for individual flows	> 75% of cases	88% (238)
GEH < 10 for individual flows	> 95% of cases	95% (259)

The model statistics show that the individual link calibration for the AM peak road model meets the recommendations set out in TAG, for link flows and GEH values.

Detailed calibration results, highlighting specific links that pass or fail the recommended calibration criteria are included in Appendix A. The maximum recoded GEH was 25.6. All GEH values in excess of 15 were reviewed, and often these GEH values were recorded on links with small levels of observed traffic. In this specific example, the GEH of 17.3 was recorded on the N84 Headford Road westbound. This is part of the Ballinfoyle inbound screenline in the north of Galway City. The observed traffic flow is 748 vehicles per hour while the modelled flow is 345 vehicles per hour. In this instance, traffic was re-routing via parallel routes to avoid excessive delays at the N84 / N6 roundabout. The delays however were required in order to better match observed journey times.

5.8.4 Screenline calibration criteria compliance – AM Peak

A total of nine two-way screenlines (inbound and outbound) were compared as part of the network calibration exercise.

Table 5.19 details the number of SATURN links forming each screenline, and the difference between the total observed traffic volume across the screenline and the total modelled traffic volume across the screenline.

Table 5.19 AM Screenline Flow Calibration

Screenline	Number of Links	Modelled Difference
West Screenline (Inbound)	5	-1%
West Screenline (Outbound)	5	2%
R338 Screenline (Inbound)	4	-11%
R338 Screenline (Outbound)	4	3%
River Corrib Screenline (Eastbound)	4	-1%
River Corrib Screenline (Westbound)	4	0%
Ballinfoyle Screenline (Outbound)	5	2%
Ballinfoyle Screenline (Inbound)	5	-12%
East Screenline (Outbound)	6	-1%
East Screenline (Inbound)	6	-3%
Castlebar Screenline (Inbound)	4	4%
Castlebar Screenline (Outbound)	4	9%
Loughrea Screenline (Outbound)	4	6%
Loughrea Screenline (Inbound)	4	-2%
Outer West Screenline (Inbound)	4	0%
Outer West Screenline (Outbound)	4	1%
Outer East Screenline (Outbound)	5	0%
Outer East Screenline (Inbound)	5	1%

78 per cent of the screenlines meet the recommended calibration criteria as set out in TAG Unit M3-1, which is below the recommended acceptability criteria of "all or nearly all" screenlines meeting the criteria, though the remaining four screenlines fail by less than seven percentage points.

5.8.5 Individual Link Calibration Criteria Compliance – Inter-peak 1

There are a total of 272 traffic counts used during the Inter-peak 1 road model network calibration. Table 5.20 details the individual link count acceptability criteria.

Table 5.20 Inter-peak 1 Link Flow Calibration

Criteria	Acceptability Guideline	Model Statistics
Link Flow	> 85% of cases	93% (254)
GEH < 5 for individual flows	> 65% of cases	86% (234)
GEH < 7 for individual flows	> 75% of cases	92% (251)
GEH < 10 for individual flows	> 95% of cases	98% (266)

The model statistics show that the individual link calibration for the Inter-peak 1 road model meets the recommendations set out in TAG, for link flows and GEH values.

Detailed calibration results, highlighting specific links that pass or fail the recommended calibration criteria are included in Appendix A. The recorded maximum GEH was 15.4. GEH values in excess of 15 were reviewed, and often these GEH values are recorded on links with small levels of observed traffic. In this specific example, the GEH of 15.4 was recorded on the minor road connecting Castlegar Village to the N17 in the northeast of Galway City. The observed traffic flow is 128 vehicles per hour while the modelled flow is 3 vehicles per hour. Given the location and density of the zones, it is often difficult to calibrate links with low levels of observed traffic given the strategic nature of the WRM.

5.8.6 Screenline calibration criteria compliance – Inter-peak 1

A total of nine two-way screenlines were compared as part of the network calibration exercise.

Table 5.21 details the number of SATURN links forming each screenline, and the difference between the total observed traffic volume across the screenline and the total modelled traffic volume across the screenline.

Table 5.21 Inter-peak 1 Screenline Flow Calibration

Screenline	Number of Links	Modelled Difference
West Screenline (Inbound)	5	-1%
West Screenline (Outbound)	5	0%
R338 Screenline (Inbound)	4	-13%
R338 Screenline (Outbound)	4	-5%

River Corrib Screenline (Eastbound)	4	-5%
River Corrib Screenline (Westbound)	4	-1%
Ballinfoyle Screenline (Outbound)	5	2%
Ballinfoyle Screenline (Inbound)	5	-11%
East Screenline (Outbound)	6	6%
East Screenline (Inbound)	6	6%
Castlebar Screenline (Inbound)	4	5%
Castlebar Screenline (Outbound)	4	3%
Loughrea Screenline (Outbound)	4	-5%
Loughrea Screenline (Inbound)	4	-5%
Outer West Screenline (Inbound)	4	0%
Outer West Screenline (Outbound)	4	0%
Outer East Screenline (Outbound)	5	4%
Outer East Screenline (Inbound)	5	1%

67 per cent of the screenlines meet the recommended calibration criteria as set out in TAG Unit M3-1, which is below the recommended acceptability criteria of “all or nearly all” screenlines meeting the criteria. However, a further four screenlines fail by less than one percentage point.

5.8.7 Individual Link Calibration Criteria Compliance – Inter-peak 2

There are a total of 272 traffic counts used during the Inter-peak 2 road model network calibration. Table 5.22 details the individual link count acceptability criteria.

Table 5.22 Inter-peak 2 Link Flow Calibration

Criteria	Acceptability Guideline	Model Statistics
Link Flow	> 85% of cases	92% (249)
GEH < 5 for individual flows	> 65% of cases	86% (234)
GEH < 7 for individual flows	> 75% of cases	90% (245)
GEH < 10 for individual flows	> 95% of cases	95% (259)

The model statistics show that the individual link calibration for the Inter-peak 2 road model meets the recommendations set out in TAG, for link flows and GEH values.

Detailed calibration results, highlighting specific links that pass or fail the recommended calibration criteria are included in Appendix A. The recorded maximum GEH was 17.6. GEH values in excess of 15 were reviewed, and often these GEH values are recorded on links with small levels of observed traffic. As with the Inter-peak 1 period, this GEH of 17.6 was recorded on the minor road connecting Castlegar Village to the N17 in the northeast of Galway City. The observed traffic flow is 156 vehicles per hour while the modelled flow is 1 vehicle per hour. This issue is consistent with the Inter-peak 1 assignment.

5.8.8 Screenline calibration criteria compliance – Inter-peak 2

A total of nine two-way screenlines were compared as part of the network calibration exercise.

Table 5.23 details the number of SATURN links forming each screenline, and the difference between the total observed traffic volume across the screenline and the total modelled traffic volume across the screenline.

Table 5.23 Inter-peak 2 Screenline Flow Calibration

Screenline	Number of Links	Modelled Difference
West Screenline (Inbound)	5	-5%
West Screenline (Outbound)	5	-3%
R338 Screenline (Inbound)	4	-3%
R338 Screenline (Outbound)	4	-5%
River Corrib Screenline (Eastbound)	4	0%
River Corrib Screenline (Westbound)	4	0%
Ballinfoyle Screenline (Outbound)	5	-3%
Ballinfoyle Screenline (Inbound)	5	-5%
East Screenline (Outbound)	6	1%
East Screenline (Inbound)	6	6%
Castlebar Screenline (Inbound)	4	4%
Castlebar Screenline (Outbound)	4	4%
Loughrea Screenline (Outbound)	4	-4%
Loughrea Screenline (Inbound)	4	-10%
Outer West Screenline (Inbound)	4	0%
Outer West Screenline (Outbound)	4	0%
Outer East Screenline (Outbound)	5	2%
Outer East Screenline (Inbound)	5	3%

78 per cent of the screenlines meet the recommended calibration criteria as set out in TAG Unit M3-1, which is below the recommended acceptability criteria of “all or nearly all” screenlines meeting the criteria. A further screenline narrowly fails to meet the criteria.

5.8.9 Individual Link Calibration Criteria Compliance – PM Peak

There are a total of 272 traffic counts used during the PM peak road model network calibration. Table 5.24 details the individual link count acceptability criteria.

Table 5.24 PM Link Flow Calibration

Criteria	Acceptability Guideline	Model Statistics
Link Flow	> 85% of cases	88% (240)
GEH < 5 for individual flows	> 65% of cases	81% (220)
GEH < 7 for individual flows	> 75% of cases	88% (238)
GEH < 10 for individual flows	> 95% of cases	94% (257)

The model statistics show that the individual link calibration for the PM peak road model meets the recommendations set out in TAG, for link flows and for GEH values less than 5, and the typically acceptable criteria for GEH values less than 7. The GEH value less than 10 narrowly fails the typically acceptable criteria by one percentage point.

Detailed calibration results, highlighting specific links that pass or fail the recommended calibration criteria are included in Appendix A. The recorded maximum GEH was 16.8. GEH values in excess of 15 were reviewed, and often these GEH values are recorded on links with small levels of observed traffic. As with the Inter-peak 1 and Inter-peak 2 periods, this GEH of 16.8 was recorded on the minor road connecting Castlegar Village to the N17 in the northeast of Galway City. The observed traffic flow is 141 vehicles per hour while the modelled flow does not record any vehicles on this minor link. This issue is consistent with observations noted for the Inter-peak 1 and Inter-peak 2 assignments.

5.8.10 Screenline Calibration Criteria Compliance – PM Peak

A total of nine two-way screenlines were compared as part of the network calibration exercise.

Table 5.25 details the number of SATURN links forming each screenline, and the difference between the total observed traffic volume across the screenline and the total modelled traffic volume across the screenline.

Table 5.25 PM Screenline Flow Calibration

Screenline	Number of	Modelled

	Links	Difference
West Screenline (Inbound)	5	-1%
West Screenline (Outbound)	5	-1%
R338 Screenline (Inbound)	4	-6%
R338 Screenline (Outbound)	4	-12%
River Corrib Screenline (Eastbound)	4	0%
River Corrib Screenline (Westbound)	4	-1%
Ballinfoyle Screenline (Outbound)	5	-2%
Ballinfoyle Screenline (Inbound)	5	-4%
East Screenline (Outbound)	6	-5%
East Screenline (Inbound)	6	3%
Castlebar Screenline (Inbound)	4	16%
Castlebar Screenline (Outbound)	4	9%
Loughrea Screenline (Outbound)	4	-11%
Loughrea Screenline (Inbound)	4	-14%
Outer West Screenline (Inbound)	4	4%
Outer West Screenline (Outbound)	4	0%
Outer East Screenline (Outbound)	5	-1%
Outer East Screenline (Inbound)	5	2%

61 per cent of the screenlines meet the recommended calibration criteria as set out in TAG Unit M3-1, which is below the recommended acceptability criteria of “all or nearly all” screenlines meeting the criteria. However, a further three screenlines fail by less than four percentage point.

