

# Modelling Services Framework

## East Regional Model

### Public Transport Model Development Report

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# 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 Regional Modelling System

The NTA has developed a Regional Modelling System 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 overleaf.

**Table 1.1 Regional Models and their Population Centres**

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

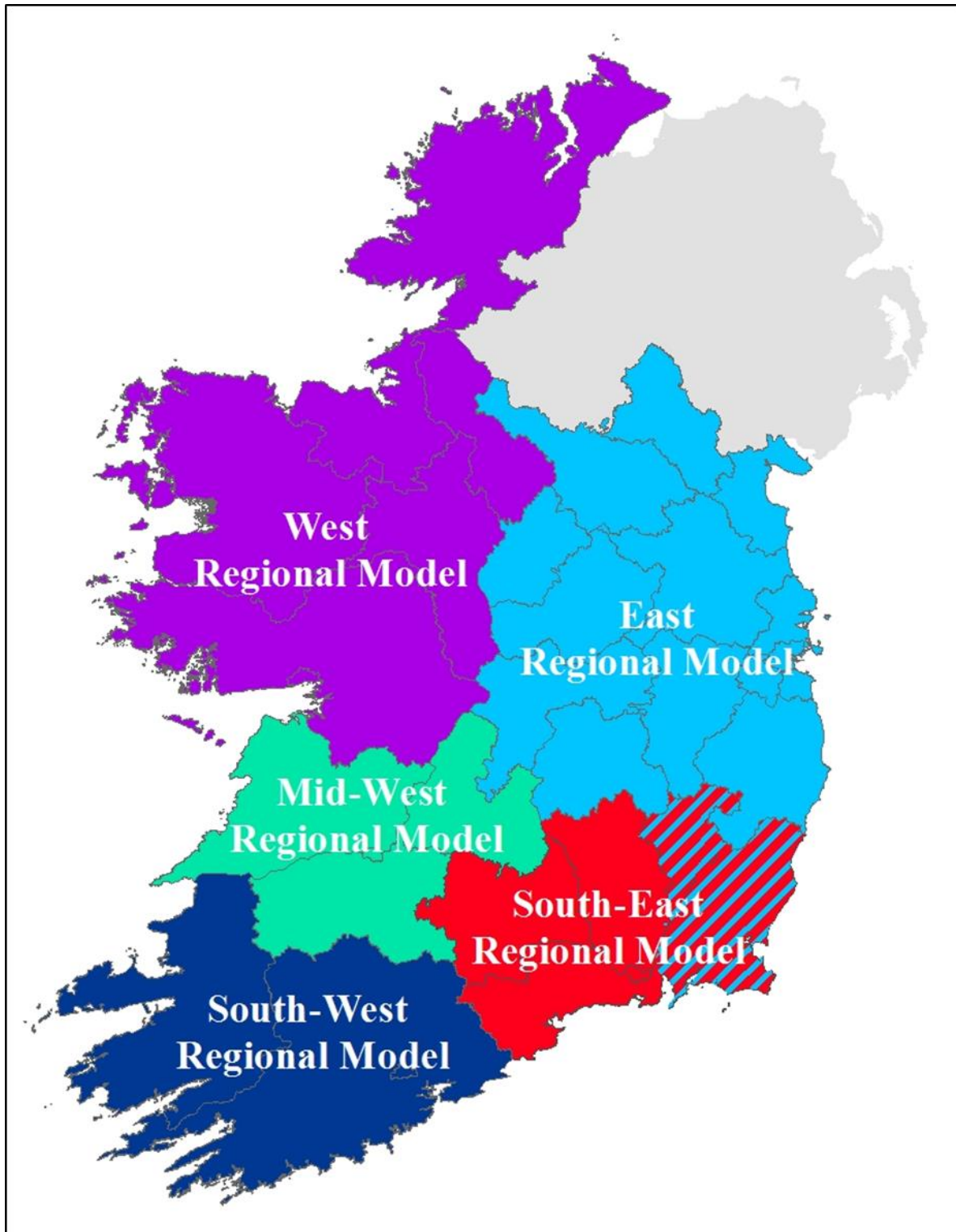


Figure 1.1 Regional Model Areas

## 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.

### 1.2.1 National 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.

### 1.2.2 Regional 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 RM Spec 1 Full Demand Model Specification Report, RM Full Demand Model Development Report and ERM 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 Spec 2 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 Spec 3 Public Transport Model Specification Report for further information (referred to as the PTM Specification Report for the remainder of this document).

## ***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.

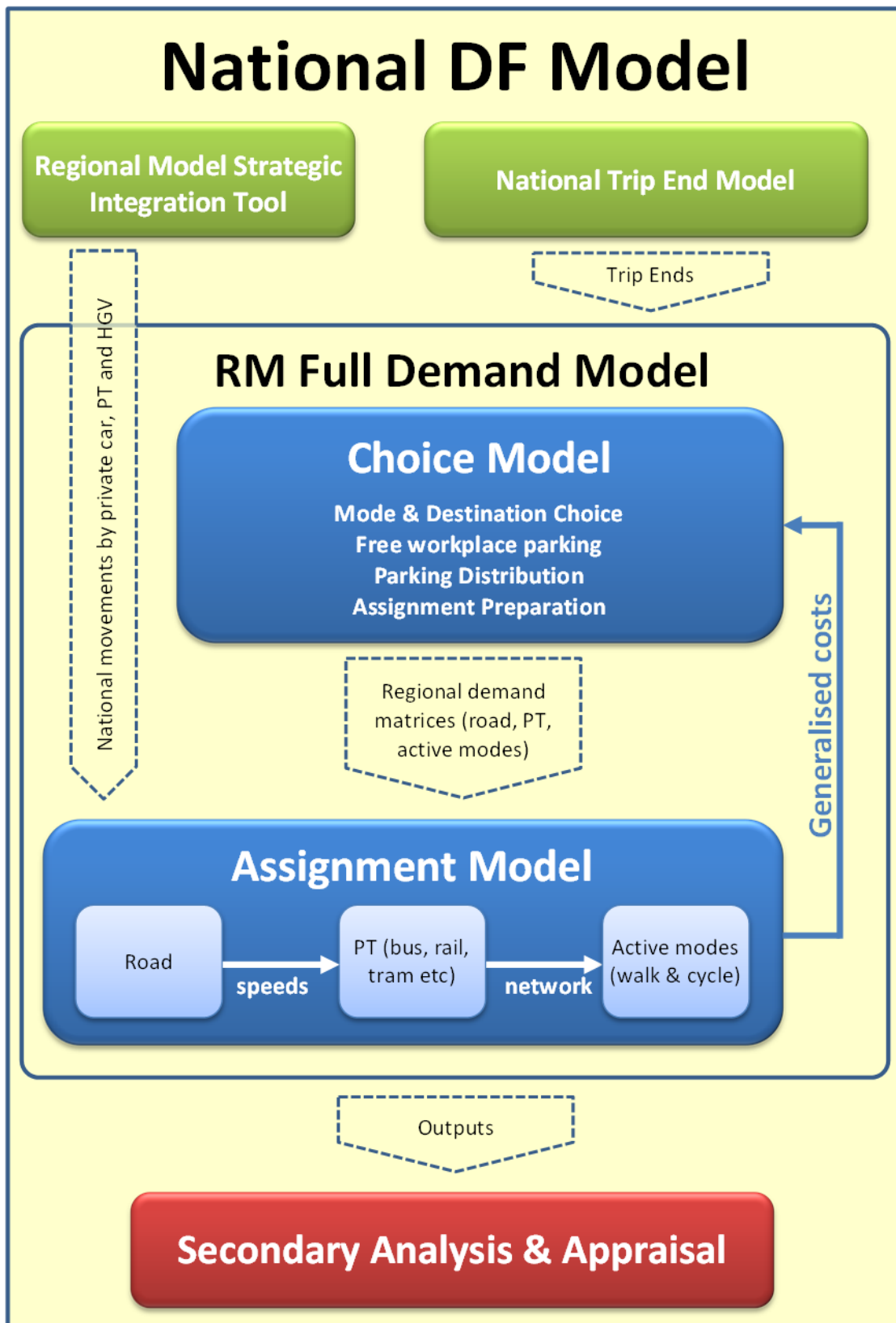


Figure 1.2 RMS Model Structure

## 1.3 ERM Public Transport Model Overview

### 1.3.1 ERM Public Transport Model Development

Public Transport Model development and calibration is a task common to each of the NTA regional transport models. The PTM Specification Report, that provides a basis for consistency across all of the models, was used as a guide for the development of the ERM Public Transport Model.

The development of the ERM has been broken down into a number of high-level tasks, of which the principal ones are shown below:

- Road model development and calibration;
- Public transport model development and calibration; and
- Demand model development and calibration.

The ERM Public Transport development provides the methodology, guidance and techniques to develop the Regional Modelling System through a 'Repeatable Methods' approach. The development of Eastern Regional Model Public Transport Model was based on the specification outlined in PTM Specification Report.

### 1.3.2 PTM Demand Segmentation

The following user classes are defined in the PT assignment model:

- **Employers-Business (EMP):** trips on employers business;
- **Commute (COM):** commuting trips between home and work;
- **Other (OTH):** all other journey purposes including shopping, visiting friends, escort to education etc;
- **Non-Dedicated School (SCH):** primary and secondary school pupil trips on general PT services between home and place of education;
- **Concessionary Travel :** passengers eligible for free travel passes on PT through the Free Travel Scheme; and

Further details are provided in Section 3.8.2 of the PTM Specification Report.

### 1.3.3 Network Development

The ERM PT network comprises a number of input components, as follows:

- Road network links (copied directly from SATURN to Cube Voyager network format);
- Walking links (added to the road network to permit walk only paths and access to rail stations);
- Rail links; and
- Zone connectors (the connection points from zone centroids to the 'physical' network).

### 1.3.4 Linkages with Overall ERM Transport Model

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

- Definition of Zone System
  - Definition of zonal boundaries for ERM.
- System Architecture
  - Consideration of model procedures and their impact on run-times;
  - Coordination with overall Regional Modelling System (RMS);
  - Standardisation with overall RMS (e.g. scripts, procedures, units); and,
  - Derivation and calculation of annualisation factors.

In addition, there are a number of inter-dependencies with other elements of ERM:

- Road Model
  - Interchange of key data, notably network details and bus speeds.
- Demand Model

#### ***Inputs to PT Model***

- PT Assignment Matrices; and
- Generalised Cost parameters and specifically the value of time of public transport users.

#### ***Outputs from PT Model***

- Cost skims for feedback into mode and destination choice (MDC)

### 1.3.5 ERM Zone System

The PT Model zone system is the same as the zoning system specified for the overall ERM as described in the ERM Zone System Development Report. The zone system has 1854 zones and is shown in Figure 1.3 below.

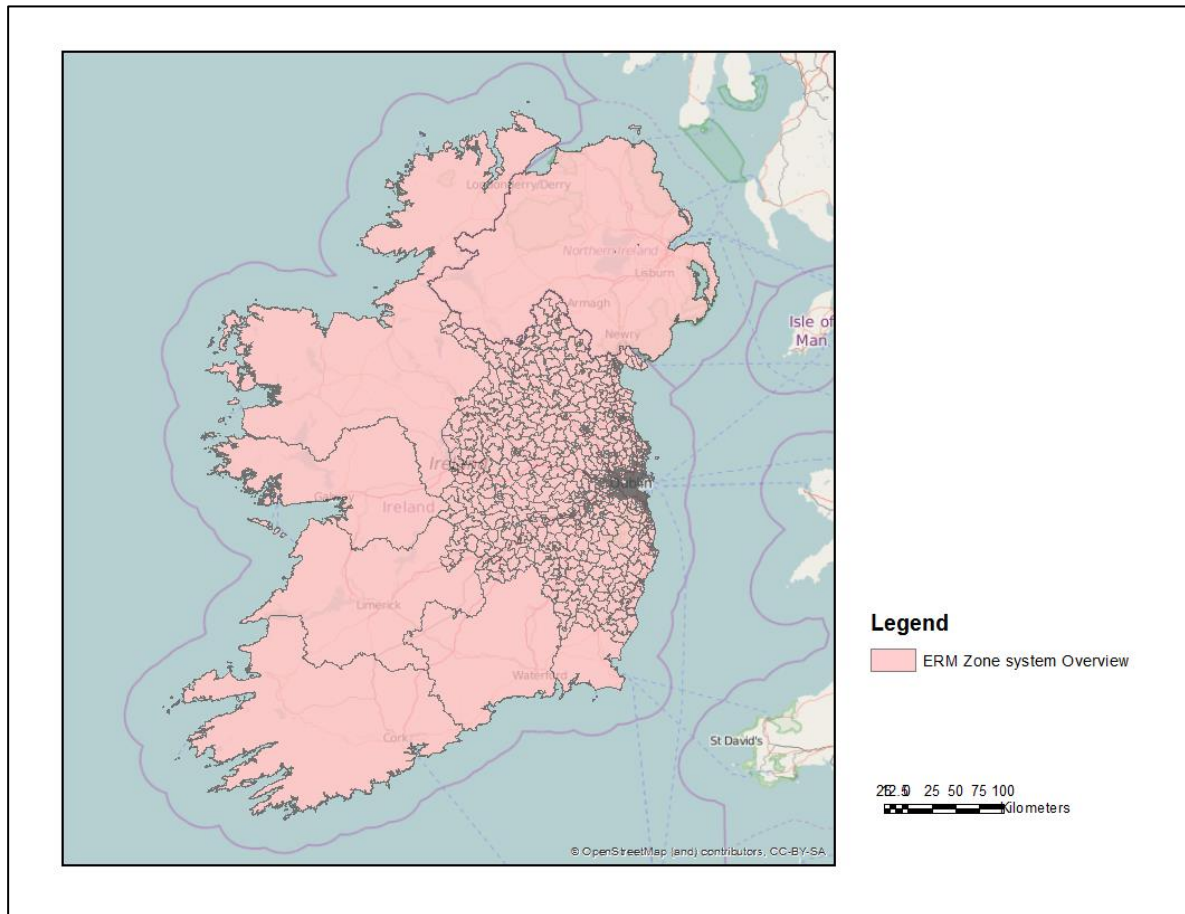


Figure 1.3 ERM Zone System

The key zone system statistics include:

- **Total zones: 1854;**
- Dublin City: 491 zones
- County Dublin (excl. Dublin City): 649 zones
- Kildare, Wicklow, Meath, Louth, Laois, Offaly, Monaghan, Cavan, Longford, Westmeath, Carlow and Wexford counties: 704 zones
- External (7) and special (3) zones: 10.

The high level of zonal detail allows access to Public Transport services to be modelled to a greater degree of accuracy. Increased zonal density in urban areas such as Dublin 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 Base Year

The base year of the model is 2012 with a nominal month of April. This is largely driven by the date of the Census (POWSCAR) and other travel surveys (e.g. the National Household Travel Survey). It should be noted that the POWSCAR dates to 2011 but the travel patterns are assumed to be broadly the same in 2012.

### 1.3.7 Time Periods

The five weekday periods modelled in the ERM are detailed in Table 1.2. The time periods allow the relative differential in travel cost to be represented. The PT assignment model requires a single hour to be assigned as representative of each period. Peak hour matrices were obtained from the period matrices by applying peak hour factors which were calculated from the NHTS based on the mid-point of the journey time, but without regard to journey purpose.

Table 1.2 ERM Time Periods

PERIOD	DEMAND MODEL FULL PERIOD	ASSIGNMENT PERIOD	PERIOD TO PEAK HOUR FACTORS
<b>AM Peak</b>	07:00-10:00	Peak hour (factored from period)	0.47
<b>Morning Interpeak “Lunch Time” (LT)</b>	10:00-13:00	Average hour from full period	Average (1/3)
<b>Afternoon Interpeak “School Run” (SR)</b>	13:00-16:00	Average hour from full period	Average (1/3)
<b>PM Peak</b>	16:00-19:00	Peak hour (factored from period)	0.40
<b>Off Peak</b>	19:00-07:00	not assigned	Average (1/12)

### 1.3.8 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 and calibration of the Public Transport Model (PTM) within the Eastern Regional Model (ERM) and includes the following chapters:

- **Chapter 2 ERM PT Model Development:** provides information on the specification of the PTM and an overview of its development.
- **Chapter 3 ERM Cube Voyager Implementation:** describes the implementation of the PTM within Cube Voyager.
- **Chapter 4 PT Model Calibration:** details information on the PTM calibration, including tests and checks carried out on model route enumeration and assignment.

- **Chapter 5 PT Model Validation:** sets out the specification and execution of the model validation process.
- **Chapter 6 Conclusion and Recommendations:** summarises the calibration and validation of the ERM PTM, and identifies recommendations for subsequent versions of the model.

## 2 ERM PT Model Development

### 2.1 Overview

The Public Transport Model component of the ERM comprises the following networks:

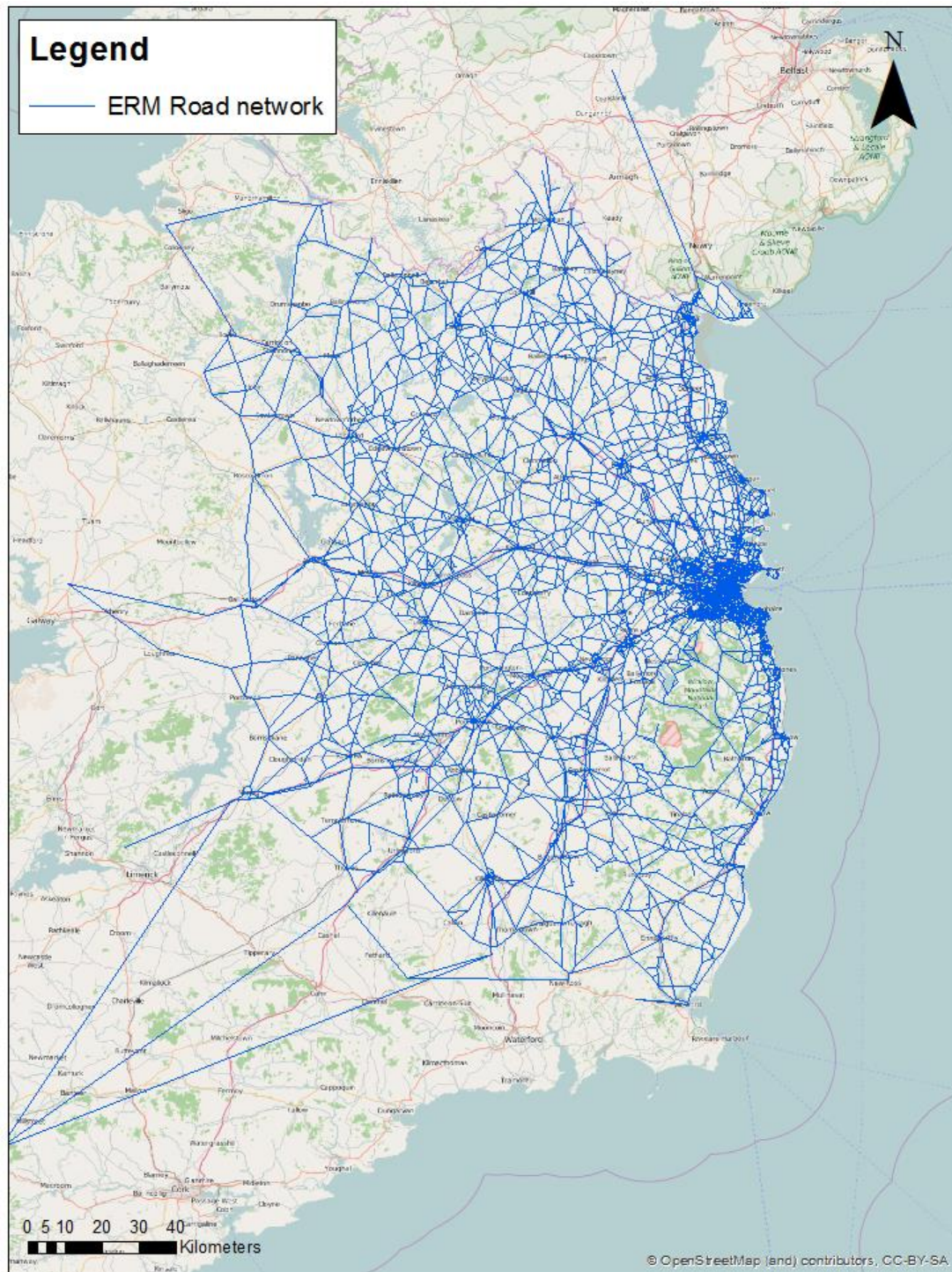
- Road Network;
- Rail Network; and
- Walk Network.

These are described below, addition to other key elements required for the development of the ERM PTM including fares models, crowd curves and wait curves.

#### 2.1.1 ERM Road Network

Within the overall ERM, the primary network is stored as a SATURN road model network. This is then converted into Cube Voyager format for each time period whenever the full model is run. The conversion process translates node coordinates, links distances, capacity indexes, bus lanes and congested speeds into Cube Voyager format for use in the PT Model. The ERM CUBE Voyager PT Road Network is shown in Figure 2.1.

Bus speeds in the PT Model are calculated as part of this process depending on whether there is a bus lane coded on the link or not. Where a bus lane exists on a link, the bus speed is taken as the car speed on an uncongested assignment, to take account of signalised junction delays. Where no bus lane exists on the link, the bus speed is calculated as the assigned network congested speed. A link category based factor was calibrated to match journey time data during the calibration process. The final values are provided in Table 4.8 later in this report.



**Figure 2.1 ERM CUBE Voyager PT Road Network**

### 2.1.2 ERM Rail Network

Rail networks were built in ArcGIS, using General Transit Feed Specification (GTFS) shapefiles. This data is prepared by the NTA Journey Planner team, is publicly available, and provides a comprehensive representation of all PT services in the ERM area covering all sub-modes. The key input files for the PTM include nodes and links files. Any modifications to the rail networks are made to these input files. Section 3 details all the inputs to the Cube Voyager implementation of the PTM. The ERM CUBE Voyager Rail Network is shown in Figure 2.2. In

accordance with the ERM repeatable methods guidance, the network extends to one stop beyond the limit of the model area. All services were coded to stop at this first stop outside of the modelled area to ensure that flows entering the model area are loaded onto the correct services. For example, all services from Dublin to Cork were coded to stop at Templemore, and a centroid connector from Cork to Templemore included, so that rail trips from Cork to Dublin enter the model area on this rail corridor.



Figure 2.2: ERM Rail network

### 2.1.3 ERM Walk Network

Additional links are sometimes necessary to accurately represent walk access to PT stops. Therefore, walk links were added to the network to represent pedestrian only streets and roads that were not coded in the road network. The parts of the network where additional walk details were required were identified by using a very detailed network GIS shape file (i.e., the 'Introute' geographical network data from the NTA journey planner network, detailed in the PTM Specification Report, Section 3.2)..

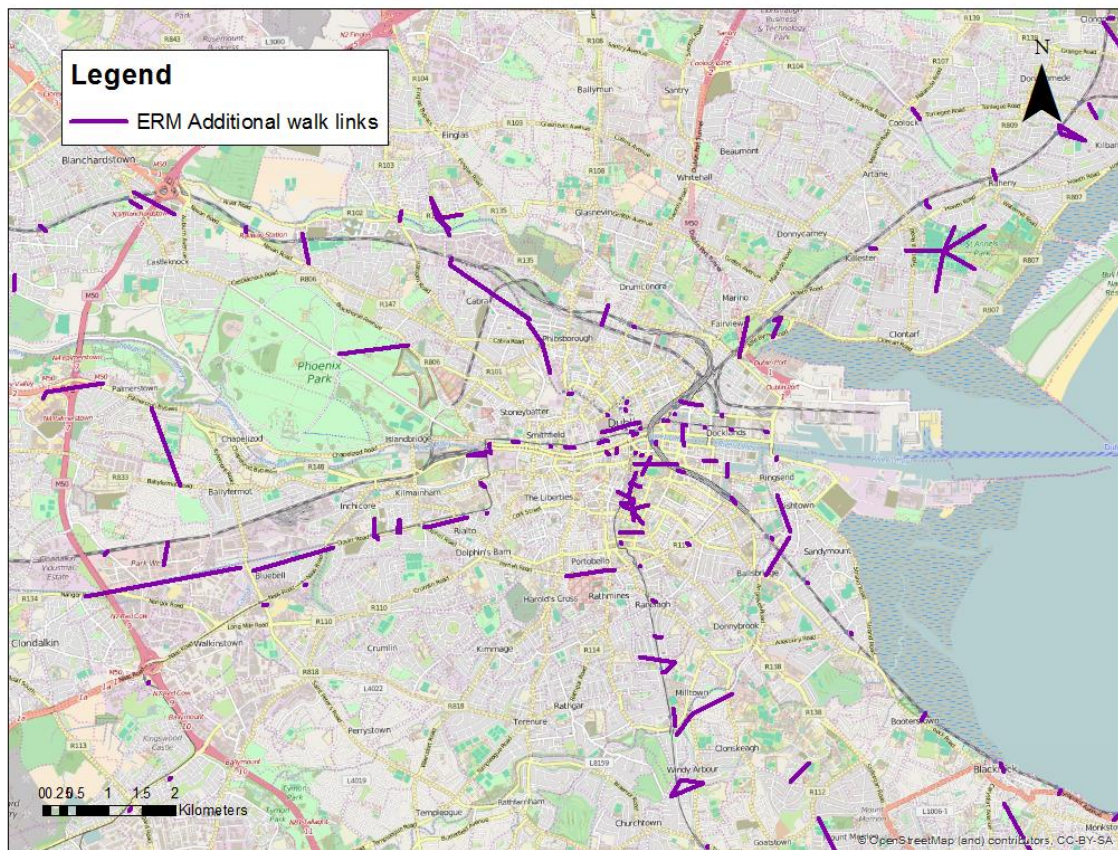


Figure 2.3: ERM additional walk links

The coded road network and Introute shape files were superposed to manually define additional walk links where a lack of connectivity was identified. Examples include all pedestrian bridges, main pedestrian streets (e.g. Henry St., Grafton St.) and pathways crossing parks (e.g. St Stephen's Green, Phoenix Park). The additional walk links included in the PTM are illustrated in Figure 2.3.

### 2.1.4 Node Convention

The node convention used within the PT Model is hierarchical, i.e., each node is numbered based on the geographical area in which it is located. Details on the methodology for node numbering used can be found in *SA TN07 Regional Model Hierarchical Numbering System*. In line with convention in Cube Voyager, the start

of the node numbering system is reserved for zone numbers (i.e. zone numbers are numbered sequentially, starting from 1). Following this, Road, Rail, Luas and Walk nodes have pre-defined ranges of node numbers, and headroom was left to add extra network in coding any future year transport schemes. The numbering of Road Network nodes provides a consistency between the Public Transport and Road Models.

The following node convention has been adopted for the ERM PT network:

- 1 to 1,999: Zones;
- 2,000 to 39,999: Road network nodes inside the GDA;
- 99,000 to 99,499: Rail network nodes;
- 99,500 to 99,599: Luas Green line nodes (including CrossCity);
- 99,600 to 99,699: Luas Red line nodes;
- 99,900 to 99,999: Walk/Cycle network nodes;
- 99,700 – 99,900: Spare / Scheme coding; and
- >99,999: Road network nodes outside the GDA.

### 2.1.5 Initial Zone Centroid Convention

As detailed in the PTM Specification Report (section 3.9.1), initially zone centroid positions and connector locations were inherited from the road model. This was later revised during calibration to provide an improved representation of PT travel costs, as detailed in Section 4.3.3 below.

### 2.1.6 Non-Transit Legs

Access to the PT network is provided by non-transit legs. Non-transit legs are minimum-cost segments, traversed by non-mechanized modes. They are generated by the Cube Voyager program to represent any leg of a route not undertaken on a PT service.

There are four types of zone centroid non-transit leg. In each case the initial values have been taken from an early calibration of the ERM; these were subsequently revised as part of the PT Model network and parameter calibration described in Section 4.4.2.

#### 1) Zone centroid to PT stop access by walk.

Walking is the most frequently used mode of access and egress to PT services. It is limited to 30 minutes with a maximum of 5 legs by zone centroid/by mode (10 for modes 4 and 5, corresponding to buses).

#### 2) Zone centroid to PT stop access by driving.

This allows for access to a PT stop in areas where walk access would be too long or impractical – this applies especially in rural areas where zones are larger and PT supply is sparse. The access by drive links correspond to a “kiss and ride” for PT users – i.e. PT users being dropped off by car at PT stops. A 30 minutes penalty is applied to these legs to ensure that the walk access leg is preferred for all short distance access

**3) Zone-to-zone access legs.**

The PT Model requires all PT trips to board at least one PT service. However, for zones located near to each other where there is limited network detail this can result in inconsistent routes and high generalised costs. This causes a problem for the demand model. Zone-to-zone direct access is therefore included as a non-transit leg. This allows walk trips between two zones if the cost is less than the cost of using PT between these zones. This ensures generalised costs increase consistently with distance. Initially this value was limited to a 10 minute walk, with the cost of this multiplied by a weight of 2 based on an initial review of short distance trips within the model. Zone-to-zone direct access was investigated further during model calibration as detailed in Section 4.4.2 later in this report.

**4) Stop-to-stop transfer legs.**

In addition to the three zone centroid non transit legs, there is a fourth type of non-transit leg: stop-to-stop transfer legs. These correspond to transfer walking legs between two transit legs. Initially, they were limited to a 20 minute walk.

## 2.2 Public Transport Services Preparation

### 2.2.1 Overview

This section details the input data used and conventions adopted in the coding of PT Services in Cube Voyager software. As per Section 3.9.2 of the PTM Specification Report, service patterns were defined based on GTFS data.

### 2.2.2 System Data

Cube Voyager requires additional 'system data' information for each service, such as mode, operator, and details of the fare system. The ERM PTM includes the following modes of transport:

- 1 – DART
- 2 – Other Rail
- 3 – Light Rail
- 4 – Dublin Bus
- 5 – Other Bus
- 6 – BRT (not used in the base year)
- 7 – Metro (not used in the base year)

It also includes the following operators:

- 1 – DART
- 3 – Luas
- 4 – Dublin Bus
- 5 – Bus Eireann
- 6 to 62 – Private Operators

- 100 to 102 – Irish Rail (1 operator defined by corridor)
- 104 – Dublin Bus, Airport services
- 105 – Bus Eireann, Airport services
- 106 to 149 – Private Operators, Airport services
- 150 – BRT operator (not used in the base year)
- 151 – Metro operator (not used in the base year)

All Irish Rail services were initially defined with a single operator (number 2). However, in order to more accurately represent model fares, it was necessary to split the services by main corridor of travel i.e. Sligo line, Dundalk-Rosslare and Southwest. Different operator categories have to be defined for airport services to allow for different airport fare systems.

### 2.2.3 Conversion from GTFS to Cube Voyager PT Service Code

The GTFS process outlined in Section 3.9.2 of the PTM Specification Report was used to convert GTFS data to Cube Voyager PT service coding – i.e. conversion to PT lines files. Although it is an automatic process, manual adjustments were required to modify some routes, e.g. to match road network structure or to fill gaps in the GTFS route definition.

The earliest ‘complete’ set of GTFS data that was available for this conversion was from February 2014. There was insufficient information available to identify which services in the 2014 dataset should be considered as invalid for inclusion in a 2012 base model. In the absence of this information, it was decided to use all of the February 2014 data, and to supplement it where necessary if some routes which weren’t included in GTFS were identified. These routes included:

- Ardcavan Coach Tours: Wellington Bridge to Dublin Airport;
- Finlays Coach Hire: Dundalk to NUI Maynooth;
- Finlays Coach Hire: Drogheda to NUI Maynooth;
- Finlays Coach Hire: NUI Maynooth to Dundalk;
- Finlays Coach Hire: Ardee to DKIT;
- Finlays Coach Hire: DKIT to Ardee;
- Streamline Coaches: Cavan to NUI Maynooth;
- Streamline Coaches: NUI Maynooth to Cavan;
- Slevins Coaches: Dundrum to NUI Maynooth;
- Slevins Coaches: Templeogue to NUI Maynooth;
- Slevins Coaches: NUI Maynooth to Dundrum;
- OK Transport: Edenderry to NUI Maynooth;
- OK Transport: NUI Maynooth to Edenderry;
- OK Transport: Allenwood to NUI Maynooth;
- OK Transport: NUI Maynooth to Allenwood;
- Silver Dawn Travel: Portarlinton to UCD; and
- Silver Dawn Travel: UCD to Portarlinton.

On completion of the GTFS conversion process, a total of 1,053 lines were coded in the ERM PT Model, split across three lines files, one for bus services, one for rail services and one for services on new modes (empty in the base year).

The distribution of services across different operators is provided below:

- DART: 17 services;
- Rail: 61 services;
- Luas: 15 services;
- Dublin Bus: 342 services;
- Bus Éireann: 332 services; and
- Other buses: 286 services.

Modelled headways are based on the number of services that operate in each time period (i.e. 0700 – 1000, 1000 – 1300 and 1600 – 1900) with the time period definition based on the timetable mid-point within the model network.

The PT Lines Files for the ERM PTM represents the coded public transport services for rail, inter urban bus routes, urban bus, Luas and DART routes as illustrated in Figure 2.4.

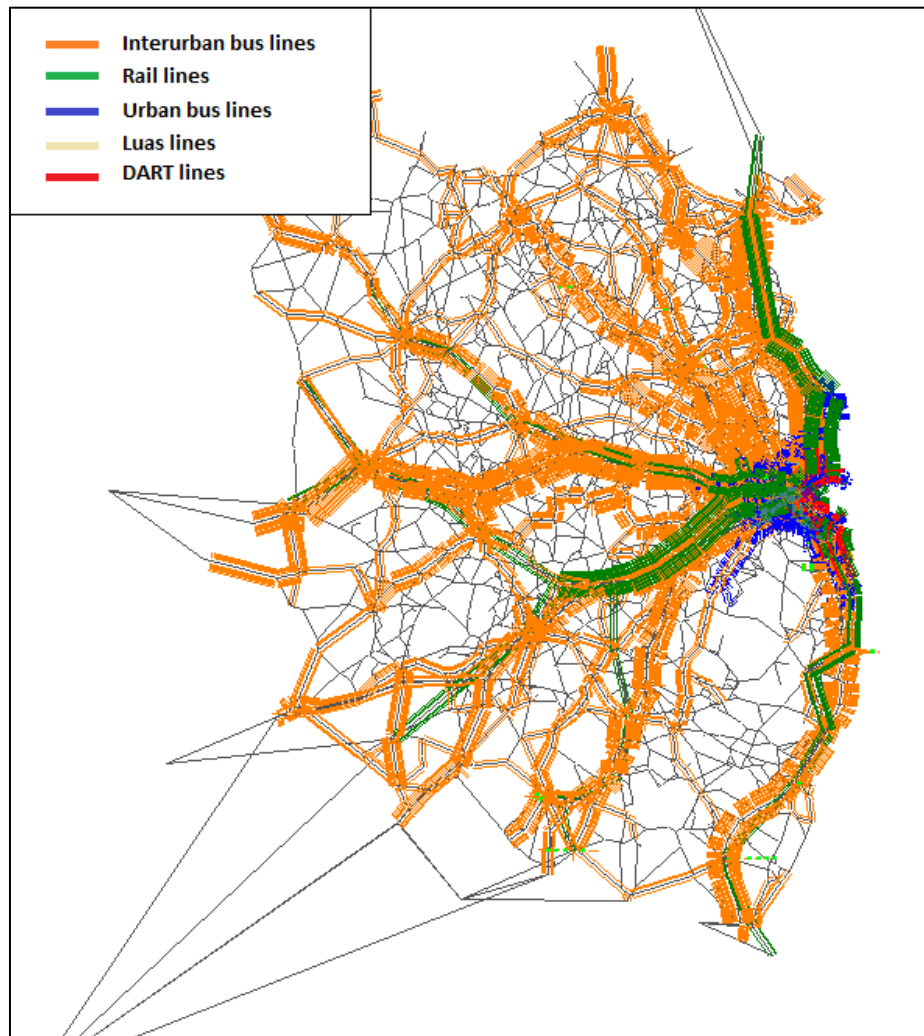


Figure 2.4: ERM PTM PT Lines Files

## 2.3 Fares Model Preparation

The methodology and source data used to define fares by operator in the ERM PT Model are detailed in Section 3.13 of the PTM Specification Report.

The section below provides information on what was coded in the model. The fare system differs by user class: Free-travel users have a zero fare for all PT services, School-travel fares are flat fares defined by mode on Public Service Operators, and Commute-, Employers' Business- and Other-travel fares are defined by mode as detailed in the sections below.

### 2.3.1 Rail Fares

Within ERM there are four main Irish Rail fare structures:

- DART fares
- Rosslare-Dundalk line fares
- Sligo line fares
- SouthWest line fares

Fares for intercity services are based on four categories associated with approximate distance travelled, along with service quality i.e. Express, Economy 1 and Economy 2 services.

In the ERM PTM, Irish Rail fares are modelled using a distance based fare system. This method is more flexible than a fixed fare matrix (between OD stations). It allows the model itself to calculate distances and is more flexible when implementing future schemes (i.e., a new railway station added to the network).

Fares and ticket sales information for 2012 were obtained from the NTA, for the top 100 Irish Rail InterCity OD routes based on demand. The information included single, return, open return, weekly, monthly and annual ticket sales data. This data was then filtered for stations which are included in the ERM area.

An average fare per trip was calculated for each OD route using the ticket sales information provided. The following assumptions on the number of journeys made on season tickets were applied to calculate the average fare per trip to be used in the Voyager fare model within the PTM<sup>1</sup>;

- 1 day ticket = 3 trips;
- 3 day ticket = 6 trips;
- 7 day ticket = 9 trips;
- Monthly ticket = 40 trips; and
- Annual ticket = 500 trips

The distances between stations were calculated using the accurate CUBE Voyager representation of the GTFS rail network. These distances were then used to plot the average fare per trip versus distance travelled for each of the InterCity ODs for which ticket sales data was available.

A 'best fit' analysis was carried out on these scatter plots to identify the appropriate Rail fare models which could accurately represent observed data. The generated model fare structures are based on distance travelled.

The generated model fare structures are based on distance travelled, and the associated fares calculations are outlined in Table 2.1 below. Figure 2.5 - Figure 2.8, overleaf, illustrate the observed average fares from the 2012 ticket sales data, plotted against the fares calculated using the model fare structures.

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<sup>1</sup> Average trips per ticket type taken from consultant team's experience from other projects in Ireland & the UK. Rates were discussed with members of the NTA ticketing team and were deemed plausible.