5.9 Road Model Matrix Calibration

5.9.1 Overview

Matrix estimation was undertaken on the final prior matrices, including constraints at a cellular and trip end level.

5.9.2 Calibration criteria compliance – AM Peak

Table 5.26 details the overall change in inter-zonal matrix size between the pre-estimation matrix and the post-estimation matrix. Intra-zonal matrix totals are not adjusted by matrix estimation and do not affect assignment in SATURN.

Table 5.26 WRM RM AM Peak Matrix Totals

User Class	Prior (PCU)	Post-Incremental (PCU)	Change (%)
Taxi	2,281	2,322	2%
Car Employers Business	4,361	4,361	0%
Car Commute	37,722	36,833	-2%
Car Education	1,409	1,389	-1%
Car Other	68,204	67,652	-1%
LGV	2,879	2,879	0%
OGV1	2,020	2,020	0%
OGV2 Permit Holder			
Other OGV2	7	7	0%

A table of sectored matrix differences is presented in Appendix B.

The changes to all user classes are of an acceptable level.

GEH analysis was undertaken on the individual (non-zero) cells and their change between the pre-estimation and post-estimation values. 43 per cent of cells have a GEH value of less than 0.01, with 90 per cent of cells having a GEH value of less than 0.1. A graph illustrating the distribution of GEH values is shown in Figure 5.4 and Figure 5.5. Please note the change in scale for both axes in Figure 5.5.

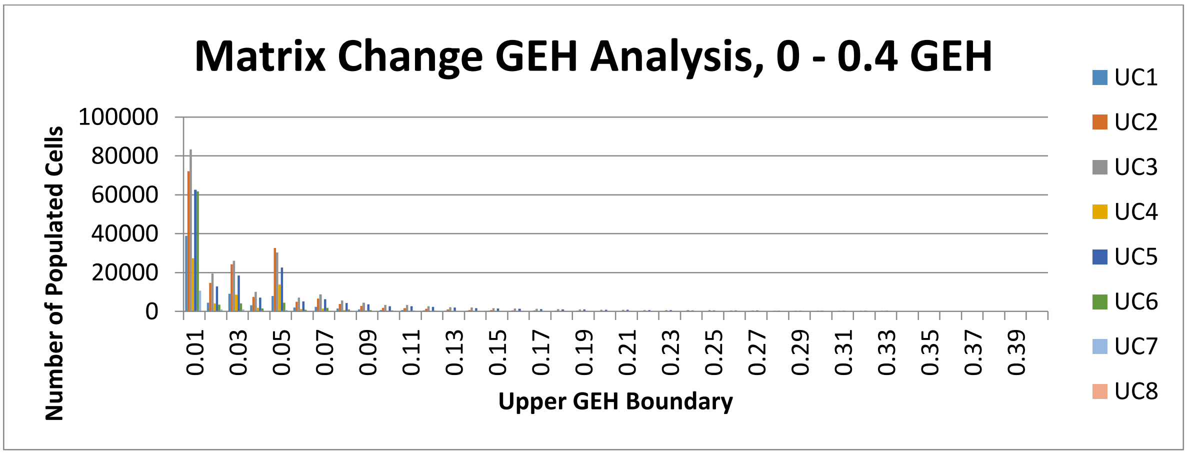

Figure 5.4 SATME2 AM Matrix Change GEH Analysis; 0 GEH to 0.4 GEH

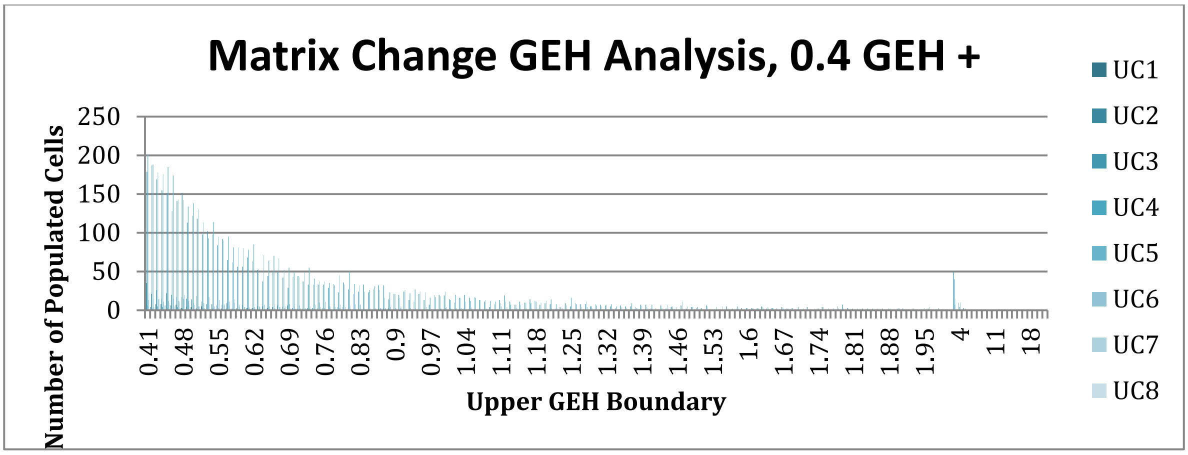

Figure 5.5 SATME2 AM Matrix Change GEH Analysis; 0.4 GEH Upwards

R^2 analysis was undertaken to further understand the matrix changes made by SATME2. Table 5.27 details the R^2 values for each individual user class. These are represented graphically in Appendix C.

Table 5.27 SATME2 AM Matrix Change R^2 Analysis

User Class	Cell R^2 Value	Cell Slope	Cell Y-Int
TAG Criteria	> 0.95	0.98 - 1.02	Near 0
Taxi	0.98	0.99	0.00
Car Employers Business	0.94	0.96	0.00
Car Commute	0.95	0.97	0.00
Car Education	0.98	0.98	0.00
Car Other	0.99	0.99	0.00
LGV	0.86	0.94	0.00
OGV1	0.86	1.07	0.00
OGV2 Permit Holder			
Other OGV2	1.00	1.00	0.00

TAG Unit M3-1, Section 8, Table 5 indicates that an acceptable R^2 value for individual matrix zonal changes is in excess of 0.95. Five of the user classes pass the R^2 test, and the one user class that did not pass, has a R^2 value of 0.94. Four of the user classes pass the recommended criteria for Slope values between 0.98 – 1.02. Two values of 0.96 – 0.97 narrowly fail to meet the TAG criteria. All Y-Intercept values are 0.00 and so are in accordance with the “Near 0” TAG criteria.

Trip End analysis was undertaken for each user class and summarised in Table 5.28.

Table 5.28 AM Trip End Matrix Change R^2 Analysis

User Class	Trip End R^2 Value	Trip End Slope	Trip End Y-Int
TAG Criteria	> 0.98	0.99 - 1.01	Near 0
Taxi	0.99	1.00	0.00
Car Employers Business	0.99	0.98	0.14
Car Commute	0.99	0.97	0.85
Car Education	0.99	0.99	0.00
Car Other	1.00	0.98	1.40
LGV	0.94	0.98	0.11
OGV1	0.95	1.08	-0.05
OGV2 Permit Holder			
Other OGV2	1.00	1.00	0.00

The R^2 value for the trip ends is greater than 0.98 for all user classes with the exception of “LGV and OGV1”. The trip end slope passes the TAG criteria for three user classes, with four narrowly failing to meet the TAG criteria. Values for the y-intercept are between -0.05 and 1.40.

Table 5.29 WRM RM AM Screenline Check

User Class	Observed (Veh)	Model (Veh)	Difference (%)
TAG Criteria			**Within 5%**
West Screenline (Inbound)	1846	1834	-1%
West Screenline (Outbound)	731	743	2%
River Corrib Screenline (Eastbound)	3633	3609	-1%
River Corrib Screenline (Westbound)	3012	3016	0%
East Screenline (Outbound)	2018	1996	-1%
East Screenline (Inbound)	6044	5848	-3%

Traffic levels across the West, River Corrib and East Screenlines are within the acceptability criteria outlined in TAG unit M3-1. However, the other screenlines do not meet the recommended criteria of total screenline flows being within 5 per cent.

Trip length distribution was also assessed as part of the matrix calibration process post-estimation. All of the user classes pass the criteria of a change in the mean trip length of less than 5 per cent, and in the criteria of a change in the standard deviation of the trip length of less than 5 per cent.

Table 5.30 Trip Length Distribution Analysis – AM

User Class **(TAG Criteria)**	Mean Percentage Change **(< 5%)**	Standard Deviation Change **(< 5%)**
Taxi	-1%	-1%
Car Employers Business	0%	2%
Car Commute	2%	3%
Car Education	0%	2%
Car Other	1%	2%
LGV	-1%	0%
OGV1	-1%	0%
OGV2 Permit Holder		
Other OGV2	0%	0%

Graphical representation of the trip length distribution changes at a user class level are presented in Appendix D.

5.9.3 Calibration criteria compliance – Inter-peak 1

Table 5.31 details the overall change in inter-zonal matrix size between the pre-estimation matrix and the post-estimation matrix. Intra-zonal matrix totals are not adjusted by matrix estimation and do not affect assignment in SATURN.

Table 5.31 WRM RM Inter-peak 1 Matrix Totals

User Class	Pre-Estimation (PCU)	Incremental (PCU)	Change (%)
Taxi	2,007	2,077	3%
Car Employers Business	4,369	4,490	3%
Car Commute	7,042	6,621	-6%
Car Education	63	70	11%
Car Other	60,657	60,391	0%
LGV	2,355	2,355	0%
OGV1	1,721	1,721	0%
OGV2 Permit Holder			
Other OGV2	12	12	0%

A table of sectored matrix differences is presented in Appendix B.

Car Commute and Car Education both fail to meet the recommended TAG criteria. However, Car Education changed by seven PCUs, therefore the level of change is considered acceptable. Car Commute failed to meet the recommended criteria by one per cent.

GEH analysis was undertaken on the individual (non-zero) cells and their change between the pre-estimation and post-estimation values. 43 per cent of cells have a GEH value of less than 0.01, with 92 per cent of cells having a GEH value of less than 0.1. 99.9 per cent of cells have a GEH value of less than 1.0. A graph illustrating the distribution of GEH values is shown in Figure 5.6 and Figure 5.7. Please note the change in scale for both axes in Figure 5.7.