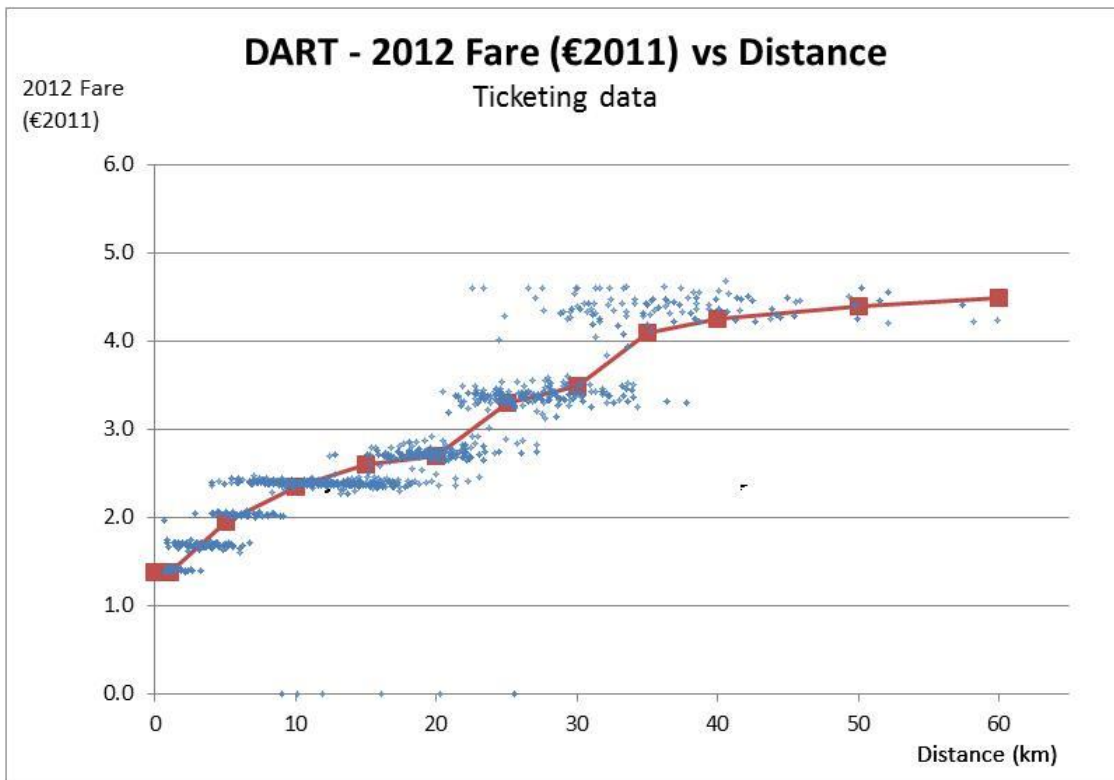


Figure 2.5: DART Fare model

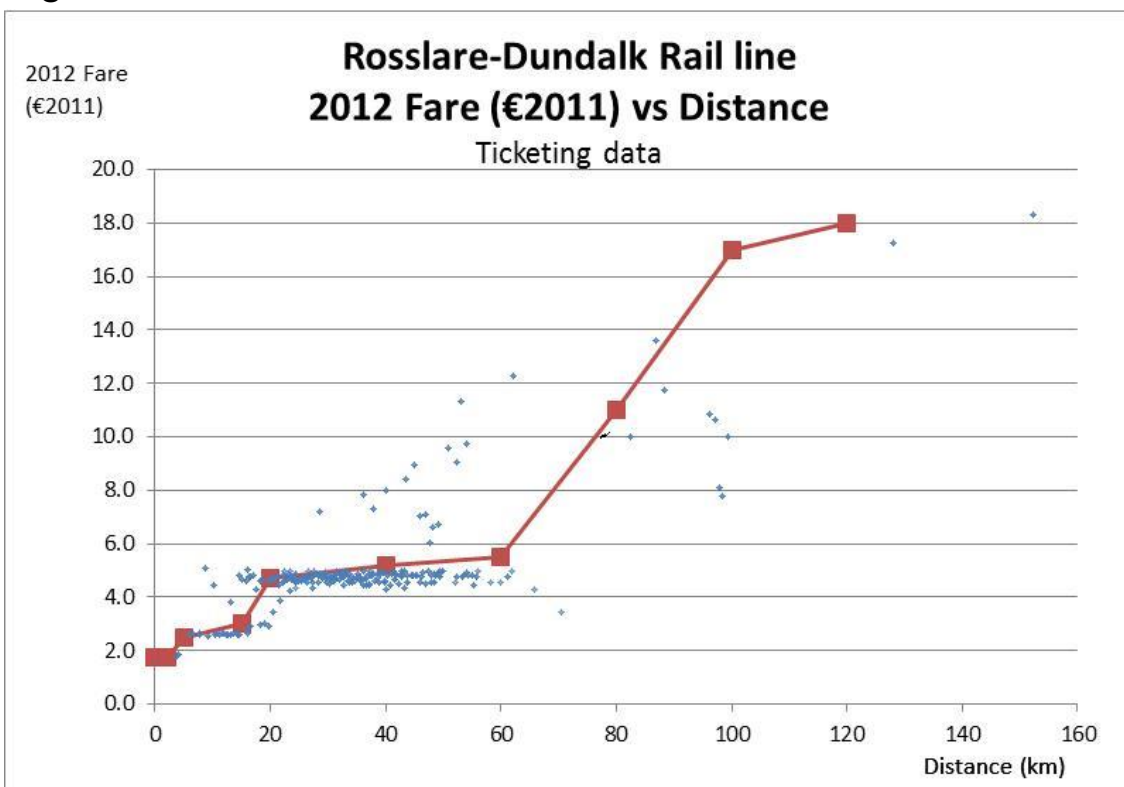


Figure 2.6: Rosslare-Dundalk line Fare model

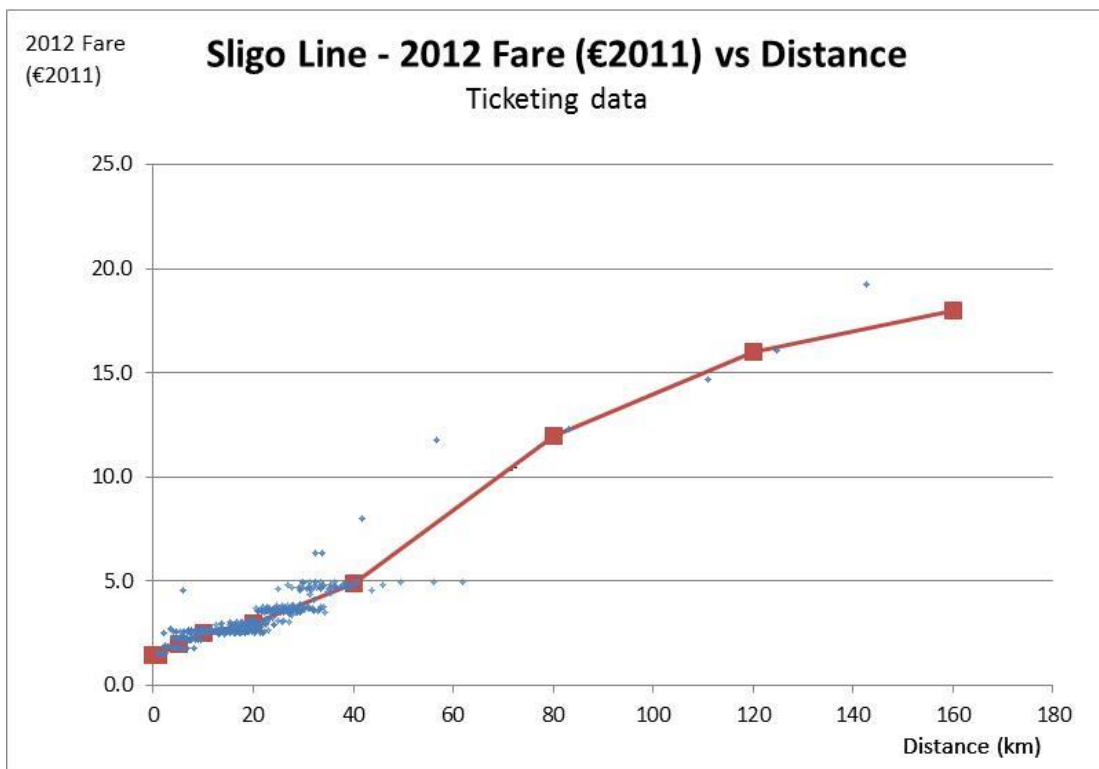


Figure 2.7: Sligo Line Fare model

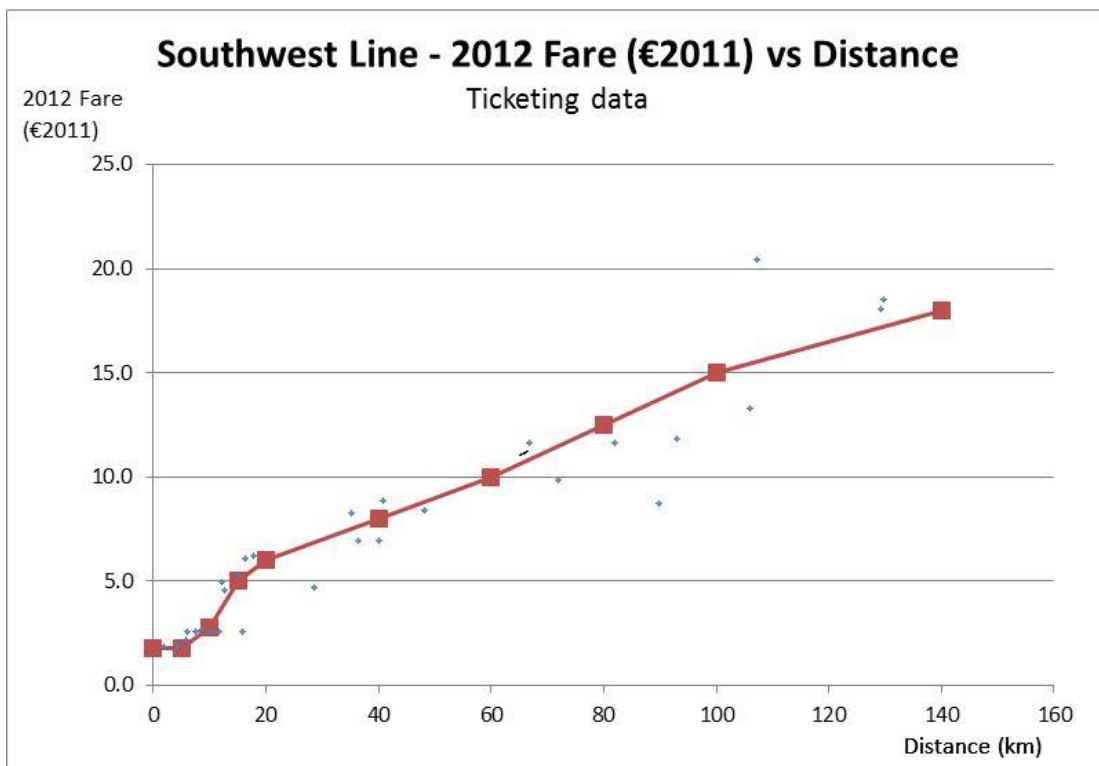


Figure 2.8: Southwest line Fare model

The average fares (from observed 2012 ticket sales data) for each of the four fare structures (outlined in Table 2.1) were compared against those calculated using the new fares model, and the results are presented in Table 2.2 below. The results indicate that the modelled fares provide a good representation of observed fare data with greater than 85% of ODs, for which ticketing data was available, having a modelled fare of between +/- 25% observed values.

**Table 2.2 Modelled vs Observed Average Fares**

Validation Band	% ODs within Validation Bands			
	DART	Rosslare - Dundalk	Sligo	South West
<-50%	0%	2%	0%	0%
Btw -50% & -25%	1%	8%	3%	0%
Btw -25% & +25%	99%	85%	95%	87%
Btw -25% & +50%	0%	2%	1%	7%
> +50%	0%	3%	0%	7%

### 2.3.2 Luas Fares

A stage-based fare system was developed to represent Luas fares in the ERM PT Model. Modelled fares are a weighted average across different ticket types expressed in euro 2011 prices using the Consumer Price Index (CPI). The minimum Luas fare in the model is €1.45 and maximum fare is €1.95. The fare system defined in the base year anticipates the realisation of Luas Cross-City and it includes fares from/to these future stations.

Luas fares defined in the model are:

- Travelling one stage: €1.45;
- Travelling two stages: €1.62;
- Travelling three stages: €1.82; and
- Travelling more than three stages: €1.95

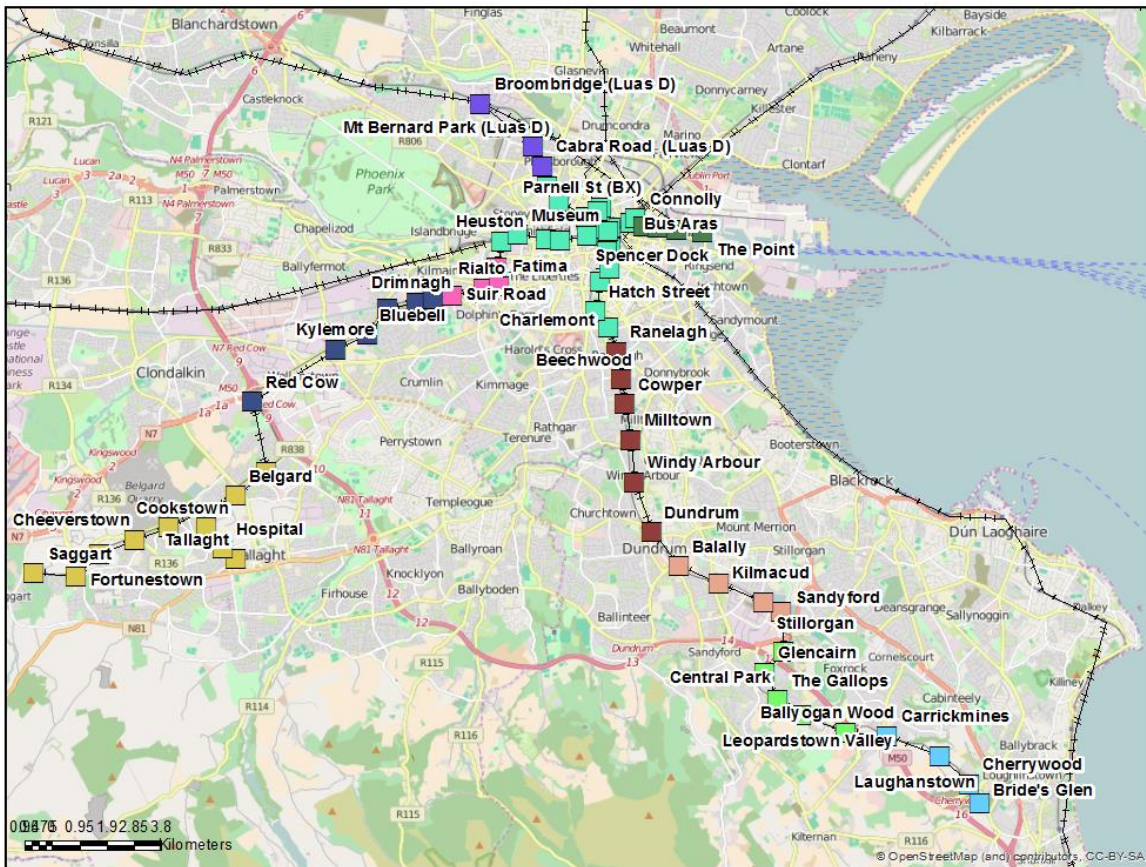


Figure 2.9: Luas fare system stages

### 2.3.3 Dublin Bus Fares

2013 ticket sales and revenue data for Dublin Bus services was obtained from the NTA. This included information on all ticket types, including; singles, returns, day saver, 10 journey etc., and season products including TaxSaver tickets.

This data was used to calculate an approximate weighted average fare per trip for Dublin Bus services. As outlined for Irish Rail above, a number of assumptions were made regarding the number of trips made on season tickets to calculate an approximate fare per trip.

A weighted average fare was calculated for each Dublin Bus fare band and this is applied as a stage based fare system within CUBE. The City Centre Fare (a lower flat fare if travelling within a defined central area) is also represented in the model. The Dublin Bus fares defined in the model are as follows:

- City Centre Fare: €0.58;
- Travelling 1 to 3 stages: €1.40;
- Travelling 4 to 7 stages: €1.87;
- Travelling 8 to 13 stages: €2.02; and
- Travelling more than 13 stages: €2.28.

### 2.3.4 Bus Éireann Fares

A distance based fare model was built for application to all Bus Éireann services based on ticket sales revenue and journey data available on key routes. Below is a plot of 2013 average fares versus distance for a sample of 30 Dublin commuting journeys. The red curve is the modelled distance fare, which was converted to 2012 fares in 2011 prices to be consistent with other fare systems.

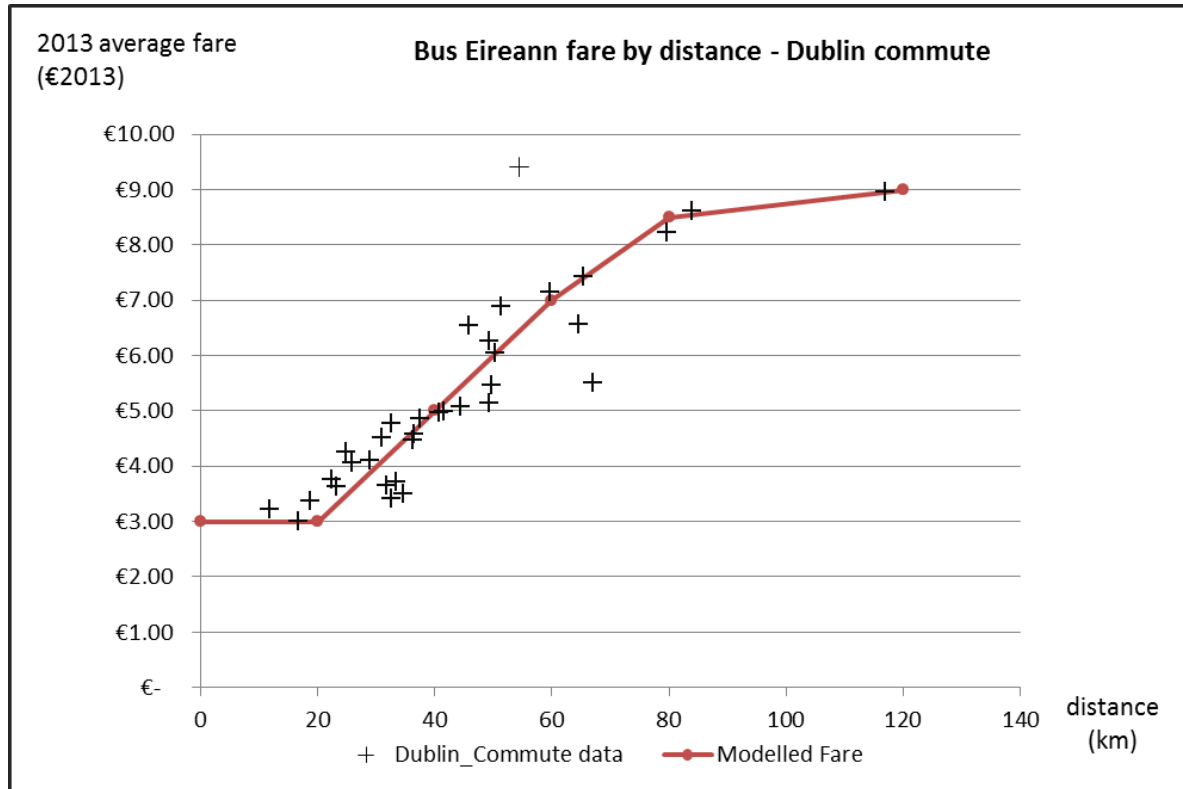


Figure 2.10 Bus Éireann Fare Model

### 2.3.5 Private Operator Fares

A similar approach to the Bus Éireann fare definition was used to model private operator fares. All such fares are represented using a single 'private operator' fare model. The steps in developing this model were:

- Collect fare data from the private operator websites;
- Build a list of Origin-Destination records with fare and distance information;
- Plot the data on a Fare Vs. Distance chart; and
- Build a distance-based fare model to fit the data.

As ticket sales and revenue data are not available for private operators, this model was based on single ticket fares. To take account of cheaper fares (season tickets, return tickets, etc.), private operator fares are factored by 0.83 (this factor was calculated using average fares / single fares ratio from Public Service Operators).

Investigation of existing services operating to and from Dublin Airport found that their fares structures are significantly different from the equivalent structure for non-Airport related services. For this reason, it was necessary to develop two separate fare models. Below

are plots of 2014 single fares versus distance for about 15 Dublin Airport and 45 non Dublin Airport journeys. The red curves are the modelled distance fares, which have been converted to average 2012 fares in 2011 prices to be consistent with other fare systems.

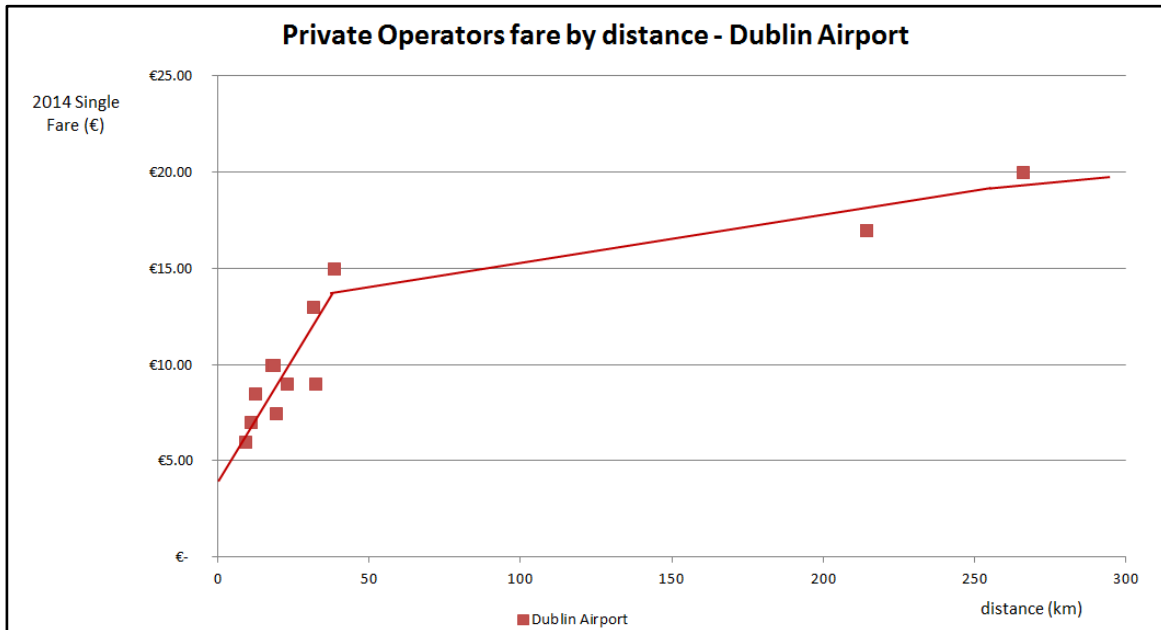


Figure 2.11 Private operators fare models (Airport and non-Airport services)



Figure 2.12 Private operators fare models (Airport and non-Airport services)

### 2.3.6 Transfer fares

Transfer fares between modes were defined to represent combined tickets for multi-modal users in the model. Based on pre-paid TaxSavers data, an average 31% fare reduction has been calculated for users of at least two of the three modes (Rail, Luas, and Dublin Bus). Assuming that 50% of the users can benefit from that reduction, a flat reduction of 15% of the cheapest fare of the mode was applied to users transferring between Public Service Operators. No transfer fare reduction was applied in the case of private operators.

## 2.4 Wait Curve Preparation

A wait curve was implemented for all PT lines in the PTM. This defines the relationship between services headways and perceived wait times. The wait curve initially implemented for the ERM PT Model is the Passenger Demand Forecasting Handbook (PDFH) Non-London Inter Urban curve as per Section 3.12.3 of the PTM Specification Report. The curve data points are shown in Table 2.3, and illustrated in Figure 2.13, below. A single wait curve is used for all modes in the model. This curve was updated during model calibration to provide an improved estimation of generalised costs (please refer to section 4.4.2 below for further details).

**Table 2.3 Wait Curve Definition**

HEADWAY	PERCEIVED WAIT TIME (MINUTES) INTER-URBAN
5	5
10	10
15	14
20	18
30	23
40	26
60	31
90	39
120	47
180	63

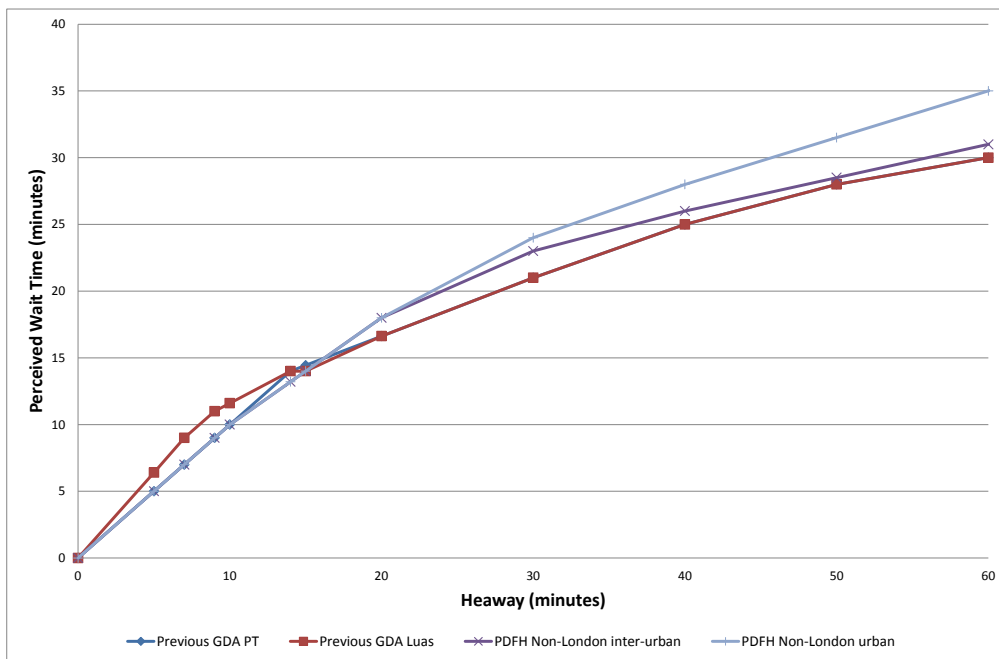


Figure 2.13 Wait Curves

## 2.5 Crowding Model Preparation

As discussed in Section 3.12.4 of the PTM Specification Report, crowding is modelled for all time periods. Modelling PT crowding is an iterative process. The model calculates an initial set of crowding factors and passenger loadings, feeds these back into the model and produces a revised set of passenger loadings and corresponding perceived crowding costs.

Three different crowding curves are used, one for each PT sub-mode (i.e. Rail, Bus and Light Rail) and have been set as identical to those used in the previous GDA model (see Figure 2.14 overleaf). Crowding curves are implemented as multiplicative curves in the CUBE Voyager PT assignment procedures. For each level of utilisation, the free link journey time is multiplied by the appropriate adjustment factor to represent the perceived journey time spent in crowded conditions. It should be noted that all modelled occupants perceive the same crowding on a given section of the route, regardless of where they boarded.

The measure of utilisation is expressed as the percentage of standing passengers as a proportion of the standing capacity. Utilisation is therefore zero until seated capacity is reached, and is 100% when the vehicle is at crush capacity, i.e. all standing room is taken.

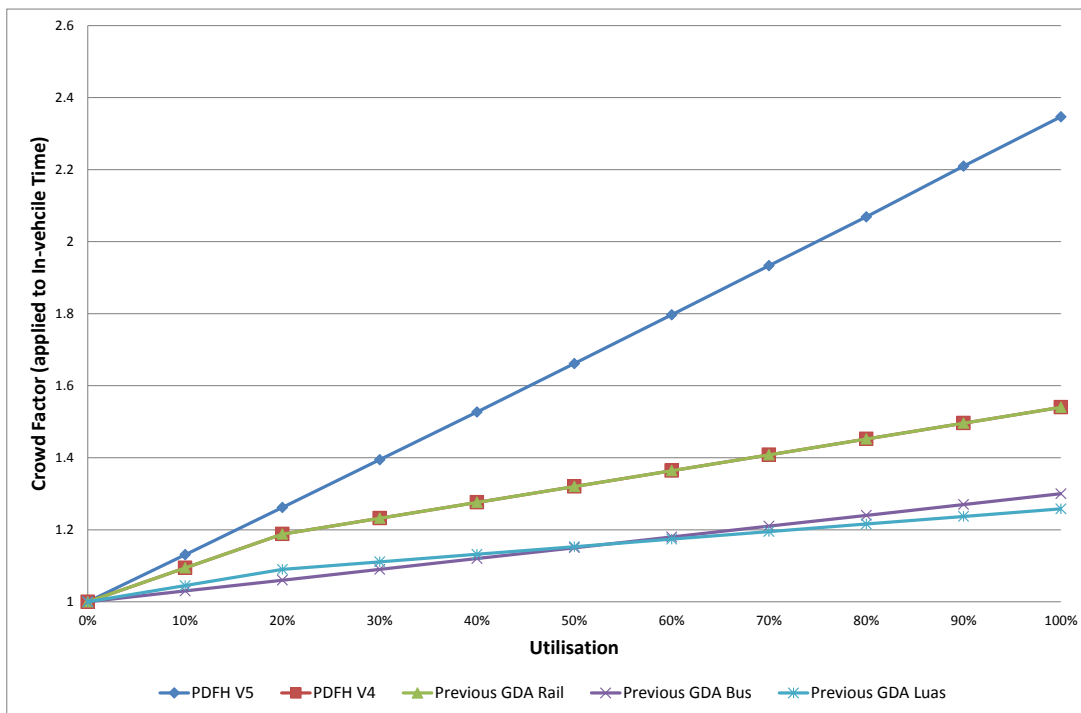


Figure 2.14 Crowding Curves – Utilisation to Crowding Factors

Based on vehicle capacity data and surveys, seating and crush capacities by mode were initially coded as:

- DART, Seating capacity: 308 / Crush capacity: 1,013
- Irish Rail, differ by service
- LUAS Red, Seating capacity: 72 / Crush capacity: 292
- LUAS Green, Seating capacity: 68 / Crush capacity: 319
- Dublin Bus, differ by service
- Bus Eireann, private operators, Seating capacity: 50 / Crush capacity: 52

In accordance with Section 3.12.4 of the PTM Specification Report, the model is set up to run 5 crowding iterations to ensure a sufficient redistribution of the demand on crowded services.

## 3 ERM Cube Voyager Implementation

### 3.1 Overview

Figure 3.1 illustrates the general implementation of the PTM within Cube Voyager. The PTM takes user specified inputs, and outputs from the Full Demand Model (FDM), to generate outputs for reporting purposes and cost skims which are fed back into the demand model. The inputs, outputs and calculation steps (the latter being identical for each time period) for the PTM are described in more detail in the following sections of this report.

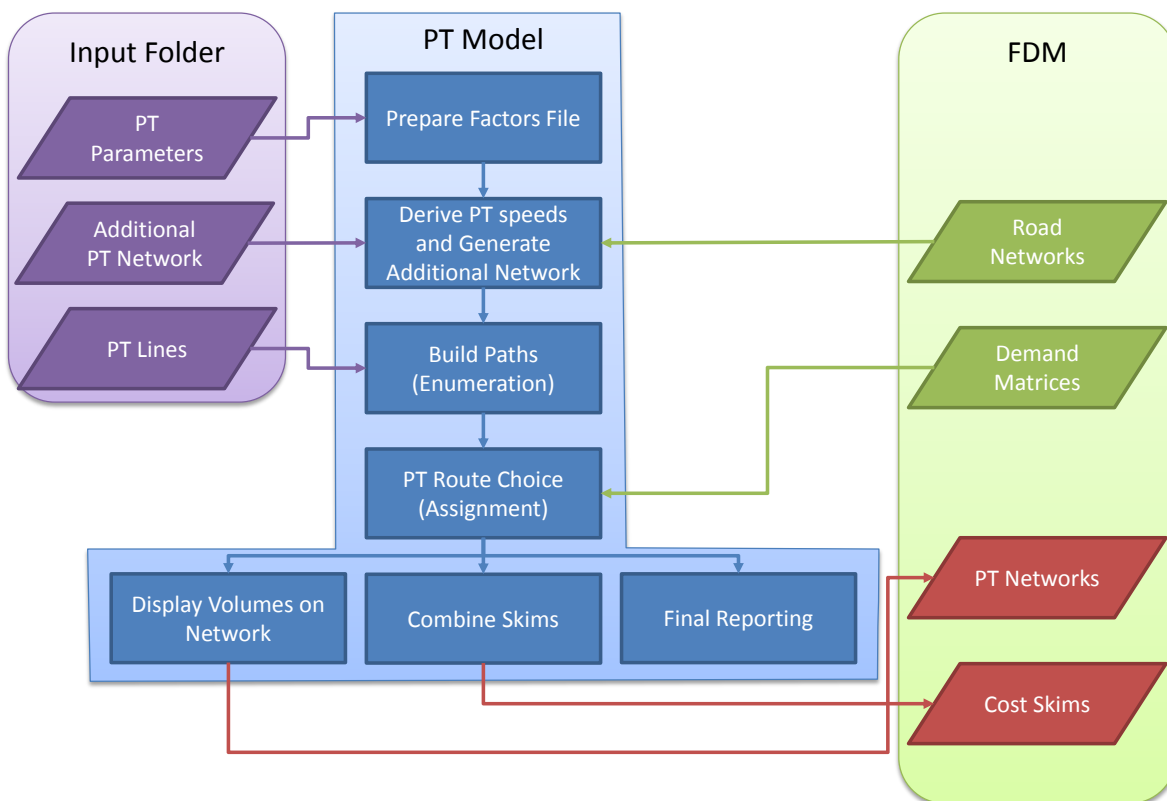


Figure 3.1 General PT Model Flow

### 3.2 Inputs

The PTM takes two categories of inputs: outputs from the FDM and inputs supplied by the user describing the scenario to be modelled. Each of these categories can then be further divided as follows:

### **User Supplied Inputs**

- network files (which describe the “supply” of public transport, comprising public transport infrastructure and services, including associated infrastructure such as walk connectors, bus lanes and roads along which buses run);
- parameters (which control how the model operates); and
- analysis files (which specify the reports to be created as the PT model runs).

### **FDM Outputs**

- matrices (which contain the demand for public transport services);

#### **3.2.1 Network Files**

The basic PT network structure is generated as an output from the road model assignment, and this is then supplemented with additional network detail such as non-transit (walk) links supplied by the user. In total, seven additional network files required by the PTM have to be supplied by the user as inputs to the model:

**Table 3.1 Additional PTM Network Files**

<b>FILE</b>	<b>DESCRIPTION</b>
<b>DBus_FareZones.DBF;</b>	Dublin Bus Fare Zones
<b>Luas_Links.DBF;</b>	Luas Links
<b>Luas_Nodes.DBF;</b>	Luas Stops
<b>Rail_Links.DBF;</b>	Rail Links
<b>Rail_Nodes.DBF;</b>	Rail Stations
<b>Walk_Links.DBF; and</b>	Walk Links
<b>Walk_Nodes.DBF.</b>	Walk Nodes

Node files contain node numbers and their X and Y coordinates. Link files contain an A and B node, distance (in kilometres), link type (used in assignment definition), and reverse flag (indicating whether it is a two-way link).

#### **3.2.2 Matrices**

The FDM outputs demand matrices by user class for input to the PTM. The five user classes are detailed previously in Chapter 1. As noted also in that section, these demand matrices are calculated within the FDM individually by time period reflecting persons travelling in a representative peak hour.

#### **3.2.3 Parameters**

The PTM relies on a large number of parameter definitions, and they are contained within a number of files in the *Factor\_Files* and *Additional\_PT* folders in the input directory.

#### ***Factor Files***

Factor files contain a range of parameters used for routes enumeration and assignment, including In-vehicle time weights, boarding and transfer penalties, wait curves and fare

systems etc. More details on how these parameters operate can be found in the Cube Voyager Help manual. Separate factor files are defined for each combination of user class and time period. In addition, a set of additional factor files (one for each time period) is defined with the suffix ZOD (for Zero Demand). This is used to reduce PT assignment run times by reducing the level of calculation in the model for OD pairs between which there is no PT demand.

### **Fares**

The *Additional\_PT* folder contains Fares files which set out the various fare systems to be utilised within the PTAM for each mode and time period. In addition, PT operators and modes are defined using a system text file, **SYSTEM\_FILE.PTS**.

### **Non-Transit Legs**

Finally, an external script file, **NTL\_GENERATE\_SCRIPT.txt**, is contained in the Additional PT folder and is read in during a model run. This file is generally not altered. This script defines various parameters used to build the Non-Transit Legs, such as maximum number of PT stops a zone can reach by mode or specific PT access for external zones.

### **3.2.4 Analysis Files**

Select links are undertaken during PTM assignment and are defined using a script file (not a core part of the model but referenced by the true scripts), **SELECT\_LINK\_SPEC.txt**. The select link input file provides a way for the user to input links / lines to be skimmed, with output matrices added at the end of the cost matrices.

## **3.3 Network Link Attributes**

The PT network shares attributes with the road network, but also includes others. Below is a list of those attributes and their meanings:

- Distance: Link distance in kilometres;
- CI: Capacity Index - dumped from the road network;
- Bus\_Lanes: Indicator whether a bus lane is coded on the link (=1) or not (=0) - dumped from the road network;
- Link\_Type: Attribute to identify the main role of the link as follows:
  - 1 – Road link
  - 25 – Walk only link
  - 27 – Rail / Luas link
  - 31 – Zone connector to the road network
  - 32 – Zone connector to the rail network
- Crosscity: Indicates whether the link is part of the Luas crosscity extension (=1) or not (=0).

## 3.4 Key Parameters

Key parameters are outlined in Section 3.12 of the PTM Specification Report, and include:

- **Route enumeration controls** – these determine the spread of routes that are taken forward to evaluation and the more detailed assignment stage;
- **Boarding & Interchange Penalties** – these relate not only to service reliability but also to the provision of facilities at boarding points, such as waiting facilities, information and security. These may relate to future proposed network enhancements;
- **In-vehicle weights** by modal preference factors – associated with the relative comfort and perception of travel time in different modes, or different vehicle types; and
- **Wait Curves and Factors** - these relate service frequencies to the actual perceived wait time experienced by passengers. This is especially important when journeys involve interchange and services of differing frequencies, for example interchange between rail and bus services.

Table 3.2 below outlines the range of initial values for parameters used to set up the PT Model.

Table 3.2 PT Model Parameters

MODEL PARAMETER	VALUE/FACTOR		
	LOWER	INITIAL	UPPER
Spread Factor	1.2	1.25	1.75
Spread Constant (minutes)	0	15	15
Route Enumeration Fare In-vehicle Time Factors (vary by sub-mode)	0.75	1.00	1.25
Boarding Penalty (minutes, may vary by sub-mode)	0	5	10
Transfer Penalty (minutes, may vary by sub-mode)	0	5	20
In-vehicle Time Factors (initial from BRT study; calibrated may vary by time period):			
DART rail	1.00	1.39	2.00
Rail	1.00	1.39	2.00
Luas	1.00	1.00	2.00
urban bus	1.00	1.90	2.00
Inter-urban bus	1.00	1.90	2.00
BRT and Metro	determined from BRT study relative to other calibrated sub-mode IVTs		
Walk Time Factor	1.60	1.60	2.00
Minimum Wait Time		0 mins	
Maximum Wait Time		60 mins	
Wait Curves		see previous section	
Crowd Model Parameters		see previous section	

## 3.5 Outputs

The outputs of the PTM fall into two categories, namely:

- Those required by the FDM; and
- Those produced purely for reporting.

### 3.5.1 FDM Outputs

The outputs required by the FDM include:

- **Assigned Networks** which are passed on to the active mode assignment as the starting point for their network build procedure; and

- **Generalised Cost Matrices** by user class for each of the four assigned time periods to be fed back into mode and destination choice. For the unassigned time periods, assumptions are applied to derive approximations of generalised costs as detailed in Chapter 20 of the RM Full Demand Model Specification Report.

### 3.5.2 Reporting Outputs

The PTM produces a number of reporting outputs specifically by time period (in individual folders). Table 3.3 summarises these outputs.<sup>2</sup>

Table 3.3 PT Model Outputs

REPORT	DESCRIPTION
TP_MATRIX_TOTALS.CSV;	Summary of matrix totals
TP_LINK_RECS.DBF;	Network links with PT lines data (Count of lines, services/hour) and assigned trips.
TP_LINK_RECS_PREP.DBF;	Network links with PT lines data (Count of lines, services/hour).
TP_ON_OFFS.DBF;	Network links with Boarding and Alighting data by line.
TP_ON_OFFS_NT.DBF;	Network links with Boarding and Alighting (Non Transit legs only).
TP_ON_OFFS_PREP.DBF;	File to prepare the ON_OFFS file
TP_RAIL_B&A.DBF;	Total boarding and alighting by node.
TP_RAIL_B&A_SPLIT.DBF;	Total boarding and alighting by node and by mode.
TP_RAIL_LOADINGS.DBF;	Rail network links flows by line.
TP_PT_ASSIGNED.LIN;	Line file with volume information.
TP_PT_COMPCST.MAT;	PT Composite Costs matrices for all user classes.
TP_PT_EMP.MAT;	Detailed components of PT costs for UC Employers Business.
TP_PT_COM.MAT;	Detailed components of PT costs for UC Commute.
TP_PT_RET.MAT;	Detailed components of PT costs for UC Free Travel.
TP_PT_OTH.MAT;	Detailed components of PT costs for UC Other.
TP_PT_EDU.MAT;	Detailed components of PT costs for UC Education.

<sup>2</sup> The **TP** indicates a time period variable and can take the values AM, LT, SR, and PM.

<b>TP_PT_WKONLYTRIPS.MAT;</b>	PT Walk Only trips – Matrices of trips that do not board a service.
<b>TP_SELECTLINK.MAT;</b>	Select Link Matrices defined by input file “SELECT_LINK_SPEC.TXT”, i.e., PT trips which pass through the select link.
<b>SKIM_TP_PT_EMP.MAT</b>	PT skims extracted from the assignment for UC Employers’ Business, including composite cost, distance, time, boardings, wait and transfer costs.
<b>SKIM_TP_PT_COM.MAT;</b>	PT skims extracted from the assignment for UC Commute, including composite cost, distance, time, boardings, wait and transfer costs.
<b>SKIM_TP_PT_RET.MAT</b>	PT skims extracted from the assignment for UC Free-Travel, including composite cost, distance, time, boardings, wait and transfer costs.
<b>SKIM_TP_PT_OTH.MAT;</b>	PT skims extracted from the assignment for UC Other, including composite cost, distance, time, boardings, wait and transfer costs.
<b>SKIM_TP_PT_EDU.MAT;</b>	PT skims extracted from the assignment for UC Education, including composite cost, distance, time, boardings, wait and transfer costs.
<b>SKIM_TP_PT_ZD.MAT;</b>	PT skims extracted from the assignment for zone pairs with zero demand, including composite cost, distance, time, boardings, wait and transfer costs.
<b>TP_PT_ASSIGNED.NET;</b>	Assigned PT network.
<b>TP_PT_ENUM.NET;</b>	PT network with enumerated routes.
<b>TP_PT_LOADED.NET;</b>	PT network with PT flows loaded on links.
<b>PRIOR.NET;</b>	PT network (Road network + PT specific links).
<b>PT_PREP.NET;</b>	PT network post Non-Transit legs generation.
<b>PT_SPEEDS.NET;</b>	Road network with PT speeds defined.
<b>PT_PREP.NTL;</b>	Non Transit Leg file – Zone access to PT stops.
<b>TP_PT_ASSIGNED.REP; and</b>	Data on assignment parameters.
<b>TP_PT_ENUM.REP.</b>	Data on Route enumeration parameters.