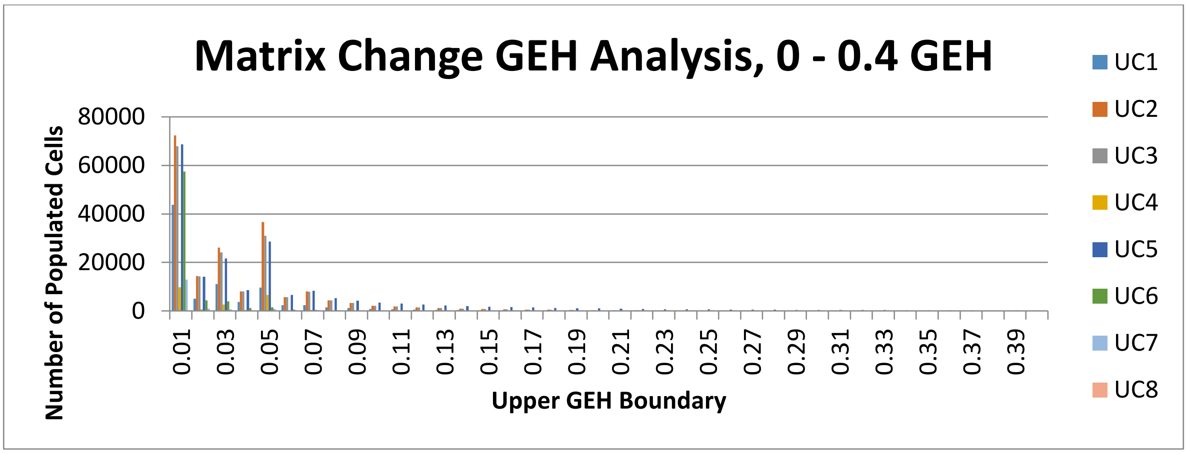

Figure 5.6 SATME2 IP1 Matrix Change GEH Analysis; 0 GEH to 0.4 GEH

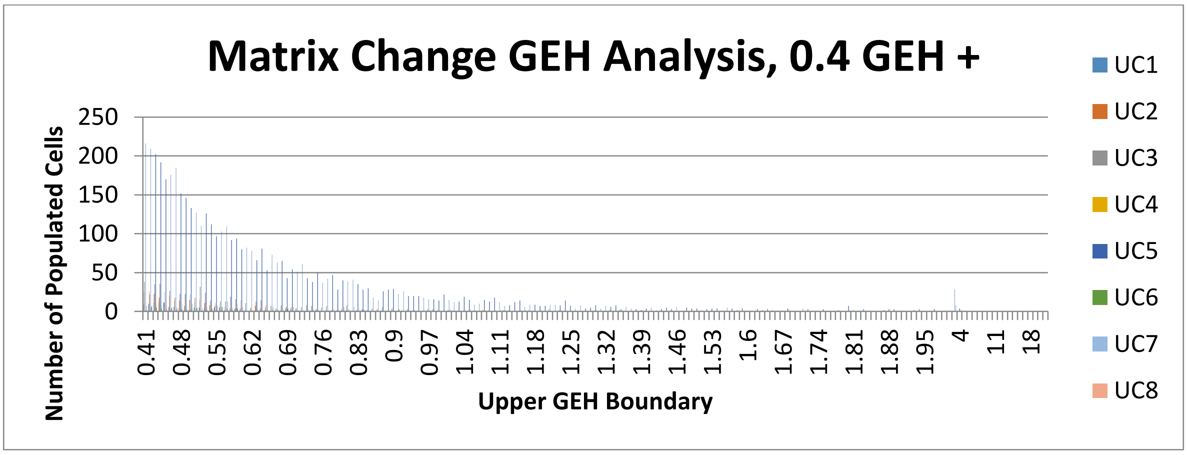

Figure 5.7 SATME2 IP1 Matrix Change GEH Analysis; 0.4 GEH Upwards

R^2 analysis was undertaken to further understand the matrix changes made by SATME2. Table 5.32 details the R^2 values for each individual user class. These are represented graphically in Appendix C.

Table 5.32 SATME2 IP1 Matrix Change R^2 Analysis

User Class	Cell R^2 Value	Cell Slope	Cell Y-Int
TAG Criteria	> 0.95	0.98 - 1.02	Near 0
Taxi	0.97	1.00	0.00
Car Employers Business	0.93	0.98	0.00
Car Commute	0.95	0.97	0.00
Car Education	0.93	1.02	0.00
Car Other	0.99	0.99	0.00
LGV	0.96	1.02	0.00
OGV1	0.93	0.93	0.02
OGV2 Permit Holder			
Other OGV2	1.00	1.00	0.00

Four of the user classes pass the R^2 test, with the four that did not pass having R^2 values of 0.93 – 0.95. Five user classes pass the TAG criteria for Slopes, with the values between 0.98 – 1.02. The three remaining user classes have a Slope value of 0.93 – 1.02, which narrowly fails to meet the TAG criteria. Seven of the Y-Intercept values are 0.00, with one at 0.02 and so are in accordance with the “Near 0” TAG criteria.

Trip End analysis was undertaken for each user class and summarised in Table 5.33.

Table 5.33 IP1 Trip End Matrix Change R^2 Analysis

User Class	Trip End R^2 Value	Trip End Slope	Trip End Y-Int
TAG Criteria	> 0.98	0.99 - 1.01	Near 0
Taxi	0.99	1.04	-0.06
Car Employers Business	0.99	0.99	0.13
Car Commute	0.98	0.90	0.48
Car Education	0.98	1.07	-0.01
Car Other	0.99	0.98	1.44
LGV	0.99	1.01	-0.03
OGV1	0.98	1.03	0.00
OGV2 Permit Holder			
Other OGV2	1.00	1.00	0.00

The R^2 value passes the recommended TAG criteria for seven user classes, with the remaining user class only narrowly failing the recommended criteria. Three of the user classes pass the TAG criteria for trip end slope, with a further one only narrowly failing. Values for the y-intercept near zero are between -0.06 and 1.44.

Table 5.34 details the total traffic crossing the screenlines.

Table 5.34 WRM RM IP1 Screenline Check

User Class	Observed (Veh)	Model (Veh)	Difference (%)
TAG Criteria			Within 5%
West Screenline (Inbound)	871	866	-1%
West Screenline (Outbound)	691	690	0%
River Corrib Screenline (Eastbound)	2592	2460	-5%
River Corrib Screenline (Westbound)	2383	2349	-1%
East Screenline (Outbound)	2012	2139	6%
East Screenline (Inbound)	2421	2576	6%

Traffic levels across the West and River Corrib Screenlines are within the acceptability criteria outlined in TAG unit M3-1. The East Screenline narrowly fails with a 6 per cent difference in either direction.

Trip length distribution was also assessed as part of the matrix calibration process. Five of the eight user classes pass the criteria of a change in the mean trip length of less than 5 per cent, and four of the user classes pass the criteria of a change in the standard deviation of the trip length of less than 5 per cent.

Table 5.35 Trip Length Distribution Analysis – IP1

User Class	Mean Percentage Change	Standard Deviation Change
(TAG Criteria)	(< 5%)	(< 5%)
Taxi	-4%	-7%
Car Employers Business	-8%	-10%
Car Commute	-9%	-7%
Car Education	-1%	0%
Car Other	-8%	-13%
LGV	0%	0%
OGV1	0%	0%
OGV2 Permit Holder		
Other OGV2	0%	0%

Graphical representation of the trip length distribution changes at a user class level are presented in Appendix D.

5.9.4 Calibration criteria compliance – Inter-peak 2

Table 5.36 details the overall change in inter-zonal matrix size between the pre-estimation matrix and the post-estimation matrix. Intra-zonal matrix totals are not adjusted by matrix estimation and do not affect assignment in SATURN.

Table 5.36 WRM RM Inter-peak 2 Matrix Totals

User Class	Pre-Estimation (PCU)	Incremental (PCU)	Change (%)
Taxi	2,298	2,333	2%
Car Employers Business	3,747	3,743	0%
Car Commute	14,836	14,493	-2%
Car Education	1,337	1,313	-2%
Car Other	75,934	75,163	-1%
LGV	2,270	2,270	0%
OGV1	1,894	1,894	0%
OGV2 Permit Holder			
Other OGV2	7	7	0%

A table of sectored matrix differences is presented in Appendix B.

The changes to all user classes are of an acceptable level.

GEH analysis was undertaken on the individual (non-zero) cells and their change between the pre-estimation and post-estimation values. 42 per cent of cells have a GEH value of less than 0.01, with 91 per cent of cells having a GEH value of less than 0.1 and 99.9 per cent of cells having a GEH value of less than 1.0. A graph illustrating the distribution of GEH values is shown in Figure 5.8 and Figure 5.9. Please note the change in scale for Figure 5.9.

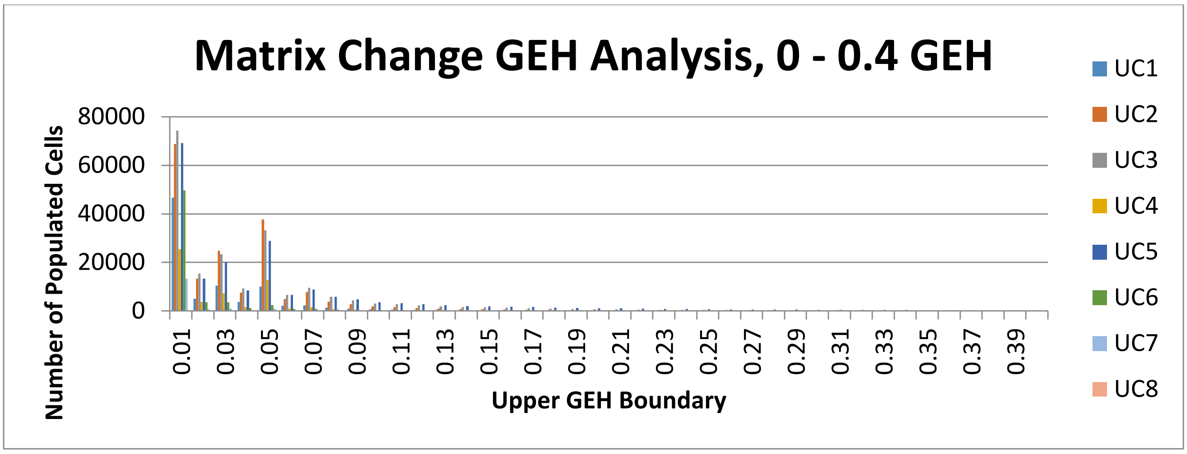

Figure 5.8 SATME2 IP2 Matrix Change GEH Analysis; 0 GEH to 0.4 GEH

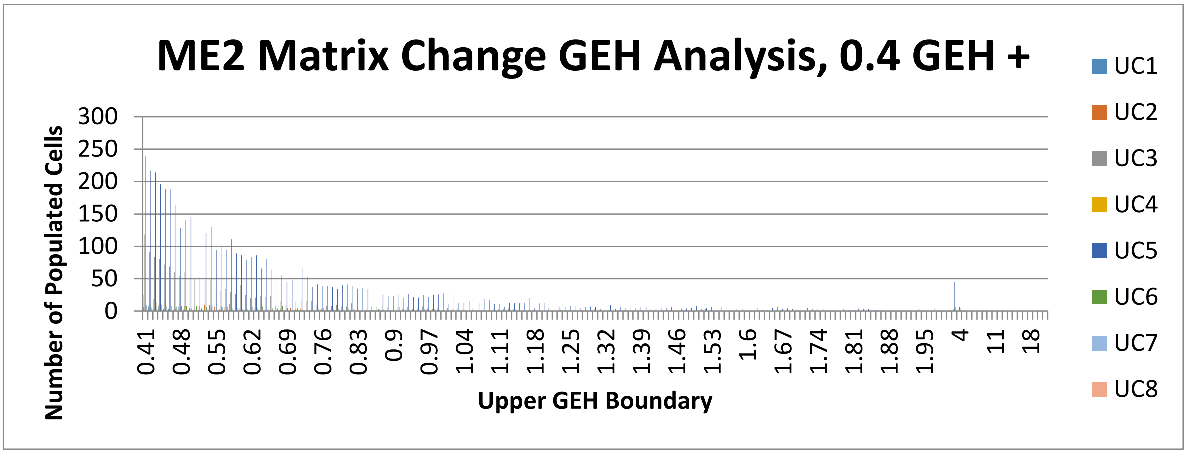

Figure 5.9 SATME2 IP2 Matrix Change GEH Analysis; 0.4 GEH Upwards

R^2 analysis was undertaken to further understand the matrix changes made by SATME2. Table 5.37 details the R^2 values for each individual user class. These are represented graphically in Appendix C.

Table 5.37 SATME2 IP2 Matrix Change R^2 Analysis

User Class	Cell R^2 Value	Cell Slope	Cell Y-Int
TAG Criteria	> 0.95	0.98 - 1.02	Near 0
Taxi	0.98	0.99	0.00
Car Employers Business	0.93	0.98	0.00
Car Commute	0.95	0.99	0.00
Car Education	0.98	0.98	0.00
Car Other	0.99	0.99	0.00

LGV	0.92	1.02	0.00
OGV1	0.88	1.00	0.01
OGV2 Permit Holder			
Other OGV2	1.00	1.00	0.00

Four of the user classes pass the R^2 test, and the four that did not pass, have R^2 values of between 0.88 – 0.95. All of the Slopes pass the TAG criteria with the values between 0.98 – 1.02. All Y-Intercept values are 0.00 apart from OGV1 which is -0.01 and so are in accordance with the “Near 0” TAG criteria.

Trip End analysis was undertaken for each user class and summarised in Table 5.38.

Table 5.38 IP2 Trip End Matrix Change R^2 Analysis

User Class	Trip End R^2 Value	Trip End Slope	Trip End Y-Int
TAG Criteria	> 0.98	0.99 - 1.01	Near 0
Taxi	0.99	1.02	-0.02
Car Employers Business	0.99	0.98	0.09
Car Commute	0.97	0.98	0.09
Car Education	0.99	0.96	0.09
Car Other	0.99	0.98	1.58
LGV	0.97	1.01	0.01
OGV1	0.98	1.05	-0.01
OGV2 Permit Holder			
Other OGV2	1.00	1.00	0.00

The R^2 value passes the TAG criteria for six of the user classes with the remaining two values narrowly failing at 0.97. The trip end slope passes for two of the eight user classes with the remaining values between 0.96 – 1.05. Values for the y-intercept near zero are between -0.02 and 1.58.

Table 5.39 details the total traffic crossing the screenlines.

Table 5.39 WRM RM IP2 Screenline Check

User Class	Observed (Veh)	Model (Veh)	Difference (%)
TAG Criteria			Within 5%
West Screenline (Inbound)	934	888	-5%
West Screenline (Outbound)	1029	1000	-3%
River Corrib Screenline (Eastbound)	2708	2707	0%
River Corrib Screenline (Westbound)	2631	2631	0%

East Screenline (Outbound)	3017	3061	1%
East Screenline (Inbound)	2444	2591	6%

Traffic levels across the East (Outbound), West and River Corrib Screenlines are within the acceptability criteria outlined in TAG unit M3-1. The East (Inbound) Screenline narrowly fails with a 6 per cent difference.

Trip length distribution was also assessed as part of the matrix calibration process. Seven of the eight user classes pass the criteria of a change in the mean trip length of less than 5 per cent, with the eighth failing by less than one percentage point. Once again, all apart from one pass the criteria of a change in the standard deviation of the trip length of less than 5 per cent.

Table 5.40 Trip Length Distribution Analysis – IP2

User Class	Mean Percentage Change	Standard Deviation Change
(TAG Criteria)	(< 5%)	(< 5%)
Taxi	-5%	-8%
Car Employers Business	-6%	-4%
Car Commute	-2%	-1%
Car Education	-3%	-3%
Car Other	-3%	-5%
LGV	0%	1%
OGV1	0%	0%
OGV2 Permit Holder		
Other OGV2	0%	0%

Graphical representation of the trip length distribution changes at a user class level are presented in Appendix D.

5.9.5 Calibration criteria compliance – PM peak

Table 5.41 details the overall change in inter-zonal matrix size between the pre-estimation matrix and the post-estimation matrix. Intra-zonal matrix totals are not adjusted by matrix estimation and do not affect assignment in SATURN.

Table 5.41 WRM RM PM Peak Matrix Totals

User Class	Pre-Estimation (PCU)	Incremental (PCU)	Change (%)
Taxi	2,122	2,146	1%
Car Employers Business	4,380	4,336	-1%

Car Commute	34,961	33,712	-4%
Car Education	684	663	-3%
Car Other	69,015	69,732	0%
LGV	2,241	2,241	0%
OGV1	1,516	1,516	0%
OGV2 Permit Holder			
Other OGV2	7	7	0%

A table of sectored matrix differences is presented in Appendix B.

The changes to all user classes are of an acceptable level.

GEH analysis was undertaken on the individual (non-zero) cells and their change between the pre-estimation and incremental values. 42 per cent of cells have a GEH value of less than 0.01, with 90 per cent of cells having a GEH value of less than 0.1. 99.9 per cent of cells have a GEH value less than 1.0. A graph illustrating the distribution of GEH values is shown in Figure 5.10 and Figure 5.11. Please note the change in scale for both axes in Figure 5.11.

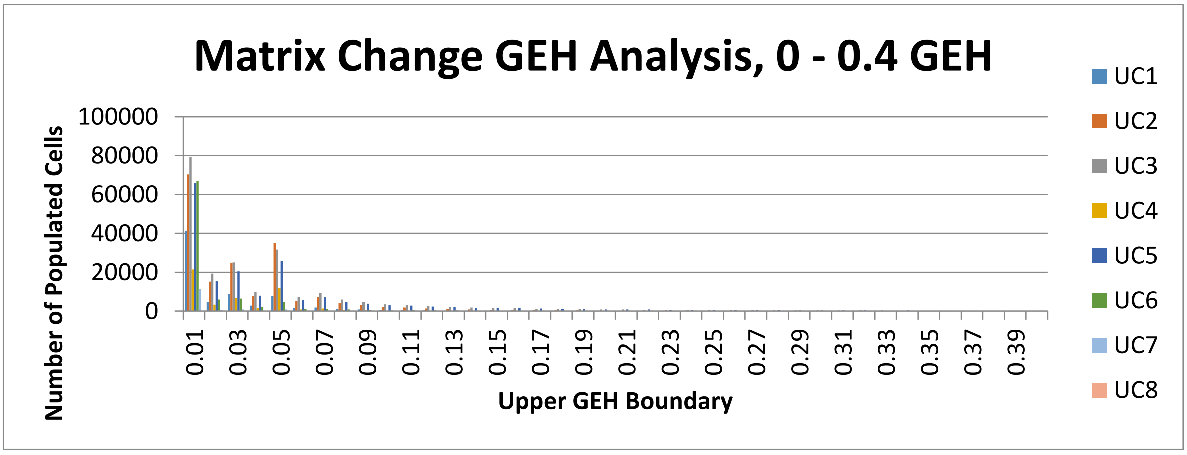

Figure 5.10 SATME2 PM Matrix Change GEH Analysis; 0 GEH to 0.4 GEH

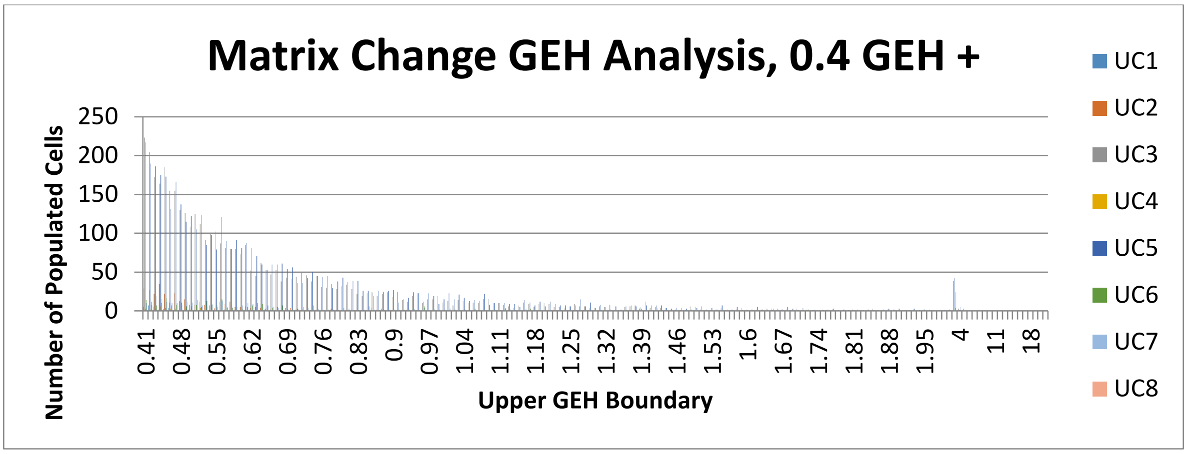

Figure 5.11 SATME2 PM Matrix Change GEH Analysis; 0.4 GEH Upwards

R^2 analysis was undertaken to further understand the matrix changes made by SATME2.