## 4 PT Model Calibration

### 4.1 Introduction

This chapter describes the process of calibration of the PTM, while Chapter 5 outlines the results of the PTM validation. In conventional modelling theory, these are two separate processes. Model calibration is the process of adjusting model parameters and inputs to ensure the model outputs match observed data as closely as possible. Model validation is the process of comparing the outputs of the calibrated model against a separate set of observed data not used in the calibration process. In practice, however, the two processes are interlinked in that issues identified during validation stage can be addressed by modifying calibration parameters.

PT Model calibration followed an iterative process, where improvements to the PT model led to better costs, which fed into the Demand Model, which in turn was improved to produce better estimates of PT demand. The Demand Model calibration process is described in ERM Demand Model Calibration Report.

### 4.2 Assignment Calibration Process

#### 4.2.1 Overview

Calibration is the process of adjusting the PT Model to ensure it provides robust estimates of sub-mode choice, assignment and generalised cost before integrating it into the full ERM. This is typically achieved in iteration with the validation of the model to independent data. For the ERM, assignment calibration was undertaken through comparisons of model outputs and observed data for the following:

- Passenger Flows;
- Boardings and Alightings;
- Bus Journey Times; and
- Interchanges.

The UK's Department for Transport's Transport Analysis Guidance (TAG) unit M3-2 PT assignment modelling, January 2014, indicates that the assignment model may be recalibrated by one or more of the following means:

- adjustments may be made to the zone centroid connector times, costs and loading points;
- adjustments may be made to the network detail, and any service amalgamations in the interests of simplicity may be reconsidered;
- the in-vehicle time factors may be varied;
- the values of walking and waiting time coefficients or weights may be varied;
- the interchange penalties may be varied;
- the parameters used in the trip loading algorithms may be modified;
- the path building and trip loading algorithms may be changed; and
- the demand may be segmented by person (ticket) type.

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 three components discussed in the following sections of this chapter, namely, adjustments to:

- PT Network;
- PT Parameters; and
- PT Matrices.

## 4.3 PT Model Network Progression

### 4.3.1 Overview

The development of the initial PT network, services and fares model has already been described in Chapter 2. Following this, two types of checks were carried out:

- **Non Transit Leg PT Access Testing:** To ensure levels of access to PT services were represented correctly for all zones in the PTM; and
- **PT Generalised Cost Checks:** To ensure the costs generated by the PT model would not cause problems during the calibration of the demand model. For example, large PT costs could lead to insensitive generalised cost parameters estimated during calibration. This may impact on the model's sensitivity to future PT scheme changes

### 4.3.2 Non Transit Leg PT Access Testing

Every model zone is assigned to a 'zone centroid' network node. PT trips to/from a zone begin and end at the centroid to access the main PT and/or road network via a centroid connector by walking.

The actual distances walked from locations within a zone boundary and the actual network within that zone can vary substantially (and this variance is in proportion to the zone size). Ideally the centroid connector length is chosen so as to minimise this variance for all trips, but since not all trips are observed, a general rule for connector length is usually applied. This can result in long connectors (and hence long walks) between the locations of trip origins/destinations, (abstractly represented by centroids), and the nearest PT services.

In order to identify any issues with access to PT services within the PTM, analysis was undertaken of the time taken to get from from each zone centroid to the nearest PT stop for each of the following sub-modes:

- DART;
- Intercity Rail;
- Luas;
- Dublin Bus; and
- Bus Éireann

The analysis involved identifying the minimum walk or driving time from each zone to access the nearest PT stop, for each sub-mode, using the modelled lines derived from GTFS and the network taken directly from the road model.

No account was taken of the other journey characteristics that would be considered in a full PT assignment, including headways, transit times and fares.

Internal zones had walk or drive access to all PT modes except for urban bus services (Dublin Bus), which were only accessible by walk. Access by car was capped to 30 minutes drive. The perceived cost for motorised access included a 30 minutes penalty, and this was multiplied by a factor of 2. For walk access, the assumed walk speed was 4.8kph and no walk access routes greater than 40 minutes were included. It should be noted that these values represent initial assignment parameters prior to model calibration. These parameters were updated during calibration as detailed in Section 4.4.2 below. External zones had motorised access only, limited to 200 minutes, and this directly connected to only the rail and inter urban bus modes.

Figure 4.1 provides a sample illustration of the PT access analysis undertaken for the ERM. The general finding expected was that zones on PT services would have low access time, with zones more distant from such services having correspondingly higher access times. Any zone (or set of zones) which contradicted this expectation was investigated for connectivity issues (e.g. missing centroid connectors or lack of PT network/service coding) and then corrected.

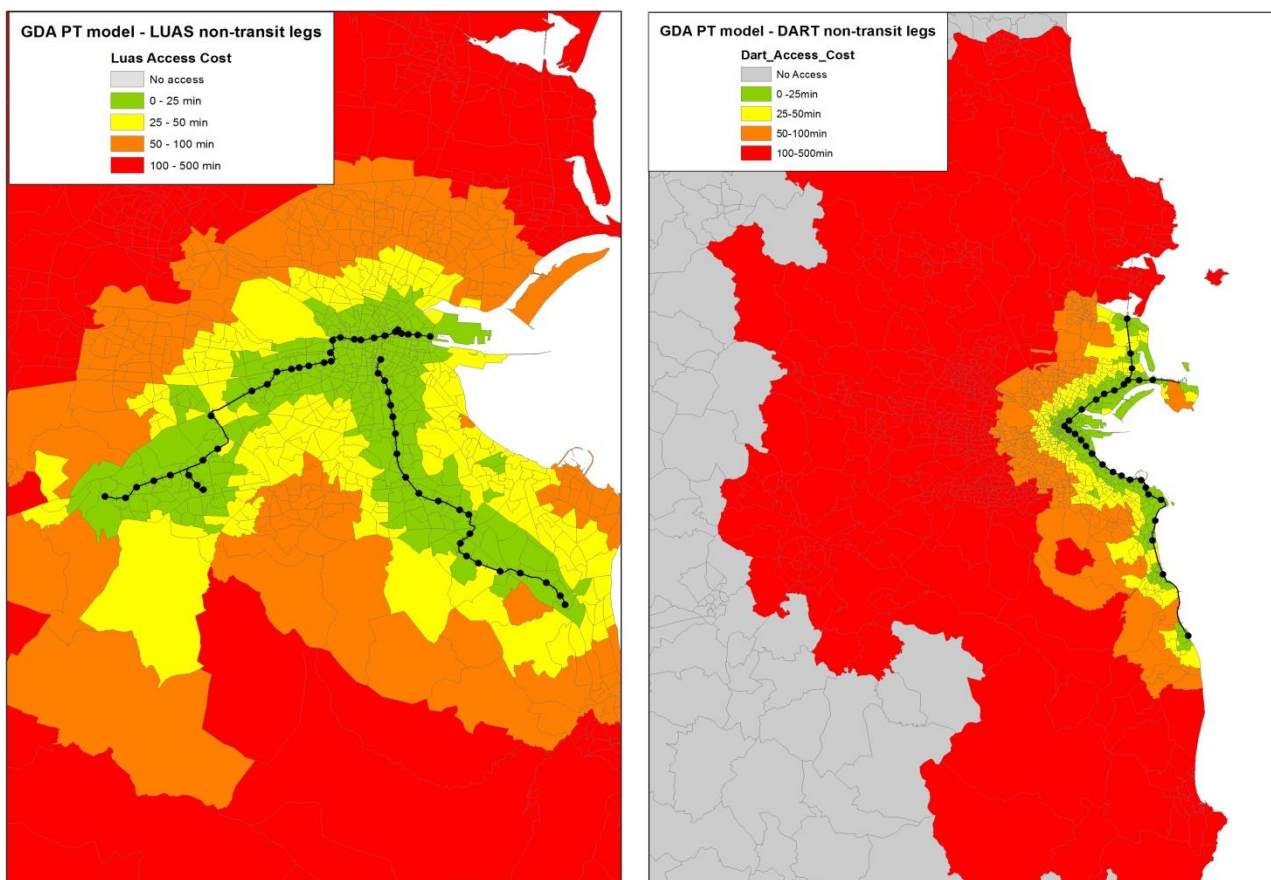


Figure 4.1 Non-Transit Leg PT Access Testing

### 4.3.3 PT Generalised Cost Checks – Network Checks

The initial access tests, detailed above, provided a check on the developed PT Network in terms of access and connectivity to public transport services. It was noted through an initial assignment of the SWRM, that the developed PT model was generating significantly high generalised costs which would cause difficulties during calibration of the FDM.

A series of tests were carried out in the SWRM to identify measures which could assist in producing more realistic PT generalised costs. These tests were primarily undertaken using the SWRM (and not the ERM) due to quicker run times which allowed numerous tests to be undertaken in a short period of time. The full set of tests are described in further detail in Section 4.3 of the SWRM Public Transport Model Development Report. For completeness, all tests were described in the SWRM report, even though not all changes were retained in the revised version of the PT Model. Table 4.1 below, provides an overview of all network tests undertaken on the SWRM including an indicator stating whether the change was retained or not in the ERM.

**Table 4.1 Summary of Generalised Cost Tests carried out in SWRM**

Test	Retained?
Zone Disaggregation	Retain
Cap PT Cost Connectors	Do Not Retain
All Services Make All Stops	Do Not Retain
Direct Zone to Stop Connectors	Retain
PT Services Reviewed	Retain
Cap Centroid Connectors	Not Retained in ERM <sup>3</sup>

It was envisaged that all of the regional models would experience similar problems in terms of high levels of PT generalised cost. Therefore, alterations from the SWRM which were found to be beneficial in terms of better representing generalised costs were adopted for all regions, including the ERM. The following sections provide a brief description of the changes which were adopted for the ERM on foot of testing carried out in the SWRM PTM.

#### ***Zone Disaggregation***

In the initial PT assignment, the length of the PT walk connector was taken to be proportional to the area of the zone (it was taken to be 2/3 of the radius of the zone, with the approximation that each zone was a perfect circle). This resulted in long walk connectors, and hence a high PT access cost, for some zones.

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<sup>3</sup> Zone areas, and corresponding connector distances, are significantly shorter in the ERM when compared to the other regional models that contain large rural areas. As such, the capping of zone connectors was not required in the ERM PT Model.

Where a zone had a walk connector longer than 3km it was flagged for review. For each of these zones the population density of each of the CSAs making up the zone was displayed on a map. If there was an area that was more densely populated (usually a small town or village) this was separated into a new zone, and the surrounding more rural area left as a separate zone. Further information on the zone disaggregation process is provided in Chapter 3 of the ERM Zone System Development Report.

### ***Direct Zone to Stop Connectors***

The repeatable methods developed for the ERM include a process for revising walk connectors in areas where the road network is not detailed enough to represent the routes used by passengers when accessing PT services (see *PT TN01 PT Model Walk Connections* technical note for further information). This is mainly an issue in rural areas. The following approach was adopted for the ERM:

- 1) All centroids were relocated based on a weighted location of Geo-Directory population and employment.
- 2) In dense areas where zones are relatively small and there is a detailed representation of the road network, a single connector to the nearest node was coded to replace the connectors inherited from the SATURN model. These are connected to spigots which are often not connected to the nearest node to the centroid. The connector distances were estimated based on crow-fly distance from relocated centroids to the closest node. Crow-fly distances were multiplied by a factor of 1.2. This is a commonly applied factor in Accession<sup>4</sup> used to estimate the actual distance walked along a road, taking into account the geometry of the road network which is represented by straight lines in the SATURN model.
- 3) In other areas where zones are bigger and the modelled network is coarser, possible walk routes are not fully represented, and this can lead to a bus/ rail bias. For example, if a network link was coded from the centroid directly to a train station, whereas there is no direct link from the centroid to the nearest bus stop. In this instance passengers have to walk along modelled links in the highway network to access bus and this may result in more passengers being modelled as using the train due to the lower access time when there is actually a bus stop closer than the train station. To avoid this, the centroids were connected:
  - a) Directly to all of the GTFS PT stops if they are located less than 2.4km from the zone centroid (crow-fly distance). (This is based on the maximum walk time of 30 minutes and a walk speed of 4.8km/h.)
  - b) To the nearest node if there is no stop less than 2.4km from the zone centroid (crow-fly distance).

To incorporate these changes within the PTM, all zone centroids connectors inherited from the highway assignment are automatically deleted. Instead all of the PT connectors are

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<sup>4</sup> An accessibility analysis software package

included in the Walk\_links.dbf input file at the network building stage. The approach described above required the categorisation of zones based on size, location and network density to select the appropriate zone connectivity method.

A manual check of the connectors produced was undertaken to ensure they are sensible. This included consideration of the PT services at each stop to ensure that valid services are connected, and to retain a single stop on each valid bus corridor by selecting the minimum distance corridor. Effort was made to remove or amend connections that may not be possible in reality due to physical barriers, for example rivers or motorways.

### ***PT Services Reviewed***

A detailed review was carried out on outputs from the GTFS extraction process. Stopping sequences for certain lines were updated as some routes weren't properly coded. In particular, issues arose where services extended outside the model area (e.g. Dublin-Limerick) and were not coded as stopping at the edge of the network.

All modelled headways were checked against timetables available online from Bus Éireann and other service provider websites. Where necessary, headways were updated to represent as accurately as possible all PT services in the modelled area.

#### **4.3.4 Detailed Network Audit**

A detailed network audit was completed after all major changes outlined above had been applied to the model. This identified a number of recommendations that were applied, and are summarised in the Table 4.2 below:

**Table 4.2 Detailed Network Audit Recommendations**

<b>Type</b>	<b>Description</b>
<b>Network Services</b>	Rail and bus services leaving and entering the model updated to have their last stopping node at the last node of the network
<b>Headways</b>	All headways capped at 61 minutes to avoid capacity issues
<b>External Connectors</b>	New methodology for calculating lengths of external connectors

### ***Crowding Headways***

The calculation of coded headways is based on the frequency of services from GTFS data at the period level (i.e. 7-10 in the AM) whereas only the peak hour (60min) is being assigned.

For a service going only once in the AM period (say at 8.30 AM), a headway of 180min was initially coded. This resulted in an hourly capacity being divided by three (180/60). In order to avoid underestimation of supply and inconsistent crowding, the headways were capped at 61 minutes. The impact of that is a correct hourly capacity for the assigned

peak hour. Nevertheless, the wait time will tend to be underestimated. This is arguable as a service running only once in the AM period would most likely run within the peak hour, and therefore, the wait time would probably correspond to that of an hourly service.

The capping of headways can have another drawback if there is a requirement to convert services into fleet requirement or 24h operating costs. The model inputs are now not able to differentiate between 60 min or 180 min headway services.

### ***Updated External Connector Distances***

External zones are generally connected to motorways and road connectors and don't necessarily join the network where PT services operate. Zones with no access to PT were listed, and zone connectors were added for those zones as part of the calibration process.

To represent accurate access costs by Public Transport, a new methodology was introduced whereby the connector distances were calculated based on the cost of travelling by sub-mode (i.e. bus and rail) from the centroid connector to a defined settlement on the edge of the model network.

The cost of travelling by sub-mode was calculated based on:

- Distance from the defined zone centroid location to the settlement on the edge of the model network;
- Time of travel based on sub-mode; and
- Approximate fare calculated utilising the ERM distance based fare structures for bus and rail.

The approximate cost of travel was calculated for each connector and PT mode available, and this was utilised to generate updated connector distances for input into the ERM PTM.

## **4.4 PT Model Parameters Progression**

### **4.4.1 Initial Parameters**

Initial PT model parameters were taken from the PTM Specification Report and an early version of the ERM, and are outlined in Table 3.2 previously, along with an acceptable range of values.

### **4.4.2 PT Generalised Cost Checks**

As part of the PT Generalised Cost checks outlined previously in Section 4.3.3 and detailed in the SWRM Public Transport Model Development Report, a number of PT assignment parameters were reviewed and updated. The main changes were made in the following PT input files:

- **NTL\_GENERATE\_SCRIPT.txt:** defines the non-transit legs generation process;
- **SYSTEM\_FILE.pts:** defines the mode, operators, wait curves and crowding curves within the PTM; and
- **AM\_PT\_ASS\_8.s:** Script controlling the PT assignment within CUBE.

As a starting point, the following assignment parameters were defined:

- Mode 96: Drive to PT Stop (see Section 2.1.6 for further details)
  - 30 min penalty on connector (no drive time included)
  - Maximum 60 minutes
  - Slack of 10 minutes
  - 1 leg by sub-mode, 5 for Inter-Urban Bus
  - Weight factor: 2
- Mode 97: Walk to PT Stop (see Section 2.1.6 for further details)
  - Maximum 30 minutes
  - Slack of 10 min
  - 5 legs by sub-mode, 10 for modes 4 and 5, corresponding to buses
  - Weight factor: 2
- Mode 98: Zone-to-zone walk (see Section 2.1.6 for further details)
  - Maximum 20 minutes
  - Pure walk cost
  - Weight factor: 2

Similar to the network checks outlined previously, a series of tests were carried out in the SWRM on alterations to PT parameters and their impact on producing improved generalised costs for calibration. Table 4.3 below provides an overview of all tests undertaken including an indicator to state whether the proposed change is to be retained in the ERM. Detailed descriptions of all tests are described in the SWRM Public Transport Model Development Report.

Table 4.3 Summary of Parameter Options Retained for Revised PTAM

Test Description	Retained
Include Drive Time on Connectors	Retain
Remove 30 minute Penalty for Driving	Do Not Retain
Increase Non-Transit Legs and Slack Value	Do Not Retain <sup>5</sup>
Remove Drive Time Weight	Do Not Retain
Remove Drive Access and Increase Walk Cap	Do Not Retain
Rural Drive Access and No Penalty	Do Not Retain
Decrease Driving Cap to 30 Minutes	Retain
Revised Maximum Waiting Time	Retain
Zone-to-Zone Walk Penalty	Retain

The following sections provide a brief description of the parameter changes which were adopted for the ERM on foot of testing carried out in the SWRM PTM.

### ***Include Drive Time on Connectors***

As noted earlier in Section 4.4.2, initially drive time along the zone connector was not taken into account in the access cost calculation. Instead, a fixed penalty of 30 minutes was added regardless of the length of the connector. Therefore, for more consistency, including the actual drive time on the connector in addition to the fixed 30 minute penalty was tested in the SWRM. The results indicated that the change had little impact on average costs and cost distribution. It was decided that this alteration should be adopted across all regional models as it provides a more accurate representation of drive access costs.

### ***Decrease Driving Cap to 30 Minutes***

Initially, drive access to PT Stops (Mode 96) was capped at 60 minutes (30 minute drive + 30 minute penalty). This high value was introduced to ensure that all zones have PT access. However, through analysis in the SWRM, it was noted that allowing a drive of 60 minutes was excessive leading to unrealistically long drive access legs for PT journeys. Through iterative testing in the SWRM, a drive access cap of 30 minutes was considered sensible based on a balance between the number of zones with available PT access and

<sup>5</sup> Slack value increased for regional models due to larger rural areas and infrequency of PT Services. In the GDA, given the level of zonal detail and PT provision, a slack value of 10 was deemed acceptable.

the drive distance allowed. This 30 minute cap was adopted across all Regional Models including the ERM.

### ***Revised Maximum Waiting time***

In order to further reduce PT generalised costs, a test was carried out in the SWRM to reduce the maximum waiting time for a PT service from 30 minutes to 15 minutes (i.e. a perceived wait time of 30 minutes based on a wait factor of 2). This is a standard value for maximum waiting time and resulted in a small reduction in average PT costs. Thus, this revised maximum wait time value was adopted in the ERM.

### ***Zone to Zone Walk Penalty***

As noted in Section 2.1.6 above, zone-to-zone direct access was included in the model to ensure that costs are increasing consistently with distance. Initially, the direct non-transit leg access from zone to zone was allocated a perceived cost of twice the walk access cost. However, it was noted during initial testing in the SWRM that using this approach was creating quite low PT access costs for short distance zone to zone trips, and thus, overestimating short distance PT demand.

The zone to zone non-transit leg was developed to re-create short distance PT journeys between zones which could not be represented within the model due to lack of network detail. Therefore, the cost of access for these journeys should reflect boarding costs, fares, wait times etc. and it was decided that it would not be fair to represent their costs as just walk costs as originally planned.

Analysis was carried out on short distance zone to zone trips within the model where PT services were coded. For these services an average penalty of 15 minutes (multiplied by two to convert it into a perceived value) was identified which represented boarding penalty, fare and waiting time. This 15 minute penalty was then applied to the direct zone-zone access costs and, in addition, the zone-to-zone walk time was capped at 10 minutes. As a result, the overall demand calibration was noted to have improved with the cost distributions more accurately matching observed data. Therefore, this zone to zone penalty was adopted for all Regional Models.