Table 5.42 details the R^2 values for each individual user class. These are represented graphically in Appendix C.

Table 5.42 SATME2 PM Matrix Change R^2 Analysis

User Class	Cell R^2 Value	Cell Slope	Cell Y-Int
TAG Criteria	> 0.95	0.98 - 1.02	Near 0
Taxi	0.98	1.00	0.00
Car Employers Business	0.93	0.97	0.00
Car Commute	0.96	0.98	0.00
Car Education	0.96	0.97	0.00
Car Other	0.99	0.99	0.00
LGV	0.87	0.98	0.00
OGV1	0.86	0.74	0.03
OGV2 Permit Holder			
Other OGV2	1.00	1.00	0.00

Five of the user classes pass the R^2 test, and the three that did not pass, had a R^2 value of 0.86 - 0.93. Five of the Slopes pass the TAG criteria with the values between 0.98 – 1.02. Two of the three remaining Slopes, with values of 0.97, narrowly fail to meet the TAG criteria. All Y-Intercept values are 0.00, apart from OGV1 which is 0.03 and so are in accordance with the “Near 0” TAG criteria.

Trip End analysis was undertaken for each user class and summarised in Table 5.43.

Table 5.43 PM Trip End Matrix Change R^2 Analysis

User Class	Trip End R^2 Value	Trip End Slope	Trip End Y-Int
TAG Criteria	> 0.98	0.99 - 1.01	Near 0
Taxi	0.99	1.00	0.01
Car Employers Business	0.98	0.98	0.19
Car Commute	0.98	0.96	1.37
Car Education	0.98	0.89	0.12
Car Other	1.00	0.98	1.47
LGV	0.97	1.00	0.06
OGV1	0.93	0.83	0.54
OGV2 Permit Holder			
Other OGV2	1.00	1.00	0.00

Six of the user classes pass the R^2 criteria for trip ends with the other two narrowly failing. Three user classes pass the TAG criteria for trip end slope, with the three of the remaining five narrowly failing. Values for the y-intercept near zero are between 0.00 and 1.47.

Table 5.44 details the total traffic crossing the screenlines.

Table 5.44 WRM RM PM Screenline Check

User Class	Observed (Veh)	Model (Veh)	Difference (%)
TAG Criteria			Within 5%
West Screenline (Inbound)	978	970	-1%
West Screenline (Outbound)	1614	1600	-1%
River Corrib Screenline (Eastbound)	2967	2957	0%
River Corrib Screenline (Westbound)	3331	3300	-1%
East Screenline (Outbound)	4983	4726	-5%
East Screenline (Inbound)	2399	2469	3%

Traffic levels across the West, River Corrib and East Screenlines are all within the acceptability criteria outlined in TAG unit M3-1.

Trip length distribution was also assessed as part of the matrix calibration process. All of the user classes pass the criteria of a change in the mean trip length of less than 5 per cent, and in the criteria of a change in the standard deviation of the trip length of less than 5 per cent.

Table 5.45 Trip Length Distribution Analysis – PM

User Class	Mean Percentage Change	Standard Deviation Change
(TAG Criteria)	(< 5%)	(< 5%)
Taxi	-2%	-4%
Car Employers Business	-1%	1%
Car Commute	0%	3%
Car Education	-5%	-5%
Car Other	1%	2%
LGV	0%	1%
OGV1	-2%	2%
OGV2 Permit Holder		
Other OGV2	0%	0%

Graphical representation of the trip length distribution changes at a user class level are presented in Appendix D.

5.10 Calibration summary

5.10.1 Overview

Table 5.46 details the status of each component of the calibration process for each modelled period.

Table 5.46 Model Calibration Status

Component	AM Status	IP1 Status	IP2 Status	PM Status
Individual Link Flows	Pass	Pass	Pass	Pass
Individual Link GEH <5 (TAG)	Fail	Pass	Pass	Fail
Individual Link GEH <5 (65%)	Pass	Pass	Pass	Pass
Individual Link GEH <7 (75%)	Pass	Pass	Pass	Pass
Individual Link GEH <10 (95%)	Pass	Pass	Pass	Fail
Screenlines	Pass	Fail	Pass	Fail
Matrix Cell R^2 Analysis	Fail	Fail	Fail	Fail
Trip End Analysis	Fail	Pass	Fail	Fail
Matrix Trip Length Distribution	Pass	Fail	Pass	Pass

5.10.2 Traffic count observations

Prior to matrix estimation, the modelled volume of LGVs is slightly higher than the observed volume and the volume of HGVs is slightly lower than the observed volume. Constraints applied to matrix estimation for these user classes were relaxed to allow greater changes to the prior matrix; further improvements to the prior goods matrices could allow stricter constraints to be used in future versions.

In three of the four time periods, the highest GEH is located on the same minor road connecting Castlegar Village to the N17 in the northeast of Galway City. As noted above, it is often difficult to calibrate links with low levels of observed traffic given the strategic nature of the WRM. However, in this instance, the nearest zone is also quite far north from the minor road. It is therefore likely that the traffic to and from this zone is using other more major links in the vicinity and avoiding the minor link, causing the minor link to register a limited flow.

Links displaying a modelled flow of zero where a flow of greater than zero was observed were investigated. The screenline and individual target counts in the AM and IP2 peak periods demonstrated no links with a modelled flow of zero where an observed flow was greater than zero. Isolated incidents on links were observed during the IP1 and PM peak periods where the modelled flow was zero and the observed flow was greater than zero. All instances were investigated with the main cause relating to low observed flows on the link.

5.10.3 Matrix observations

As would be expected, the two fully observed user classes validated against POWSCAR, Car Commute and Car Education, have relatively small changes between the prior matrices and the estimated matrices compared to the other non-fully observed user classes.

Larger changes in the goods vehicle matrices were anticipated due to the lack of observed input data. The goods vehicle matrices were matrix-estimated with lesser constraints to bring them in line with observed traffic volumes.

6 Road Model Validation

6.1 Introduction

This chapter sets out the specification and execution of the model validation process. This includes the source of calibration criteria, application of these criteria, comparison of the model outputs with these criteria and commentary on this.

6.2 Assignment validation process

6.2.1 Overview

Model validation is the process of comparing the assigned traffic volumes against data that was kept independent of the calibration process, comparing modelled versus observed journey times and comparing trip length distribution of pre- and incremental matrices. Validation serves as an essential quality check on the calibrated road model. It is recommended that modelled flows and counts should be compared by vehicle type and time period if possible.

6.2.2 Validation Criteria

Model validation is the process of comparing the assigned traffic volumes against data that was independent of the calibration process, comparing modelled versus observed journey times and comparing trip length distribution of pre- and incremental matrices. It is recommended that modelled flows and counts should be compared by vehicle type and time period if possible.

Table 6.1 outlines the screenline validation criteria as set out in TAG Unit M3-1, Section 3.2, Table 1.

Table 6.1 Road Assignment Model Screenline Validation Criteria

Criteria	Acceptability Guideline
Differences between modelled flows and counts should be less than 5% of the counts	All or nearly all screenlines

Table 6.2 outlines the journey time validation criteria as set out in TAG Unit M3-1, Section 3.2, Table 3.

Table 6.2 Road Assignment Model Journey Time Validation Criteria

Criteria	Acceptability Guideline
Modelled times along routes should be within 15% of surveyed times (or 1 minute, if higher than 15%)	> 85% of routes

6.2.3 Traffic volume comparison

The following data sources are available for the traffic volume comparisons:

- Permanent ATCs operated by the TII; and
- Individual link and junction turning counts.

Individual link validation was undertaken against the same acceptability criteria as set out previously.

6.2.4 Trip length distribution

An observed trip length distribution was used during the creation of the prior matrices. Once assigned, the trip length distribution of the SATURN assignment was compared against the observed distribution.

The trip length distributions of the prior and incremental assignments were compared to ensure that they were not significantly distorted by matrix estimation and still compared well against the observed trip length distribution profile. This included analysis of the change in mean trip length and the change in the standard deviation of the trip length. Changes in mean trip length and the standard deviation were compared to the guidance outlined in TAG.

6.2.5 Journey times

Observed journey time data is available for a number of major roads within the WRM through the TomTom dataset.

AM Peak travel times were taken as being the average observed link times between 08.00 and 09.00. Inter-peak 1 travel times were taken as being the average observed link times between 10.00 and 13.00, with Inter-peak 2 travel times being the average observed link times between 13.00 and 16.00. PM Peak travel times were taken as being the average observed link times between 17.00 and 18.00

TAG Unit M3-1, Section 3.2.10 states that modelled journey times should be within 15 per cent of the observed end to end journey time, or within one minute if higher.

6.3 Traffic volume validation

6.3.1 Overview

Permanent ATC's operated by the NRA and Individual link and junction turning counts were utilised as an independent dataset to validate the model. From this data it is possible to validate the SATURN model against an all-vehicle total across 39 links.

6.3.2 Traffic count locations

A detailed map showing the location of the three screenlines used during validation is presented in Figure 6.1.