### ***Updated Wait Curve***

As noted in Section 2.4 previously, the PDFH Non-London inter-urban wait curve was initially adopted for the ERM. However, due to the generalised costs problems noted within the SWRM, it was decided, through consultation with the NTA, that the wait curve would be altered to assist in providing more realistic cost estimates. Table 4.4Table 2.3 and Figure 4.2 below illustrate the wait curve applied to all modes within the ERM. As noted in Section 4.3.4 previously, all service headways within the ERM have been capped to 60 minutes. As such, the maximum wait time in the model is capped at 15 minutes (30 minutes perceived wait time).

Table 4.4 Wait Curve Definition

Headway	Wait Curve Value (Mins)	Perceived Wait Time (mins)
5	2.5	5
10	5	10
15	7	14
20	9	18
30	11.5	23
40	13	26
60	15	30
90	17	34
120	18	36
180	20	40

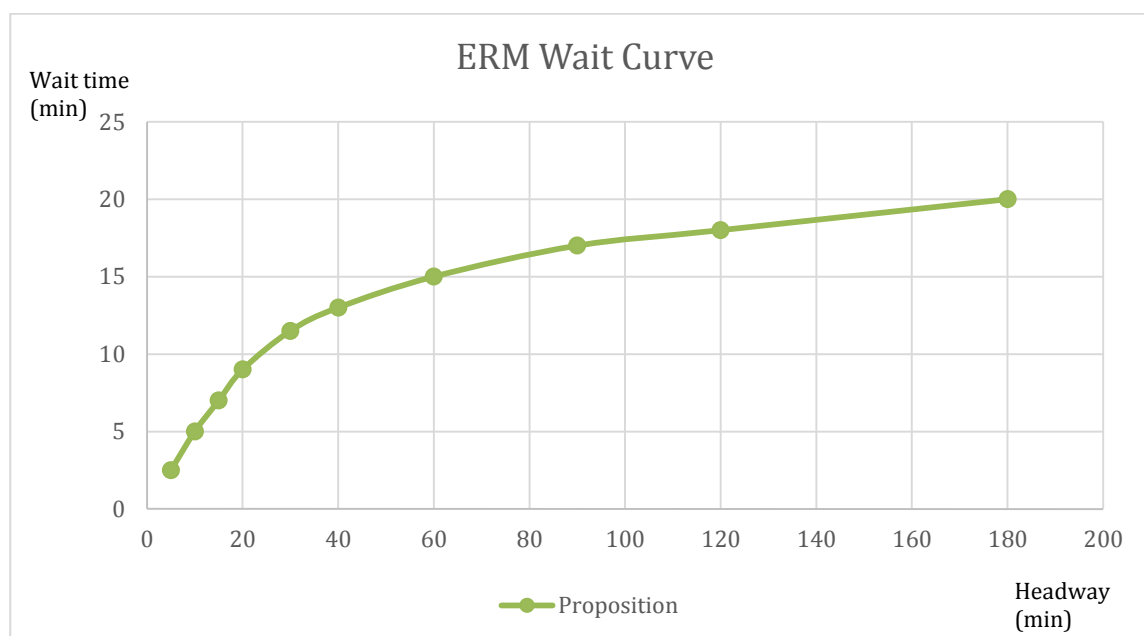


Figure 4.2 Modelled wait curve

#### 4.4.3 Detailed Parameter Audit

At the same time as the Detailed Network Audit described in Section 4.3.4, a detailed audit of parameter values was also conducted. This identified a number of recommendations that were applied, and are summarised in the Table 4.5 below. More details on the In-Vehicle Time factors, Walk and Wait Time Factors, Boarding and Interchange penalties and Load Distribution Factors are given in the following sections.

**Table 4.5 Detailed Parameter Audit Recommendations**

Type	Description
Non-Transit Legs	Revised mode 98 (zone-to-zone) cost: now estimated with 30min + 2x walk time and capped at 10 min walk (i.e. a maximum cost of 50 min)
In-Vehicle Time	Rail IVT set to 1.3 Bus IVT set to 1.5 LUAS IVT set to 1.0
Walk Time Factor	Set to 1.6
Wait Time Factor	Set to 2.0
Boarding Penalty	Set to 10
Interchange Penalty	All Modes to/from DART or Rail = 15 Dublin Bus to Dublin Bus = 15 Other Transfer = 5
Load Distribution Factor	Set to 50% for coaches in the PTM

### ***In vehicle time factors***

In-vehicle time factors are defined for the 5 modes (DART, Other Rail, Luas, Dublin Bus and Other Bus) to represent relative comfort and perception of travel time. The Calibration process started with initial values from BRT stated preference research, which have been refined to improve sub-mode share during model calibration (Table 4.6).

**Table 4.6 In-vehicle time factors – initial and calibrated values**

MODE	STATED PREFERENCE	CALIBRATED ERM
DART	1.39	1.30
OTHER RAIL	1.39	1.30
LUAS	1.00	1.00
DUBLIN BUS	1.90	1.50
OTHER BUS	1.90	1.50

### ***Walk and wait time factors***

Walk time factors represent the discomfort of walking to/ from a transit stop. This value is applied to the total walk time to/ from a transit stop, including walk time on the zone

centroid connector and on the PT network. WebTAG suggests values between 1.5 and 2.0. A walk time factor of 1.6 was calibrated in the ERM model, following stated preference study recommendations. Sensitivity tests were carried out with higher values, however, they did not improve model validation.

Drive time to PT has a higher time factor of 2.0. While driving may be expected to have a lower factor than walking (because of the relative comfort of driving compared to walking and the greater speed at which distances can be covered), the impact of reducing this factor was to increase the number of trips which drive to PT. As aspects such as car availability, and availability of parking at public transport stops, are not taken into account in the drive access to PT, this led to an over-estimation of drive trips to public transport. Therefore, the higher time factor for drive access to PT was retained within the ERM.

Wait time factor represents the discomfort of waiting for a PT service. WebTAG suggests values between 1.5 and 2.5. A mid-range value of 2.0 was used for the ERM and no further sensitivity tests have been undertaken.

### ***Boarding & Interchange penalties***

A time penalty was applied at each initial boarding to reflect the time taken to board on a particular service. Calibration has resulted in a single value of 10 minutes for all modes.

An interchange penalty was also applied to any journey with a transfer between sub-modes. A list of transfers with an interchange penalty is provided in Table 4.7 below. This reflects the transfer cost from one mode to another and the quality of the waiting facilities (information, security etc.). These penalties are also used to balance the PT demand at the sub-mode level by penalising one mode compare to another one.

**Table 4.7 Interchange penalties**

<b>TRANSFER</b>	<b>TIME PENALTY (MIN)</b>
<b>ALL MODES TO OR FROM DART OR RAIL</b>	15
<b>DUBLIN BUS TO DUBLIN BUS</b>	15
<b>OTHER TRANSFER</b>	5

### ***Bus Speed Factors***

As detailed in Section 2.1.1 previously, bus speeds are derived from the assigned road networks. Speed on bus lanes is first equated to uncongested assignment speeds on the road network. Bus speeds where bus lanes do not operate are calculated using the congested speed. During calibration, the congested speed is factored by a link characteristic based factor. Table 4.8 below shows these factors that are applied for all time periods.

Table 4.8 Bus speed factors by link characteristics and by time period

Name	Link Characteristics	All Time Period Factor
<b>FAC1</b>	Motorways	0.95
<b>FAC2</b>	Rural Single	0.90
<b>FAC3</b>	Rural Dual	0.95
<b>FAC4</b>	Urban Dual/Single	0.85
<b>FAC5</b>	Simulation area	0.85
<b>FAC6</b>	Bus Lane	0.95

A minimum bus speed of 5km/h was defined to prevent journey times from increasing excessively where the road network is locally saturated.

To take into account the varying running time of bus services, a TIME FACTOR has also been applied which is dependent on the quality and type of the service. In summary, time factors were calculated for the following category of services:

- **Urban:** Urban Bus services i.e. Dublin Bus
- **Normal:** Non Urban services, non express
- **Express:** Non Urban, express services

These factors were altered in an iterative process to match AVL and GTFS journey time data during validation (see Section 5.5 below for further details). The finalised time factors for the ERM are outlined in Table 4.9 below.

Table 4.9 Time factors by bus service characteristics and by time period

Name	AM	IP1	IP2	PM
<b>Urban</b>	1.14	1.20	1.27	1.22
<b>Normal</b>	1.11	1.14	1.18	1.12
<b>Express</b>	1.06	1.08	1.13	1.07

### ***Load Distribution Factor***

Through testing it was noted that a significant number of buses in the ERM network were experiencing crowding and this was impacting on the level of convergence which could be achieved. An issue was identified with the current regional and private operator bus capacities (outlined in Section 2.5 previously) and the way in which CUBE models crowding.

Within CUBE, the identified crowd curve increases the perceived cost of travel when occupancy on the service is between seated and crush capacity. Within the PT Model, the

seated and crush capacity for single decker coaches are very similar (i.e. Seated Capacity = 52, Crush Capacity = 54). Therefore, no crowding occurs on these services up to a load of 52 passengers and then, with a relatively small increase in demand (i.e. 2 passengers), the full crowding impact is introduced with a 30% increase in perceived travel time. This significant cost increase due a small alteration in demand was impacting on the ability of the crowding model to achieve convergence.

In order to address this issue, it was decided to alter the Load Distribution factor (LOADDISTFAC) in CUBE. This factor essentially controls the point of seat occupancy at which passengers begin to experience an increase in perceived travel time due to crowding. Initially, this value was set to 100% i.e. crowding does not occur until occupancy is above the defined seated capacity. However, in light of testing carried out in the ERM, it was decided that, for single decker coaches, crowding should begin at 50% of the seated capacity. It is assumed that at a 50% occupancy, passengers must start to share seats thus impacting on the level of space available to them for their legs, luggage etc. Therefore, this was deemed a logical value for the Load Distribution Factor for these services. Tests suggested that this updated factor improved the level of convergence achieved within the PT Crowding Model and, as such, was adopted in the ERM.

## 4.5 PT Model Matrix Progression

### 4.5.1 FDM Matrices

The PT assignment matrices are generated by the final calibrated Full Demand Model (FDM) as illustrated in Figure 1.2 previously. The FDM has been through numerous iterations and further details on the development of the ERM FDM, and the process of calibration, are provided in the ERM Full Demand Model Calibration Report and the RM Full Demand Model Development Report.

The development of the ERM PT Model has impacted on the development and calibration of the FDM through the following:

- **Decrease in PT Generalised Costs:** At an early stage of development of the FDM, it was noted that the PT Model was generating significantly high generalised costs which were causing difficulties during calibration of the FDM. To alleviate this issue, a number of tests were carried out in the SWRM to assist in reducing generalised costs leading to a series of network and parameter updates which were adopted across all regional models. Section 4.3.3 and 4.4.2 above, provide details on the various network and parameter changes incorporated in the ERM PT Model to feed more realistic costs into the FDM during calibration;
- **Detailed Model Audit:** As noted in Section 2.3 of the RM Full Demand Model Development Report, version SAVE 14 of the FDM was the first full release version of the model believed to be suitable for use across all the regions without significant error. At this stage, a detailed audit of all elements of the FDM was undertaken including the PT Model. On foot of this audit, a number of network and parameter updates, outlined in Sections 4.3.4 and 4.4.3, were

incorporated into the ERM PT Model. These updates assisted in improving the PT assignment model, and therefore allowed better costs to be fed into the FDM.

- **Iterative Feedback of costs:** As noted previously in Section 1.2, the FDM works on an iterative loop whereby generated matrices are assigned to road, PT and Active networks and associated costs are fed back into mode and destination choice to generate new demand until convergence is reached. At various stages throughout the development and calibration of the ERM FDM, costs were extracted from the PT assignment model. In some cases small network and coding issues were noted and fixed, however, these are not described in detail in this report.

The final PT assignment matrices were generated from Version 2.0.23 of the ERM FDM. As noted previously, for further information on this version of the model, including calibration statistics, the reader is referred to the ERM Full Demand Model Calibration Report.

## 4.5.2 Incremental Matrix

Once the final version of the prior matrices was created, they were passed through a factoring process whereby PT flows were adjusted to match observed count data. This factoring process and the results obtained are described in Section 4.5.3 below.

Once the prior matrices were factored, an incremental matrix was calculated as the combination of the prior matrix plus the difference between the pre and post-matrix factoring assignments. The incremental matrix reflects those parts of the full travel behaviour pattern which cannot be 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;
- a trip made to visit a tourist attraction; or
- the choice of a journey by tram or train rather than bus which is made because the user can read on a tram or a train but would get travel sick if they tried this on a bus.

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 increases the predictive power of the model by adding in a contribution from the more unpredictable parts of the travel demand.

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

- Additive incrementals, where the incremental matrices (whose values may be positive, negative, or both) 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 principle 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).

The final assignment matrices including the incremental adjustments are what the network calibration and validation assessments are based on.

### 4.5.3 PT Factoring

As noted previously, matrix factoring was carried out to provide an improved match between modelled and observed PT flows at strategic count locations. Passenger flow survey data was available for bus, rail and LUAS at two identified cordon locations entering Dublin City, namely the Canal Cordon and Outer Cordon illustrated in Figure 4.3 and Figure 4.4 below.

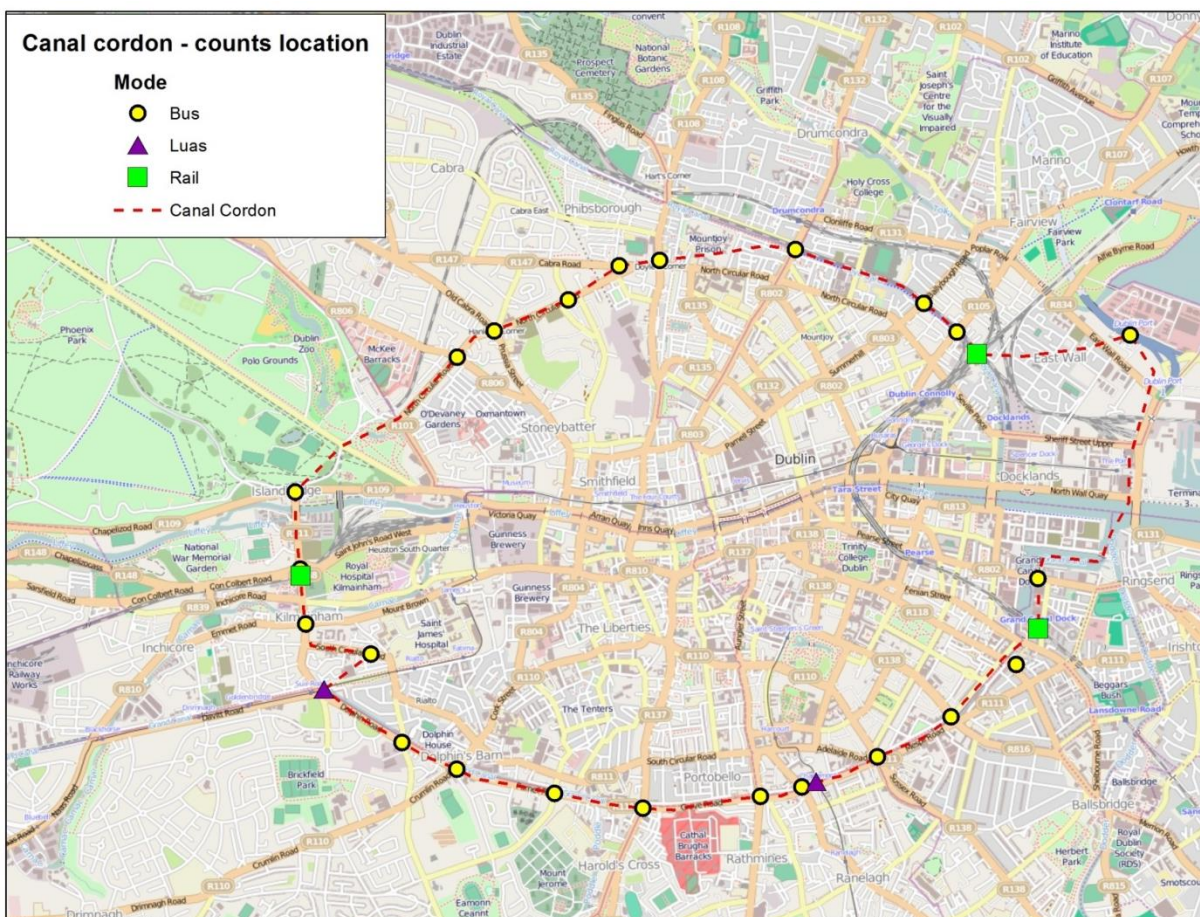
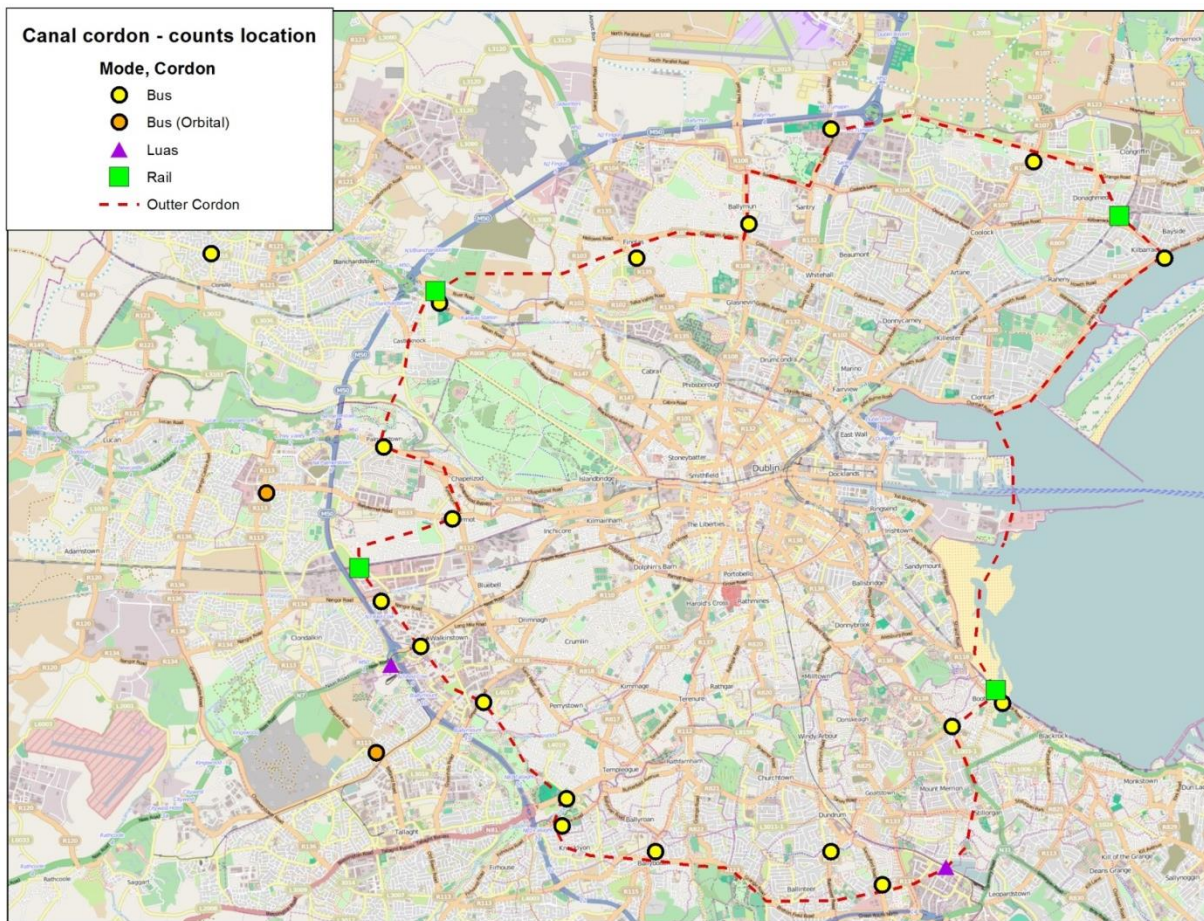


Figure 4.3 Canal Cordon PT Count Locations



**Figure 4.4 Outer Cordon PT Count Locations**

Counts along the identified cordons were grouped into screenlines where observed flows were combined in an inbound and outbound direction. Figure 4.5, overleaf, illustrates the six screenlines created at the canal cordon based on the direction entering the city centre. Select Link analysis was carried out on the assigned PT demand to identify modelled passenger flows crossing the various screenline locations.

A bespoke spreadsheet tool was used to calculate adjustment factors which could be applied to the modelled PT demand to provide a better estimate of passenger flows at a screenline level. These adjustment factors were applied to the ERM PT demand based on a defined sector system which facilitated control over sub-mode choice (Figure 4.6 overleaf). Through Select Link Analysis, it is possible to identify the origin and destination for services that travel via a particular count location. The spreadsheet tool utilised this analysis to apply specific factors to sector to sector movements to better replicate observed flows.

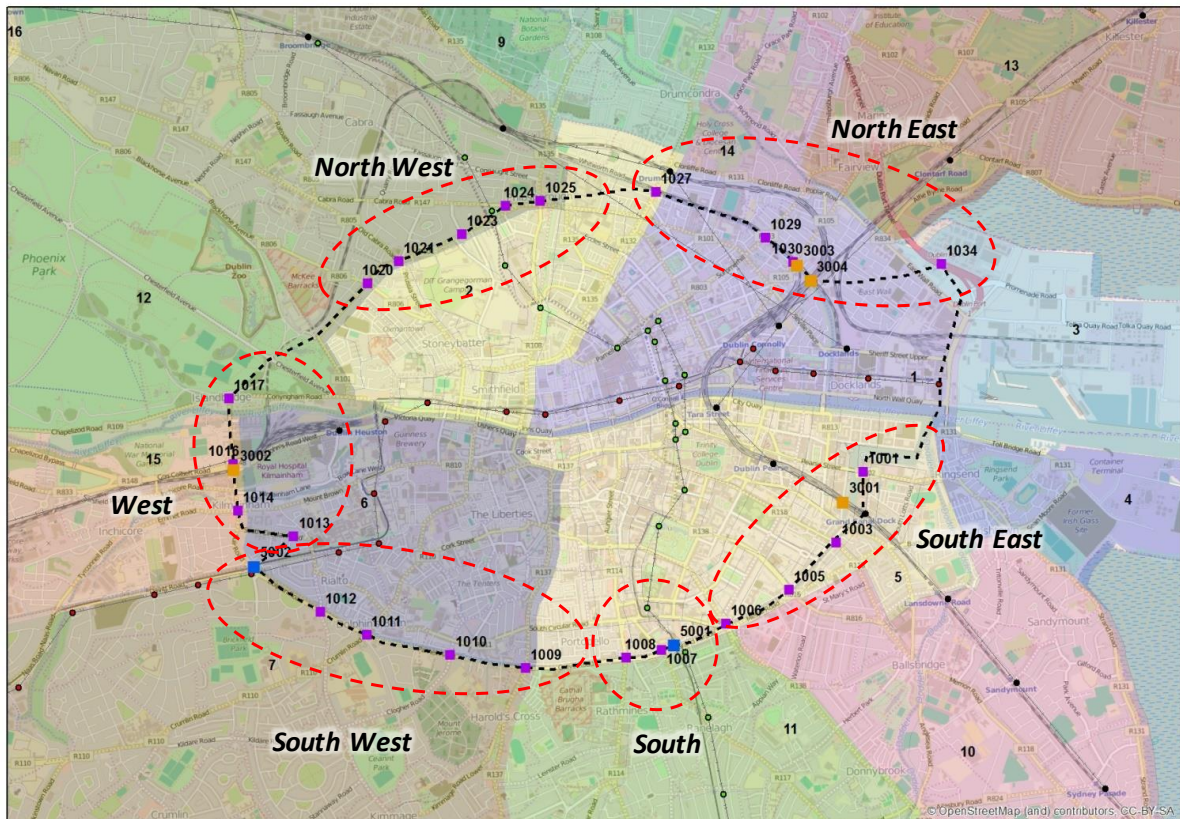


Figure 4.5 Canal Cordon Screenlines

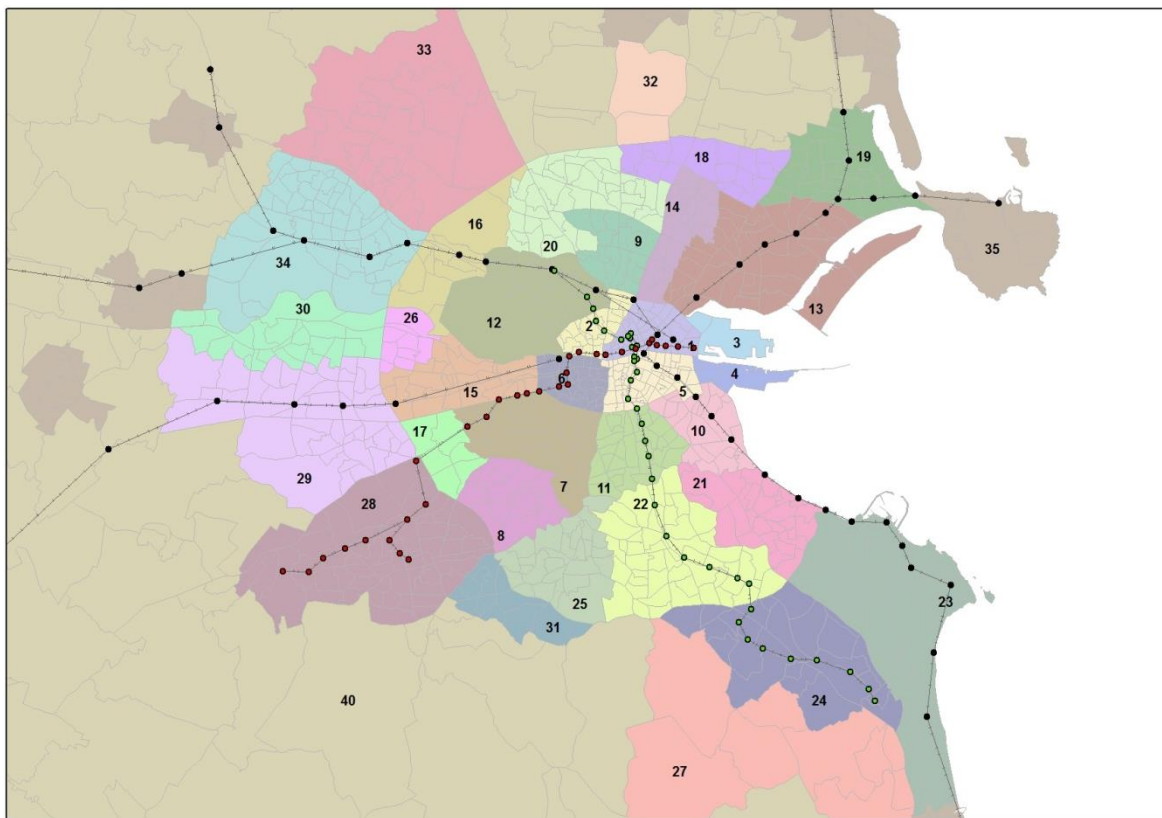
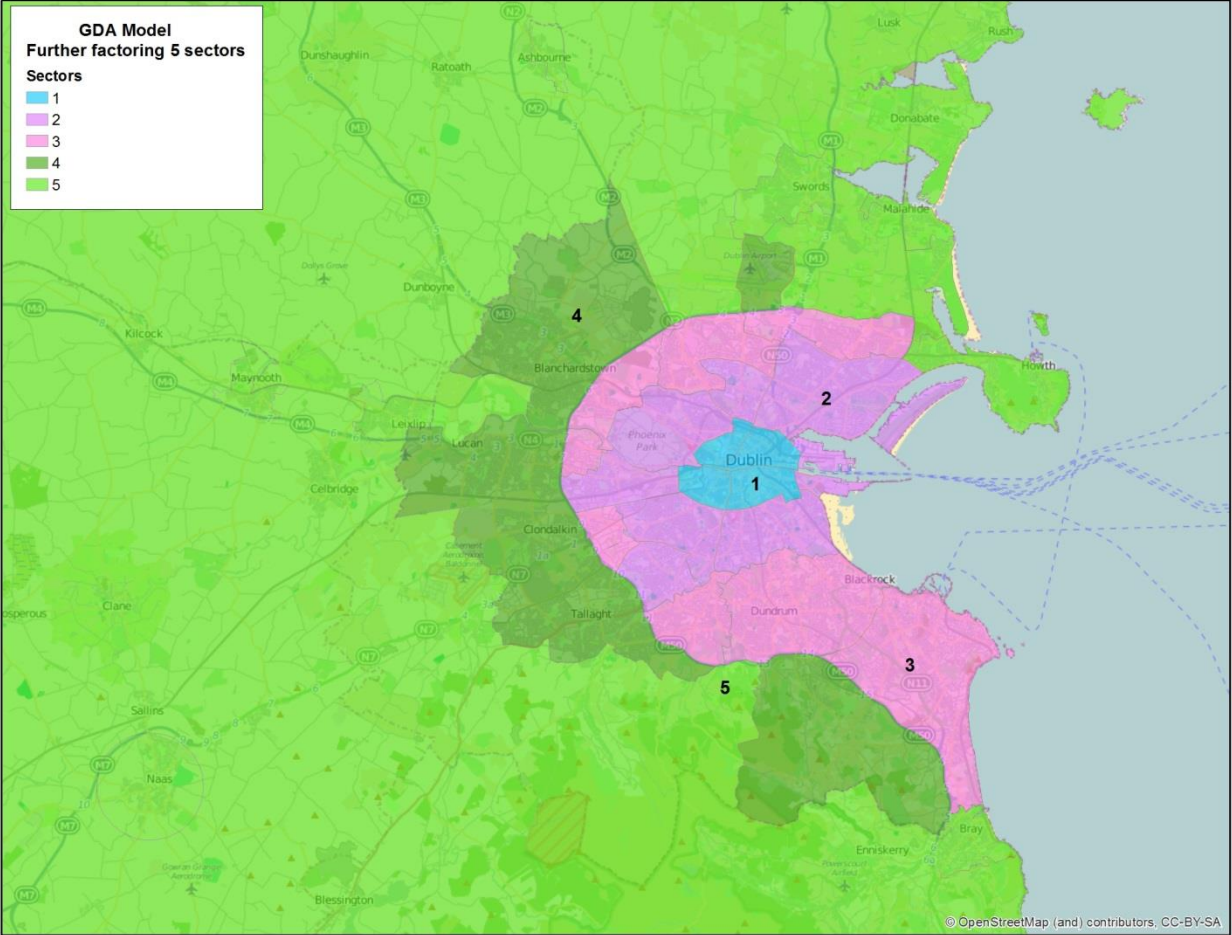


Figure 4.6 ERM Sector System

The spreadsheet tool facilitated manual refinements of factors where necessary, and all adjustment factors were constrained to limit matrix distortion. The PT factoring was run in an iterative process whereby adjusted modelled demand was re-assigned to the network and compared against observed flows until an optimal solution was achieved.

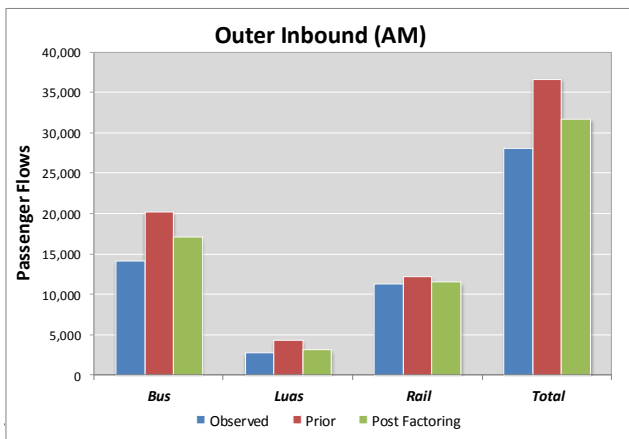


### Figure 4.7 Canal cordon PT screen lines

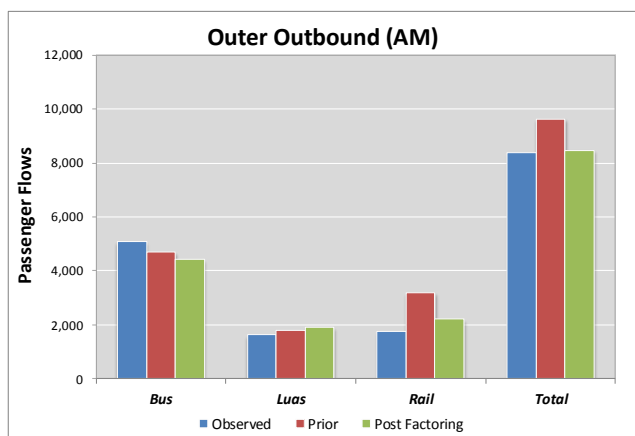
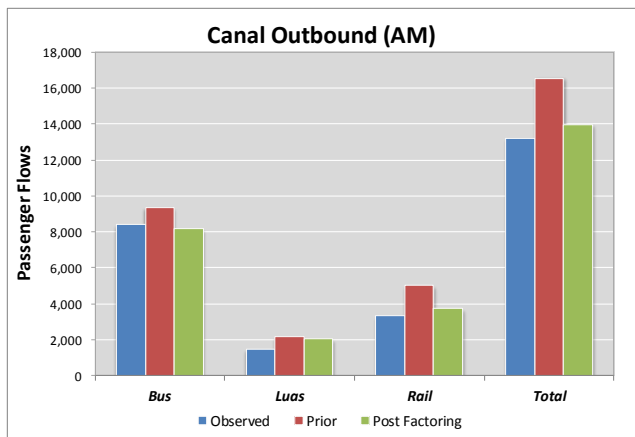
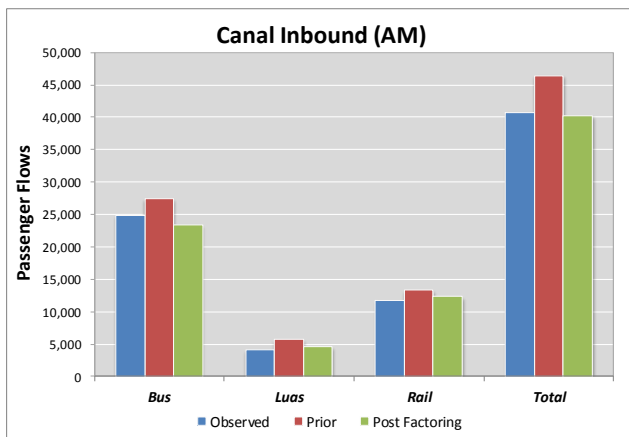
## Results

The factoring process outlined above has been carried out for each of the four time periods modelled. In order to keep this report concise, the results of the factoring are only presented for the AM and PM peak hours. Further details on pre/post factoring flows are provided later in Section 5.4 of this report and Appendix A1 and A2.

Figure 4.8 and



Passenger flows by mode at each of the two cordon (see Figure 4.4 previously) for both the prior and post-factored data.



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## Figure 4.8 Matrix calibration process – Cordon flows - AM peak hour

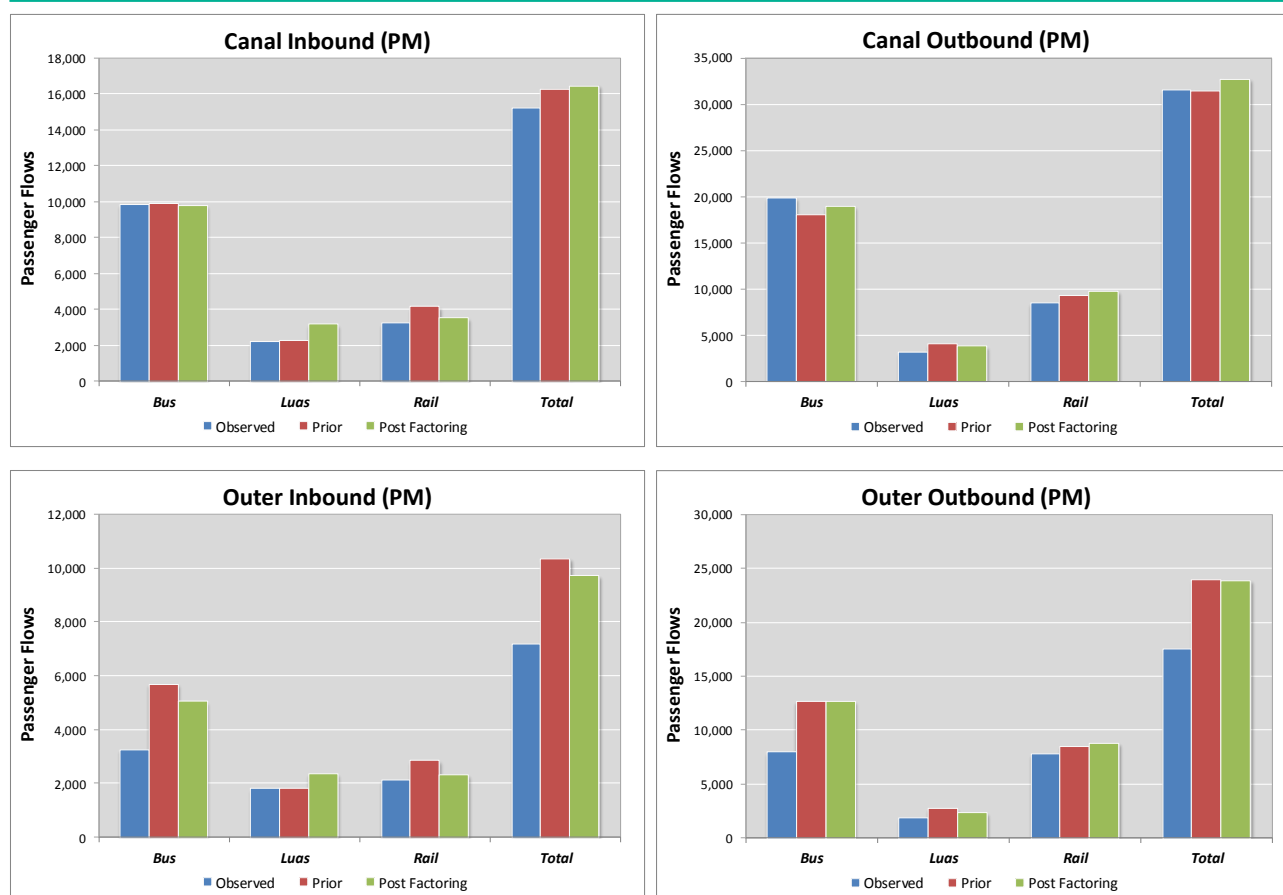


Figure 4.9 Matrix calibration process – Cordon flows - PM peak hour

As outlined on the charts above, the matrix factoring process has improved validation, particularly in the AM peak, by providing a better match of observed and modelled flows than was obtained using the prior matrices.

However, the results show that total boardings in the PM peak remain overestimated. Whilst further factoring could have been undertaken to better match observed flows, cognisance was taken of changes to the demand generated from the FDM, with careful consideration to limit overall matrix distortion. Further results on trip matrix validation post factoring are presented in Section 5.4 of this report.

#### 4.5.4 Sector to Sector Matrix Changes

In the ideal case, the amount of change between the directly output demand matrices and the factored matrices would be small. A comparison of sector to sector movements before and after PT matrix factoring is shown in Figure 4.10 and Figure 4.11, overleaf. While there are some larger differences in individual cells, the overall changes in the trip ends are approximately 3%.