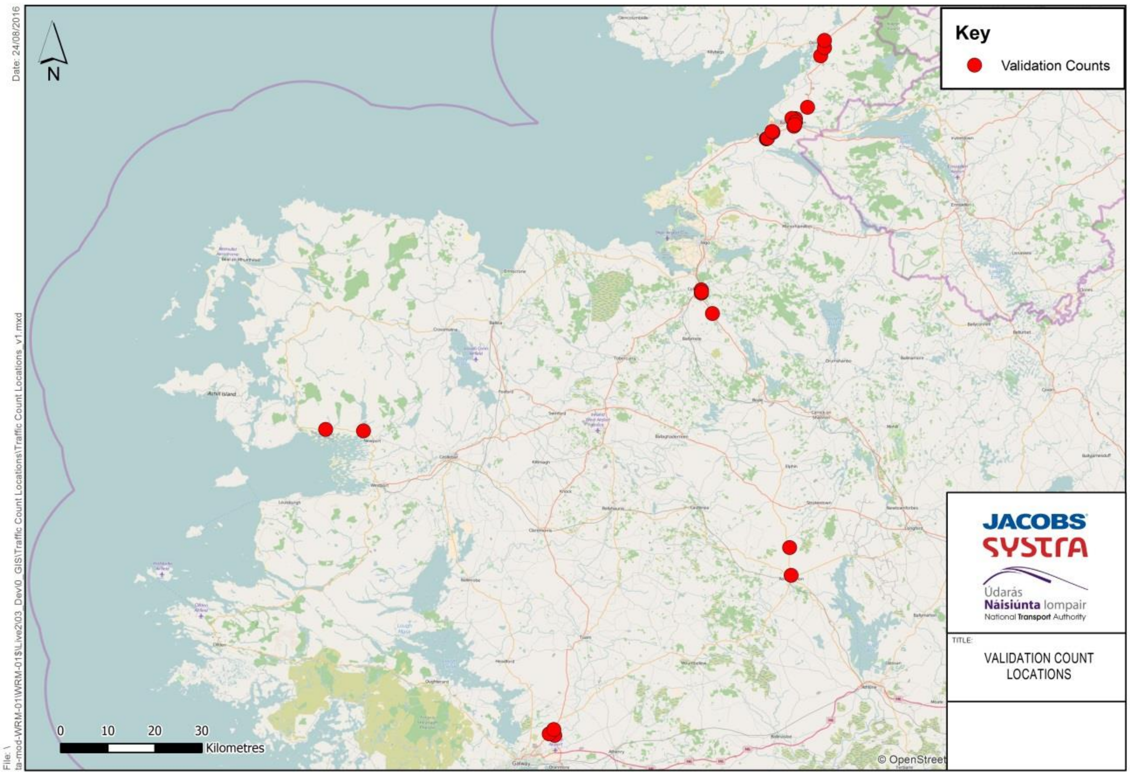

Figure 6.1 Link Validation Target Locations

6.3.3 Validation criteria compliance – AM peak

The validation statistics of the AM Peak model when compared against the individual link count validation criteria are outlined in Table 6.3.

Table 6.3 AM Link Flow Validation

Criteria	Acceptability Guideline	Model Statistics
Link Flow	> 85% of cases	77% (30)

GEH < 5 for individual flows	> 65% of cases	59% (23)
GEH < 7 for individual flows	> 75% of cases	74% (29)
GEH < 10 for individual flows	> 95% of cases	87% (34)

Across the 39 count locations in the AM Peak, 77 per cent (30) pass the TAG flow validation criteria. 59 per cent of links have a GEH of less than 5. However, slackening the criteria to include GEH values of less than 10 yields an 87 per cent pass rate. The area of poorest validation is in Bundoran at the R280 / N15 interchange. The observed two way flows on this link are quite low at 15 and 39 vehicles while the modelled two way flows are 160 and 224 vehicles. Due to the strategic nature of the WRM it is very difficult to validate links with low observed traffic flow.

Detailed validation results, highlighting specific links that pass or fail the recommended validation criteria are included in Appendix E.

In general, modelled traffic volumes are lower than observed traffic volumes. There were specific traffic volume differences that warranted further investigation, and these are discussed in more detail in Section 6.6.

6.3.4 Validation criteria compliance – Inter-peak 1

The validation statistics of the Inter-peak 1 model when compared against the individual link count validation criteria are outlined in Table 6.4.

Table 6.4 IP1 Link Flow Validation

Criteria	Acceptability Guideline	Model Statistics
Link Flow	> 85% of cases	85% (33)
GEH < 5 for individual flows	> 65% of cases	82% (32)
GEH < 7 for individual flows	> 75% of cases	85% (33)
GEH < 10 for individual flows	> 95% of cases	95% (37)

Across the 39 count locations on the Inter-peak 1, 85 per cent (33) pass the TAG flow validation criteria. 82 per cent of links have a GEH of less than 5. However, slackening the criteria to include GEH values of less than 10 yields a 95 per cent pass rate. Again the area of poorest validation is in Bundoran at the R280 / N15 interchange. The observed two way flows on this link are quite low at 8 and 26 vehicles while the modelled two way flows are 127 and 141 vehicles.

Detailed validation results, highlighting specific links that pass or fail the recommended validation criteria are included in Appendix E.

There were specific traffic volume differences that warranted further investigation, and these are discussed in more detail later in Section 6.6.

6.3.5 Validation criteria compliance – Inter-peak 2

The validation statistics of the Inter-peak 2 model when compared against the individual link count validation criteria are outlined in Table 6.5.

Table 6.5 IP2 Link Flow Validation

Criteria	Acceptability Guideline	Model Statistics
Link Flow	> 85% of cases	79% (31)
GEH < 5 for individual flows	> 65% of cases	74% (29)
GEH < 7 for individual flows	> 75% of cases	85% (33)
GEH < 10 for individual flows	> 95% of cases	90% (35)

Across the 39 count locations in the Inter-peak 1, 79 per cent (31) pass the TAG flow validation criteria. 74 per cent of links have a GEH of less than 5. However, slackening the criteria to include GEH values of less than 10 yields a 90 per cent pass rate. This remains below the TAG recommendation of 85 per cent of links passing validation, and below the typical acceptability criteria of 95 per cent of links with a GEH value of less than 10. Once again, the area of poorest validation is in Bundoran at the R280 / N15 interchange. The observed two way flows on this link are quite low at 10 and 32 vehicles while the modelled two way flows are 135 and 163 vehicles.

Detailed validation results, highlighting specific links that pass or fail the recommended validation criteria are included in Appendix E.

There were specific traffic volume differences that warranted further investigation, and these are discussed in more detail later in Section 6.6.

6.3.6 Validation criteria compliance – PM peak

The validation statistics of the PM Peak model when compared against the individual link count validation criteria are outlined in Table 6.6.

Table 6.6 PM Link Flow Validation

Criteria	Acceptability Guideline	Model Statistics
Link Flow	> 85% of cases	77% (30)
GEH < 5 for individual flows	> 65% of cases	69% (27)
GEH < 7 for individual flows	> 75% of cases	82% (32)
GEH < 10 for individual flows	> 95% of cases	87% (34)

Across the 39 count locations in the PM Peak, 77 per cent (30) pass the TAG flow validation criteria. 69 per cent of links have a GEH of less than 5. However, slackening the criteria to include GEH values of less than 10 yields a 87 per cent pass rate. The area of poorest validation is in Bundoran at the R280 / N15 interchange. The observed two way flows on this link are quite low at 13 and 51 vehicles while the modelled two way flows are 175 and 220 vehicles.

Detailed validation results, highlighting specific links that pass or fail the recommended validation criteria are included in Appendix E.

There were specific traffic volume differences that warranted further investigation, and these are discussed in more detail in Section 6.6.

6.4 Trip length distribution analysis

6.4.1 Overview

The trip length distribution of the prior and incremental matrices was assessed by combining the network distance skims, which contains the travel distance between each origin and destination within the model, with the trip demand matrices from the pre- and post-estimation scenarios.

This comparison can identify areas of weakness in the prior matrices, such as an over-reliance on longer distance trips.

6.4.2 Trip length distribution analysis

Graphical representation of the comparison for each modelled period and each user class is included in Appendix D. Overall, the matrix estimation impact on the trip length distribution does not seem significant from a profile perspective, despite the individual changes failing to meet the matrix calibration criteria.

TAG sets out the matrix changes acceptability criteria as being a change to the mean within 5 per cent, and a change to the standard deviation within 5 per cent. Table 6.7 sets out the mean change between the pre- and incremental matrices for each user class, while Table 6.8 sets out the standard deviation change between the pre-and post-estimation matrices for each user class.

Table 6.7 Percentage Change in Average Trip Length

User Class	AM Peak	IP1	IP2	PM Peak
Taxi (UC1)	-1%	-4%	-5%	-2%
Employers Business (UC2)	0%	-8%	-6%	-1%
Commute (UC3)	2%	-9%	-2%	0%
Education (UC4)	0%	-1%	-3%	-5%
Car Other (UC5)	1%	-8%	-3%	1%
LGV (UC6)	-1%	0%	0%	0%
OGV1 (UC7)	-1%	0%	0%	-2%
OGV2 permit Holder (UC8)	N/A	N/A	N/A	N/A
OGV2 (UC9)	0%	0%	0%	0%

Table 6.8 Percentage Change in Standard Deviation of Trip Length

User Class	AM Peak	IP1	IP2	PM Peak
Taxi (UC1)	-1%	-7%	-8%	-4%
Employers Business (UC2)	2%	-10%	-4%	1%
Commute (UC3)	3%	-7%	-1%	3%
Education (UC4)	2%	0%	-3%	-5%
Car Other (UC5)	2%	-13%	-5%	2%
LGV (UC6)	0%	0%	1%	1%
OGV1 (UC7)	0%	-1%	0%	2%
OGV2 permit Holder (UC8)	N/A	N/A	N/A	N/A
OGV2 (UC9)	0%	0%	0%	0%

6.5 Journey time validation

6.5.1 Overview

The NTA purchased historical journey time data from TomTom. The application of this data is a shift away from the traditional moving observer approach. The benefit of using TomTom data is that there is an abundance of journey time routes available with a larger sample of observations in order to determine the typical journey times on a particular link.

6.5.2 Journey Time Routes

Appropriate journey time routes were identified from TomTom Data and agreed with the NRA during the development of the GIM. The journey time routes cover the main arterial and through routes into Galway city centre and are described in further detail in Section 4.4 previously.

Further TomTom Journey time data and analysis is included in Appendix F.

6.5.3 Validation Criteria Compliance – AM Peak

Of the 25 journey time routes, 60 per cent (15) pass TAG criteria, which falls short of the TAG recommendation of 85 per cent of routes passing the criteria. Figure 6.2 details the validation of each route.

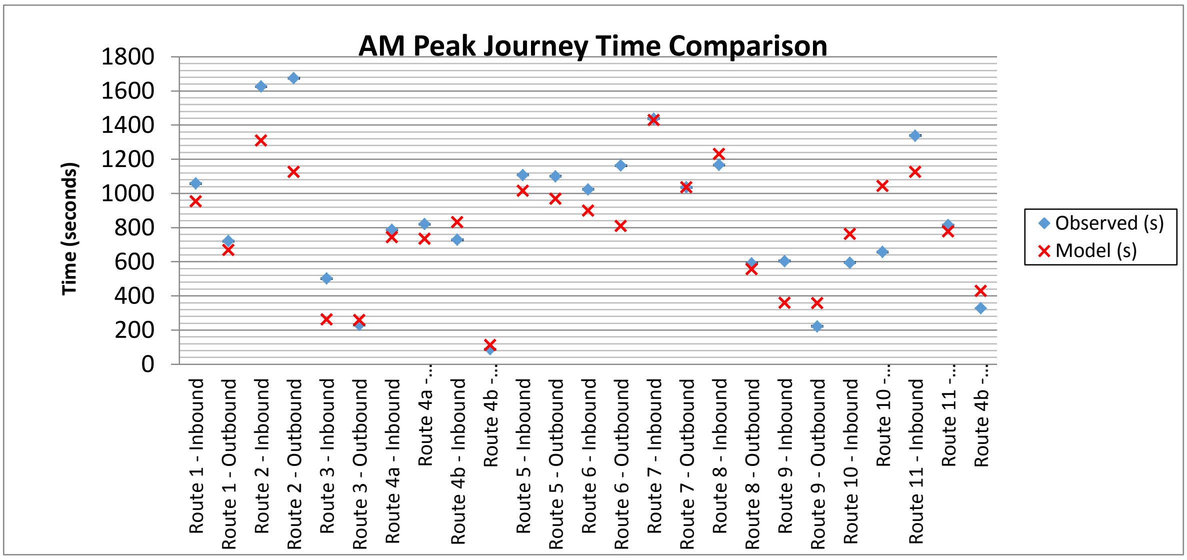

Figure 6.2 AM Peak Journey Time Comparison

In the AM Peak sixteen of the modelled routes are faster than the observed journey times, eight are slower and one is a close match. Further details are included in Appendix F, with detailed analysis of any significant issues discussed in Section 6.6.

6.5.4 Validation Criteria Compliance – Inter-peak 1

Of the 25 journey time routes, 88 per cent (22) pass the TAG criteria, which meet the TAG recommendation of 85 per cent of routes passing the criteria. Figure 6.3 details the validation of each route.

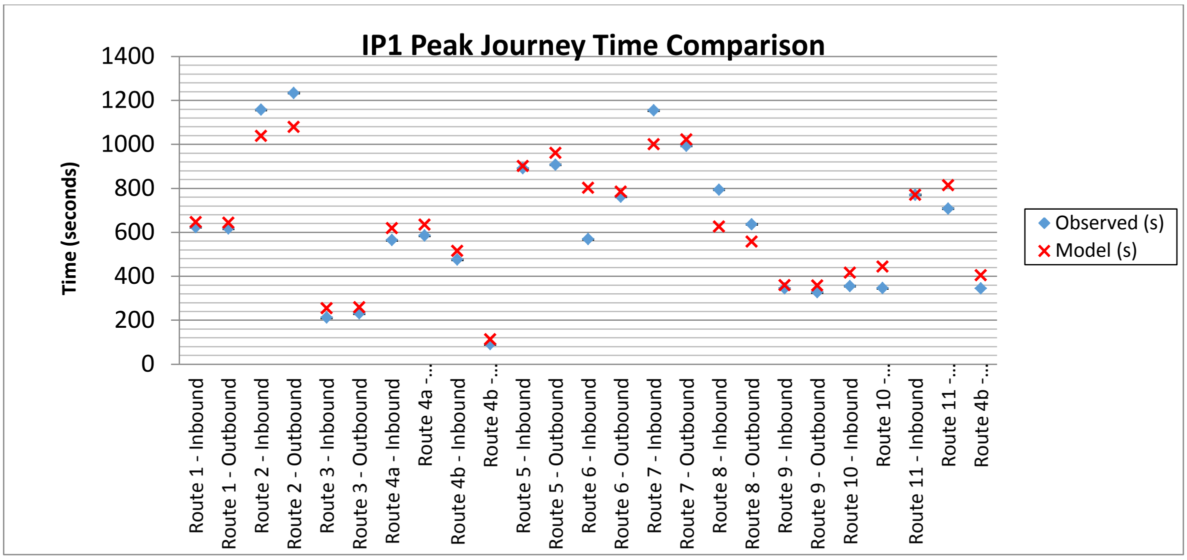

Figure 6.3 Inter-peak 1 Journey Time Comparison

Further details are included in Appendix F, with detailed analysis of any significant issues discussed in Section 6.6.

6.5.5 Validation Criteria Compliance – Inter-peak 2

Of the 25 journey time routes, 88 per cent (22) pass the TAG criteria, which meet the TAG recommendation of 85 per cent of routes passing the criteria. Figure 6.4 details the validation of each route.

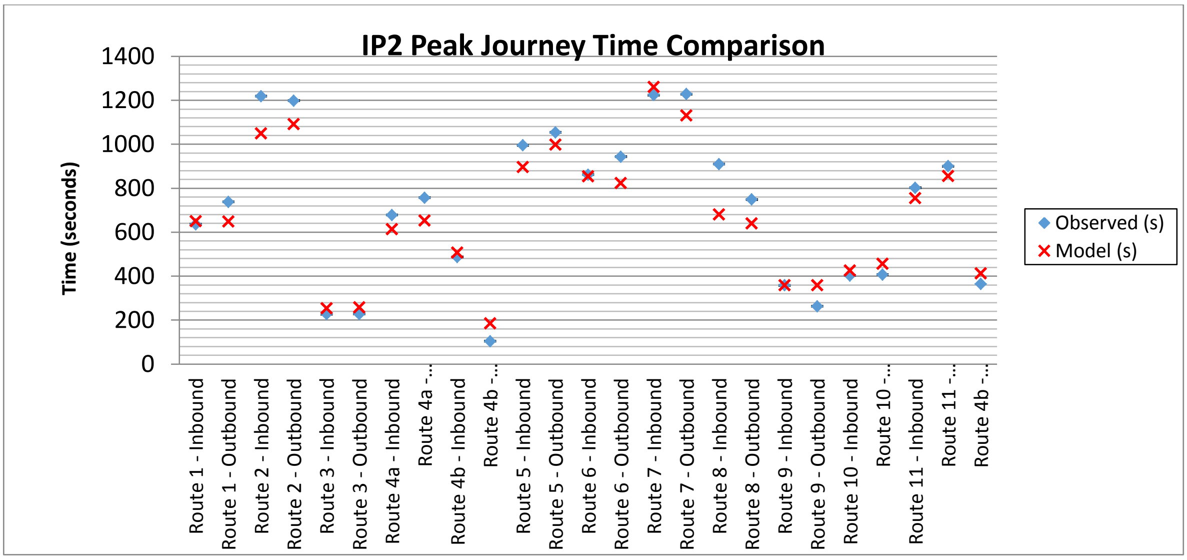

Figure 6.4 Inter-peak 2 Journey Time Comparison

Further details are included in Appendix F, with detailed analysis of any significant issues discussed in Section 6.6.

6.5.6 Validation Criteria Compliance – PM Peak

Of the 25 journey time routes, 60 per cent (15) pass the TAG criteria, which fall short of the TAG recommendation of 85 per cent of routes passing the criteria. Figure 6.5 details the validation of each route.

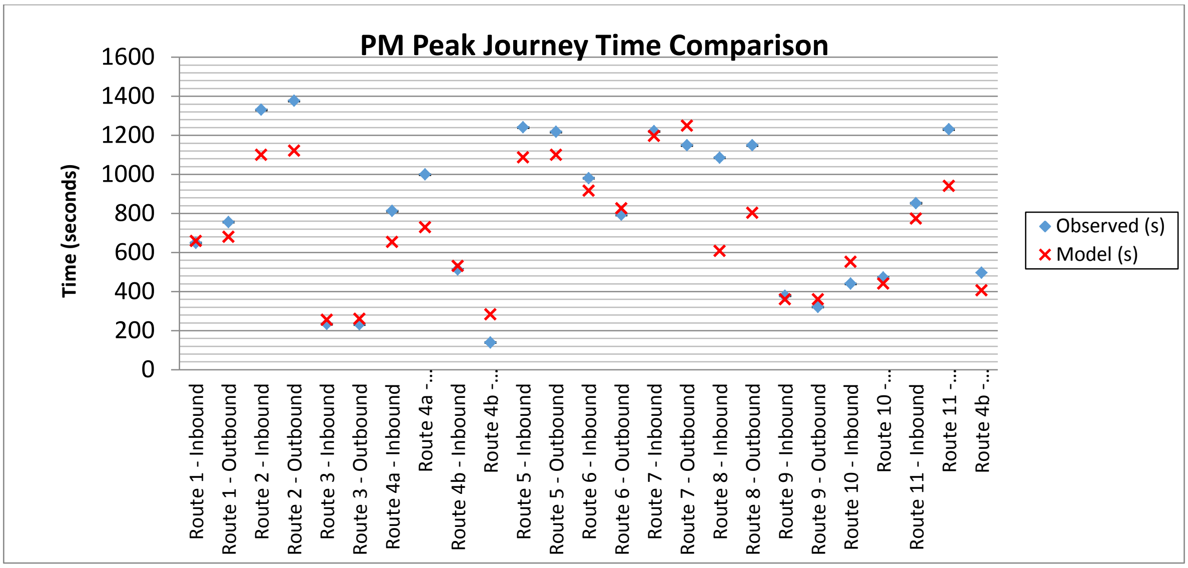

Figure 6.5 PM Peak Journey Time Comparison

In the PM peak sixteen of the modelled routes are faster than the observed journey times and nine are slower. Further details are included in Appendix F, with detailed analysis of any significant issues discussed in Section 6.6.

6.6 Validation summary

6.6.1 Overview

Table 6.9 details the status of each component of the validation process for each modelled period.

Table 6.9 Model Validation Status

Component	AM Status	IP1 Status	IP2 Status	PM Status
Individual Link Flows	Fail (77%)	Pass (85%)	Fail (79%)	Fail (77%)
Journey Times	Fail (60%)	Pass (88%)	Pass (88%)	Fail (60%)
Mean Matrix Change	8/8	5/8	7/8	7/8
Standard Deviation Change	8/8	4/8	7/8	7/8

6.6.2 Traffic count observations

The traffic count locations chosen for inclusion in the validation dataset were selected to provide a consistent coverage of observations into and through Galway City centre. Despite this, as a regional model that covers a significant area outside of the Galway urban area, the representation of final destinations (as noted above) may be an issue in some cases. However, without another comprehensive validation dataset (equivalent to the SCATS data used for ERM) this was considered the most appropriate dataset available at the time of the development of the model.

Two of the validation counts were in the Bundoran area, and produced consistently high GEH levels across the four peak periods. It is possible that insufficient detail has been modelled at this location, given its location within the buffer network, and that this data should be reviewed during future iterations of the model development.

6.6.3 Trip Length Distribution Observations

As with many implementations of a matrix estimation solution, SATURN has generated shorter distance trips in order to meet the specified target traffic flows instead of generating longer distance trips. This has the effect of reducing the mean trip length distribution and the standard deviation of trips within the estimated matrices. This is evident in the Inter-peak 1, Inter-peak 2 and PM Peak periods.

In the AM Peak, the trip length distribution has lengthened, suggesting a lack of traffic further from Galway, where the zones are larger and have a larger travel distance between neighbouring zones.

6.6.4 Journey Time Observations

Comparing the modelled journey times to the observed data in the AM Peak, it is evident that on the majority of routes, modelled end-to-end journey times are too fast compared with observed data. Following further investigation of the routes that fail to meet the criteria, it is evident that it is normally a single location / junction that does not replicate the observed travel delays. For example, journey time route 4b does not replicate the observed delay on the N4 Bothar na dThreabh / R339 Monivea Road junction which encounters very large delays in the observed data. Large delays such as this are very difficult to replicate in a strategic demand model such as the WRM without affecting the traffic flow (GEH) criteria at the same location and therefore it is necessary to make a compromise between traffic flow and journey time validation.

Modelled journey times in the Inter-peak 1 and Inter-peak 2 periods appear to be very accurate, suggesting that uncongested link speeds, which are applied, to all peak periods are correct for a less congested network. The PM peak is more similar to the AM peak in that the journey times validate well in some areas but can be improved at a number of other locations.

It should also be noted that the TomTom journey times for the AM and PM peak have been taken for the time periods 8-9am and 5-6pm respectively, whereas the road assignment matrices output from the FDM and the traffic counts are created by factoring a 3-hour peak period to a 1-hour peak, rather than modelling a specific hour. In the two inter-peak time periods, the TomTom journey times, road assignment matrices and traffic counts are calculated consistently as the average of the 3-hour period.

6.6.5 Validation Observation Summary

Table 6.8 outlines the key validation observations and indicates which modelled peaks the observation relates to.

Table 6.10 Model Validation Identified Issues

Issue	AM Peak	IP1	IP2	PM Peak
Consistently quick journey times	○			○
Low City Centre validation	○			○
Increase in short distance trips	○	○	○	○

7 Conclusion and recommendations

7.1 Summary

The West Regional Model has been developed to assist the NTA with the assessment of current and future network performance, and the appraisal of local and strategic transport infrastructure projects and investments. This report has presented the development of the road model element of the West Regional Model.

7.2 Road Model Development

The model network was in a strong position prior calibration and validation commencing due to previous work undertaken. The network and the assignment parameters, as well as the demand model, have been enhanced considerably during the task. The model makes best use of the available information at the time of model inception through to this version of the model being completed. As part of the calibration and validation process the model network was adjusted to better reflect observed data. However, further improvements could be made for future model versions to improve model calibration and validation.

7.3 Road Model Calibration

The model calibrates reasonably well, although each assigned user class does not meet all of the recommended guidelines set by the UK's TAG. These recommended criteria are summarised in Table 7.1, Table 7.2 and Table 7.3, representing a review of the change in demand and also a comparison of observed and modelled traffic levels.

Table 7.1 outlines the matrix estimation change calibration criteria, as specified in TAG Unit M3-1, Section 8.3, Table 5, and a summary of the results obtained from each peak period model.

Table 7.1 Significance of Matrix Estimation Changes

Measure	Significance Criteria	AM Peak	Inter-peak 1	Inter-peak 2	PM Peak
Matrix zonal cell value	Slope within 0.98 and 1.02;	0.96 to 1.07	0.93 to 1.02	0.98 to 1.02	0.74 to 1
	Intercept near zero;	0 to 0	0 to 0.02	0 to 0.01	0 to 0.03
	R^2 in excess of 0.95.	0.86 to 1	0.93 to 1	0.88 to 1	0.86 to 1
Matrix zonal trip ends	Slope within 0.99 and 1.01;	0.97 to 1.08	0.90 to 1.07	0.96 to 1.05	0.83 to 1
	Intercept near zero;	-0.05 to 1.40	-0.06 to 1.95	-0.02 to 1.58	1.47 to 3.76
	R^2 in excess of 0.98.	0.94 to 1	0.98 to 1	0.97 to 1	0.93 to 1

Trip length distribution	Means within 5%;	-1.45% to 1.65%	-8.50% to 0%	-5.50% to 0.05%	-5.32% to 0.91%
	Standard Deviation within 5%.	-1.43% to 3.41%	-12.96% to 0.21%	-7.53% to 1.24%	-5.38% to 2.99%
Sector to sector level matrices	Differences within 5%	36/169	36/169	25/169	35/169

In the AM peak period the matrix zonal cell changes for the observed user classes (Car Commute and Car Education) are close to the WebTAG recommended criteria, with R^2 values of 0.95 and 0.98 respectively. The slope for both of these user classes falls narrowly outside the WebTAG recommended range of 0.98 to 1.02, with values of 0.972 and 0.977 respectively, and the intercept for each of the observed user classes is within the WebTAG recommended ranges. The slope and intercept for both Taxi and Car Other also falls within the recommended ranges.

In the Inter-peak 1 period R^2 for Car Other is 0.99, which meets the WebTAG recommended criteria. The slope and intercept for Taxi, Car Employers' Business and Car Other met the criteria.

In the Inter-peak 2 period R^2 for Education and Car Other meet the WebTAG recommended criteria.

In the PM peak period R^2 for Taxi, Commute, Education and Car Other meets the WebTAG recommended criteria. The slope and intercept for Taxi and Car Other also meet he WebTAG recommended criteria.

Table 7.2 outlines the link calibration criteria as set out in TAG Unit M3-1, Section 3.2, Table 2, and the level of calibration achieved in each specific period model

Table 7.2 Road Assignment Model Calibration Guidance Source

Criteria	Acceptability Guideline	AM Peak	Inter-peak 1	Inter-peak 2	PM Peak
Individual flows within 100 veh/h of counts for flows less than 700 veh/h	> 85% of cases	87% (236)	93% (254)	92% (249)	88% (240)
within 15% of counts for flows from 700 to 2,700 veh/h					
within 400 veh/h of counts for flows more than 2,700 veh/h					
GEH < 5 for individual	> 85% of cases	80%	86%	86%	81%

flows	(217)	(234)	(234)	(220)

The AM peak period meets the criteria set out in WebTAG for individual flows, but narrowly fails to meet the criteria for GEH, with 80 per cent of links meeting the GEH criteria. Extending the analysis of GEH to assess the number of links with GEH value of 7 or less, and 10 or less, results in 88 per cent and 95 per cent of links, respectively, which is considered sufficiently robust.

The Inter-peak 1 period meets the criteria set out in WebTAG for both individual flows and GEH. Extending the analysis of GEH to assess the number of links with GEH value of 7 or less, and 10 or less, results in 92 per cent and 98 per cent of links meeting the criteria, respectively.

Similar to the Inter-peak 1 results, the Inter-peak 2 period meets the criteria set out in WebTAG for both individual flows and GEH. When the analysis of GEH is extended to assess the number of links with GEH value of 7 or less, and 10 or less, 90 per cent and 95 per cent of links meet each criterion, respectively.

In the PM peak period, 88 per cent of the links meet the individual link flow recommended criteria, however 81 per cent of links meet the GEH recommended criteria, narrowly failing to meet the criteria. Extending the analysis of GEH to assess the number of links with GEH value of 7 or less, and 10 or less, results in 88 per cent and 94 per cent of links, respectively, which is considered to be sufficient.

Table 7.3**Error! Reference source not found.** outlines the screenline calibration criteria as set out in TAG Unit M3-1, Section 3.2, Table 3, and the level of calibration achieved in each specific period model

Table 7.3 Road Assignment Model Screenline Calibration Guidance Sources

Criteria	Acceptability Guideline	AM Peak	Inter-peak 1	Inter-peak 2	PM Peak
Differences between modelled flows and counts should be less than 5% of the counts	All or nearly all screenlines	78%	67%	78%	61%

In the AM peak 78 per cent of screenlines are within 5 per cent of the observed traffic flows, and the remaining screenlines are within 12 per cent of the observed total traffic flows.

The Inter-peak 1 period has 67 per cent of screenlines meeting the WebTAG recommended criteria of total modelled screenline flows within 5 per cent of observed. Four additional screenlines are marginally outside the 5 per cent criteria.

The Inter-peak 2 period has 78 per cent of screenlines meeting the WebTAG recommended criteria of total modelled screenline flows within 5 per cent of observed. Three additional screenlines are marginally outside the 5 per cent criteria.

In the PM peak 61 per cent of screenlines are within 5 per cent of the observed traffic flows, and the remaining screenlines are within 16 per cent of observed traffic flows.

Careful consideration was given to each criterion during the calibration and validation exercise such that the level of matrix change was balanced against the observed traffic volumes and observed journey times. Calibration of the car vehicle type is very strong across all time periods.

The non-observed matrix elements (Taxi, Car Other, LGV and HGV) calibrate to a lesser extent, however this was anticipated owing to the synthetic nature of the input matrices, and the lack of disaggregated observed traffic data, particularly for Taxi.

Trip length distribution analysis and cellular GEH analysis of the matrix estimation changes indicates that the matrix estimation procedure has not excessively altered the observed user class data.

7.4 Road Model Validation

In the AM peak, 60 per cent of the journey time routes meet the WebTAG criteria, and 64 per cent are within 25 per cent of the observed journey times.

In the IP1 period, 88 per cent of the journey times meet the WebTAG criteria of 85 per cent of journey times being within 15 per cent of observed journey times, and 92 per cent are within 25 per cent of the observed journey times.

In the IP2 period, 88 per cent of the journey times meet the WebTAG criteria of 85 per cent of journey times being within 15 per cent of observed journey times, and 92 per cent are within 25 per cent of the observed journey times.

In the PM peak, 60 per cent of the journey time routes meet the WebTAG criteria, and 84 per cent are within 25 per cent of the observed journey times.

7.5 Recommendations

At present the values of time and the vehicle operating costs applied during the road model assignment are user defined within the SATURN data files prior to the final assignments. These are based on the best available model information at the time to inform the parameter calculations. The model information used is the average simulation network speed, which does not vary significantly between model versions of the same scenario. However, there are improvements to this process that could be applied to add further functionality.

A procedure could be written that takes the average network speed and re-calculates the vehicle operating cost between iterations / loops of the demand model. This would provide a more stable solution between model iterations should the network and information be refined or updated in the future. This would also ensure that the vehicle operating costs were updated in future year scenarios; a process which currently relies on user intervention.

Appendix A

Individual Link Calibration Results

Appendix B

Sectored Matrix Differences

Appendix C

R squared analysis graphs

Appendix D

Trip Length distribution Analysis

Appendix E

Individual Link Validation results

Appendix F

TOM TOM Journey Time data and analysis

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