Differences - Sector to sector matrix																																								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	TOTAL	
24%	-3%	-21%	-5%	2%	0%	-13%	-7%	27%	1%	32%	14%	-7%	18%	0%	19%	24%	6%	4%	2%	4%	7%	-21%	-1%	3%	-35%	-2%	-5%	6%	-17%	0%	-16%	-6%	0%	200%	23%	31%	140%	-8%	1%	
4%	51%	-50%	-14%	-2%	-4%	-16%	1%	35%	-7%	25%	7%	-5%	34%	-32%	22%	30%	2%	3%	-1%	5%	5%	-23%	4%	41%	-9%	9%	0%	3%	-13%	14%	-18%	-7%	0%	100%	43%	133%	0%	-12%	1%	
35%	29%	60%	0%	30%	34%	15%	41%	0%	49%	4%	79%	16%	-7%	-9%	9%	88%	37%	15%	52%	42%	48%	-15%	-1%	21%	-10%	-12%	2%	-11%	-12%	-22%	-12%	0%	0%	0%	0%	0%	-14%	5%		
0%	-1%	-14%	37%	12%	7%	-10%	-31%	15%	-1%	32%	-30%	3%	-17%	-33%	10%	13%	5%	-12%	-50%	140%	-12%	-25%	-6%	17%	-31%	-6%	-30%	-10%	200%	-52%	-33%	-20%	0%	0%	-100%	-100%	0%	-10%		
2%	0%	54%	9%	16%	-4%	-13%	-2%	39%	7%	16%	8%	-7%	27%	-2%	21%	38%	9%	6%	8%	7%	2%	-14%	8%	13%	52%	4%	1%	18%	-4%	16%	-8%	1%	-32%	-19%	3%	-60%	-13%	-25%	6%	
4%	1%	48%	15%	0%	26%	-15%	-13%	20%	-3%	12%	21%	-5%	32%	-13%	25%	24%	3%	5%	2%	5%	6%	-20%	2%	-2%	-17%	0%	2%	-4%	-26%	2%	-11%	-8%	0%	67%	-27%	50%	-100%	-28%	0%	
-13%	-11%	-8%	-6%	-19%	-13%	20%	3%	7%	-8%	23%	10%	1%	26%	-10%	29%	25%	-3%	-11%	4%	7%	-4%	-14%	-3%	-8%	6%	9%	-7%	-23%	-23%	-12%	-13%	-18%	0%	0%	25%	-100%	-100%	-41%	-2%	
-6%	-5%	8%	7%	-6%	-16%	1%	18%	14%	-3%	17%	10%	9%	42%	100%	41%	23%	6%	5%	42%	0%	16%	-6%	0%	0%	-15%	3%	11%	-14%	-50%	45%	-60%	-8%	0%	300%	0%	0%	-83%	-2%		
14%	30%	-100%	26%	11%	11%	21%	33%	5%	3%	50%	19%	-6%	30%	-31%	24%	8%	14%	18%	14%	25%	27%	-6%	4%	11%	15%	-16%	-12%	19%	7%	13%	-16%	-4%	-100%	-100%	167%	300%	100%	-15%	7%	
6%	2%	18%	15%	8%	5%	1%	7%	26%	7%	18%	-2%	-1%	19%	9%	19%	37%	5%	0%	10%	5%	-7%	-17%	5%	-3%	2%	-2%	-14%	-12%	19%	-4%	-31%	-11%	-50%	0%	-20%	-40%	-25%	-36%	-2%	
9%	5%	13%	19%	-6%	-11%	7%	3%	33%	-12%	34%	-9%	-12%	17%	-14%	21%	26%	-8%	-3%	14%	8%	-4%	-28%	-2%	10%	10%	-6%	-7%	-3%	-17%	-3%	-26%	-11%	0%	0%	-11%	-29%	29%	-12%	-3%	
14%	10%	63%	-11%	9%	23%	17%	15%	24%	-6%	42%	9%	-2%	-11%	17%	-8%	7%	-4%	-24%	9%	34%	15%	1%	9%	32%	21%	-4%	-11%	64%	-26%	8%	0%	-1%	0%	73%	-100%	-17%	-14%	6%		
-24%	-29%	-11%	-6%	-33%	-22%	6%	-2%	-6%	-12%	-6%	4%	28%	0%	-2%	-7%	-22%	-13%	-20%	-23%	13%	-30%	-24%	5%	0%	4%	-1%	-11%	-31%	-9%	-31%	22%	-21%	0%	0%	0%	0%	-38%	-18%		
10%	14%	19%	38%	6%	4%	-1%	6%	32%	-7%	8%	1%	17%	33%	-100%	-33%	-2%	-5%	-7%	0%	12%	40%	-4%	6%	0%	-3%	-9%	-2%	-38%	-25%	3%	-100%	-16%	0%	-100%	-75%	120%	75%	-11%	3%	
-7%	1%	-75%	10%	-8%	-6%	-2%	0%	13%	2%	18%	34%	6%	86%	55%	20%	32%	-10%	14%	0%	-22%	6%	-6%	-40%	-14%	-50%	0%	0%	-9%	-25%	0%	-17%	-43%	-28%	0%	0%	0%	0%	-60%	-14%	
15%	20%	4%	6%	18%	25%	9%	1%	24%	3%	45%	-7%	18%	16%	-4%	26%	1%	2%	-17%	10%	46%	18%	-6%	10%	-22%	16%	-4%	-8%	70%	91%	20%	-67%	1%	0%	-100%	0%	-100%	0%	-25%	10%	
11%	18%	18%	-6%	11%	7%	4%	14%	9%	0%	33%	4%	-3%	-5%	-13%	15%	31%	-5%	-8%	-4%	54%	2%	-17%	-9%	18%	17%	-13%	-14%	-11%	-33%	3%	200%	-11%	0%	0%	40%	0%	0%	-28%	6%	
10%	16%	13%	-1%	14%	19%	9%	5%	21%	-1%	35%	4%	18%	30%	4%	27%	49%	12%	1%	12%	53%	9%	-15%	37%	-5%	-15%	19%	-3%	-7%	3%	7%	-12%	1%	60%	13%	16%	-50%	29%	3%	8%	
4%	6%	-27%	6%	3%	7%	2%	-1%	28%	3%	31%	-18%	-1%	7%	-8%	2%	25%	6%	4%	4%	-3%	-2%	-28%	-8%	-3%	-2%	-7%	-12%	-3%	31%	-16%	-10%	-14%	-8%	20%	-100%	-100%	-50%	1%		
2%	8%	14%	-29%	6%	-2%	12%	62%	0%	9%	15%	16%	19%	0%	67%	38%	28%	15%	14%	58%	0%	-14%	-14%	-18%	-13%	7%	19%	-7%	17%	150%	-37%	200%	-3%	-100%	0%	33%	0%	0%	-75%	8%	
-42%	-44%	33%	-13%	-46%	-43%	-5%	-15%	8%	-23%	-6%	-24%	10%	-4%	36%	-34%	11%	-21%	-37%	-10%	54%	-67%	-50%	12%	-33%	-12%	-4%	-11%	-69%	-4%	-42%	33%	-21%	0%	0%	-100%	0%	0%	-14%	-29%	
12%	14%	-17%	13%	0%	14%	-6%	-8%	22%	-15%	38%	-5%	-13%	50%	4%	19%	42%	3%	0%	-21%	33%	37%	-12%	0%	-36%	-25%	30%	-19%	-50%	0%	133%	0%	-2%	-33%	33%	5%	0%	0%	0%		
-40%	-39%	-33%	-34%	-35%	-35%	-22%	-11%	-27%	-28%	-30%	-19%	-36%	1%	-38%	-5%	-16%	-21%	-25%	-16%	-23%	-9%	8%	-5%	-6%	-40%	-15%	-17%	-28%	0%	-19%	-61%	-21%	0%	-50%	-36%	-100%	-100%	-62%	-25%	
-32%	-33%	-22%	-11%	-35%	-27%	-1%	4%	-10%	-25%	3%	-18%	11%	16%	2%	-13%	-8%	-9%	-24%	-28%	30%	-48%	2%	16%	-4%	17%	14%	-5%	-21%	0%	-9%	-75%	-25%	200%	100%	-27%	133%	0%	-22%	-19%	
-9%	-1%	9%	-86%	2%	-21%	-7%	6%	7%	4%	31%	-11%	-21%	-83%	150%	12%	-7%	1%	19%	-13%	13%	20%	-10%	2%	52%	-83%	0%	-56%	-100%	0%	17%	0%	-5%	0%	0%	33%	-100%	0%	0%	0%	
40%	10%	275%	-32%	124%	114%	70%	-24%	-1%	49%	25%	-1%	16%	-31%	100%	-4%	-4%	86%	33%	104%	4%	-8%	-25%	19%	-16%	51%	-10%	10%	-17%	-15%	-5%	-14%	-15%	0%	0%	0%	0%	0%	-77%	4%	
-1%	4%	-16%	14%	-4%	-8%	-7%	-9%	-1%	-14%	-3%	-10%	1%	-2%	-20%	-3%	11%	-5%	-12%	23%	-1%	32%	-15%	7%	21%	-11%	21%	-4%	-8%	-33%	2%	8%	1%	-100%	0%	-6%	1%	28%	-3%	-2%	
-15%	-13%	-8%	-25%	-13%	-25%	-23%	-30%	-5%	-19%	1%	-14%	-10%	-2%	-19%	-11%	-12%	-6%	-7%	-23%	1%	-4%	-23%	5%	-15%	3%	2%	-1%	-12%	46%	0%	-5%	-2%	50%	167%	-6%	4%	-52%	2%	-9%	
-20%	-15%	-30%	26%	-11%	-26%	-35%	0%	28%	-20%	9%	-19%	-13%	-13%	-7%	-32%	53%	-12%	-28%	-8%	-15%	3%	-39%	-2%	-17%	-19%	3%	-12%	8%	9%	0%	0%	-3%	0%	0%	0%	-17%	50%	0%	44%	-8%
-28%	-20%	-20%	50%	-31%	-38%	-42%	20%	-30%	-38%	-22%	-19%	-4%	-13%	-80%	5%	-37%	-34%	-23%	-38%	-3%	0%	-65%	-24%	0%	-20%	300%	-3%	-5%	1%	-4%	0%	0%	0%	0%	0%	0%	0%	0%	-3%	
-23%	-14%	-13%	-51%	-16%	-33%	-48%	-13%	-1%	-1%	-27%	4%	-7%	-22%	0%	-36%	-6%	3%	-27%	-35%	-16%	-14%	13%	-21%	-3%	40%	-20%	1%	-7%	-1%	-5%	8%	8%	-2%	0%	0%	0%	40%	17%	7%	-7%
-27%	-23%	-13%	-43%	-23%	-36%	-51%	-43%	-6%	-31%	5%	-23%	-24%	40%	-22%	-29%	-22%	-29%	-29%	-20%	-36%	-100%	-61%	6%	0%	-50%	39%	-9%	-1%	1%	-1%	29%	-2%	0%	0%	0%	0%	0%	0%	-7%	
-23%	-20%	-27%	-22%	19%	-32%	-34%	-13%	0%	-26%	-6%	-15%	-20%	-1%	-37%	-8%	-6%	-21%	-19%	-20%	-4%	-4%	-30%	-6%	-9%	-19%	5%	-5%	-1%	-2%	-1%	-3%	1%	-100%	0%	-5%	-2%	6%	3%	-10%	
-50%	0%	0%	0%	-10%	0%	0%	0%	0%	-20%	0%	0%	0%	0%	0%	-100%	0%	0%	0%	-100%	-14%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-100%	32%	0%	0%	0%	0%	0%	0%	0%
0%	0%	0%	0%	-15%	20%	0%	-100%	-50%	-11%	200%	0%	0%	0%	0%	-100%	0%	0%	0%	23%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-50%	0%	62%	0%	0%	0%	0%	-1%
56%	17%	-100%	50%	22%	50%	55%	0%	200%	-8%	100%	35%	-75%	400%	0%	140%	33%	4%	-14%	23%	100%	-1%	-14%	64%	0%	400%	55%	-10%	-67%	0%	0%	-12%	0%	0%	79%	0%	0%	0%	10%		
-38%	0%	-100%	200%	17%	-67%	0%	0%	0%	17%	0%	25%	-100%	0%	-100%	-100%	20%	-25%	-50%	-100%	0%	-100%	0%	0%	-100%	0%	-100%	10%	-10%	0%	0%	0%	-7%	0%	0%	11%	0%	27%	-1%		
-45%	-7%	-50%	0%	-24%	-83%	0%	0%	-33%	-29%	-23%	67%	0%	-29%	0%	0%	-25%	-17%	0%	0%	0%	0%	0%	0%	0%	-100%	0%	-100%	7%	0%	0%	0%	0%	4%	0%	0%	0%	55%	-21%	-7%	
-9%	-20%	40%	-13%	-30%	-38%	-33%	-25%	15%	-37%	-5%	-14%	-24%	-6%	25%	57%	-17%	-7%	-10%	200%	-22%	-60%	-42%	-2%	0%	-46%	3%	3%	-40%	0%	-2%	-100%	-3%	0%	0%	6%	-20%	19%	-12%		
-5%	-7%	-5%	-8%	-5%	-14%	-8%	-1%	12%	-6%	13%	2%	-6%	15%	-21%	13%	18%	2%	-1%	7%	10%	3%	-15%	4%	5%	-7%	2%	-4%	0%	-1%	1%	-3%	-4%	-3%	8%	5%	0%	5%	-9%	-3%	

Figure 4.11 24 hour PT matrix sector % changes with factoring

### 4.5.5 R<sup>2</sup> Analysis

Regression statistics (Slopes, Intercepts and R<sup>2</sup> values) have been calculated to monitor the changes made to the PT matrices during factoring. TAG Unit M3-1, Section 8, Table 5 outlines criteria for each of these statistics at both a zonal cell and trip-end level (Table 4.10).

**Table 4.10 Significance of Matrix Estimation Changes**

Measure	Significance Criteria
Matrix zonal cell value	Slope within 0.98 and 1.02; Intercept near zero; R <sup>2</sup> in excess of 0.95.
Matrix zonal trip ends	Slope within 0.99 and 1.01; Intercept near zero; R <sup>2</sup> in excess of 0.98.

### AM

Table 4.11 details the AM peak R<sup>2</sup> statistics at the zonal cell level for each individual PT User Class.

**Table 4.11 AM Matrix Change R<sup>2</sup> Analysis – Matrix Zonal Cell Values**

User Class	Cell R <sup>2</sup> Value	Cell Slope	Cell Y-Int
TAG Criteria	> 0.95	0.98 - 1.02	Near 0
Employers Business	0.402	0.506	0.029
Commute	0.820	0.829	0.015
Other	0.967	0.905	0.002
Education	0.943	0.956	-0.004
Retired	0.311	-0.644	0.100

Only the 'Other' user class meets the recommended R<sup>2</sup> criteria, whilst all five user classes fail to meet the slope criteria. The slope and R<sup>2</sup> values fall well outside the acceptable range for the Employers Business and Retired user classes, however, they only represent approximately 5% of the overall AM PT demand.

Trip end analysis was also undertaken for each user class and the results are summarised in Table 4.12.

Table 4.12 AM Matrix Change R2 Analysis – Matrix Zonal Trip Ends

User Class	Trip End R <sup>2</sup> Value	Trip End Slope	Trip End Y-Int
TAG Criteria	> 0.98	0.99 - 1.01	Near 0
<b>Employers Business</b>	0.962	0.916	0.057
<b>Commute</b>	0.985	0.911	0.121
<b>Other</b>	0.974	0.850	0.984
<b>Education</b>	0.995	0.907	0.317
<b>Retired</b>	0.956	0.864	0.041

Both the Commute and Education user classes (representing approx. 66% of AM PT demand) meet the recommended criteria for R<sup>2</sup> with all other user classes narrowly falling outside the acceptable range. None of the user classes meet the recommended Trip End slope guidelines. Values for the y-intercept, with a TAG recommended criteria of near zero, are between 0.041 and 0.984.

## LT

Table 4.13 details the LT peak R<sup>2</sup> statistics at the zonal cell level for each individual PT User Class.

Table 4.13 LT Matrix Change R2 Analysis – Matrix Zonal Cell Values

User Class	Cell R <sup>2</sup> Value	Cell Slope	Cell Y-Int
TAG Criteria	> 0.95	0.98 - 1.02	Near 0
<b>Employers Business</b>	0.056	0.504	0.030
<b>Commute</b>	0.019	-0.153	0.075
<b>Other</b>	0.725	0.912	0.003
<b>Education</b>	0.628	0.892	0.014
<b>Retired</b>	0.199	-0.520	0.095

None of the five user classes meet the recommended R<sup>2</sup> or slope criteria in the LT time period. The slope and R<sup>2</sup> values fall well outside the acceptable range for the Employers Business, Commute and Retired user classes, however, they represent less than 30% of the overall LT PT demand. Some matrix cell movements within the LT PT demand are very small, and as such, adjustments to these can lead to large changes in terms of R<sup>2</sup> and slope.

Trip end analysis was also undertaken for each user class and the results are summarised in Table 4.14Table 4.12.

Table 4.14 LT Matrix Change R2 Analysis – Matrix Zonal Trip Ends

User Class	Trip End R <sup>2</sup> Value	Trip End Slope	Trip End Y-Int
TAG Criteria	> 0.98	0.99 - 1.01	Near 0
Employers Business	0.871	0.947	0.011
Commute	0.961	0.835	0.108
Other	0.926	0.873	0.567
Education	0.975	1.052	-0.002
Retired	0.962	0.865	0.053

All five user classes narrowly fall outside the acceptable range for both R<sup>2</sup> and Trip End Slope. Values for the y-intercept, with a TAG recommended criteria of near zero, are between -0.002 and 0.567.

## SR

Table 4.15 details the SR peak R<sup>2</sup> statistics at the zonal cell level for each individual PT User Class.

Table 4.15 SR Matrix Change R2 Analysis – Matrix Zonal Cell Values

User Class	Cell R <sup>2</sup> Value	Cell Slope	Cell Y-Int
TAG Criteria	> 0.95	0.98 - 1.02	Near 0
Employers Business	0.171	0.474	0.035
Commute	0.090	0.344	0.054
Other	0.757	0.982	0.001
Education	0.771	0.903	0.015
Retired	0.488	-0.868	0.110

None of the five user classes meet the recommended R<sup>2</sup> in the SR time period. The 'Other' user class meets the slope criteria with all other user classes falling outside the acceptable range. The slope and R<sup>2</sup> values fall well outside the acceptable range for the Employers Business, Commute and Retired user classes, however, they represent less than 25% of the overall SR PT demand. Some matrix cell movements within the SR PT demand are very small, and as such, adjustments to these can lead to large changes in terms of R<sup>2</sup> and slope.

Trip end analysis was also undertaken for each user class and the results are summarised in Table 4.16Table 4.12.

Table 4.16 SR Matrix Change R2 Analysis – Matrix Zonal Trip Ends

User Class	Trip End R <sup>2</sup> Value	Trip End Slope	Trip End Y-Int
TAG Criteria	> 0.98	0.99 - 1.01	Near 0
<b>Employers Business</b>	0.942	1.084	-0.026
<b>Commute</b>	0.986	1.107	-0.098
<b>Other</b>	0.938	1.012	-0.186
<b>Education</b>	0.993	1.055	-0.031
<b>Retired</b>	0.913	0.928	0.007

Both the Commute and Education user classes (representing approx. 41% of SR PT demand) meet the recommended criteria for R<sup>2</sup> with all other user classes narrowly falling outside the acceptable range. None of the user classes meet the recommended Trip End slope guidelines. Values for the y-intercept, with a TAG recommended criteria of near zero, are between -0.186 and 0.007.

## PM

Table 4.17 details the PM peak R<sup>2</sup> statistics at the zonal cell level for each individual PT User Class.

Table 4.17 PM Matrix Change R2 Analysis – Matrix Zonal Cell Values

User Class	Cell R <sup>2</sup> Value	Cell Slope	Cell Y-Int
TAG Criteria	> 0.95	0.98 - 1.02	Near 0
<b>Employers Business</b>	0.105	0.461	0.031
<b>Commute</b>	0.805	0.854	0.027
<b>Other</b>	0.736	0.921	0.010
<b>Education</b>	0.923	0.984	0.005
<b>Retired</b>	0.375	-0.719	0.101

None of the five user classes meet the recommended R<sup>2</sup> criteria whilst only the Education user class meets the slope criteria. The Employers Business and Retired user classes fall well outside the acceptable range, however, they represent less than 7% of the overall PM PT demand.

Trip end analysis was also undertaken for each user class and the results are summarised in Table 4.18.

Table 4.18 PM Matrix Change R2 Analysis – Matrix Zonal Trip Ends

User Class	Trip End R <sup>2</sup> Value	Trip End Slope	Trip End Y-Int
TAG Criteria	> 0.98	0.99 - 1.01	Near 0
<b>Employers</b>	0.920	0.989	-0.032
<b>Business</b>			
<b>Commute</b>	0.969	1.020	0.390
<b>Other</b>	0.962	0.959	0.681
<b>Education</b>	0.990	0.984	0.231
<b>Retired</b>	0.957	0.929	0.021

The R<sup>2</sup> value passes the TAG criteria for the Education user class only. None of five user class meet the recommended Trip End Slope criteria, all narrowly falling outside the acceptable range. Values for the y-intercept, with a TAG recommended criteria of near zero, are between -0.032 and 0.681.

## 4.6 Summary

The calibration process has involved three different but interlinked processes which have been adjusted in accordance with the hierarchy outlined in WebTAG:

- The PT Network has been reviewed and adjustments made to zone centroid connectors, costs, loading points, as well as to the coding of PT services;
- PT model parameters (in-vehicle time factors, walk and wait time coefficients, interchange penalties) have been adjusted to obtain better costs and achieve a better match between modelled flows with observed data; and
- PT demand has been calibrated through a sector based factoring process to enhance the quality of the matrices. Factors calculated by the comparison with observed data have been applied to the ODs within each sector increasing/decreasing the total number of trips in the attempt of representing more realistically the public transport demand.

## 5 PT Model Validation

### 5.1 Introduction

PT Model validation is a key step to ensure confidence that the calibrated model gives an accurate representation of observed Public Transport trips. This section outlines the observed data sources used in the PT Model validation and shows the comparisons with model outputs as a measure of how well the calibrated PT Model validates.

### 5.2 Assignment Validation Process

#### 5.2.1 Overview

The assignment calibration process was undertaken for the assignment of the ERM PT Model and matrices through comparisons of the following:

- Passenger Flows;
- Bus Journey Times;
- Boardings and Alightings;
- Line Profiles; and
- Interchanges.

#### 5.2.2 Validation Criteria

TAG unit M3-2 identifies four kinds of check for the validation of a PT assignment model:

- Validation of the trip matrix;
- Network validation;
- Service validation; and
- Assignment validation.

Table 5.1 outlines the trip matrix validation criteria, as set out in TAG Unit M3-2, Section 7.1.2:

**Table 5.1 PT Assignment Model Trip Matrix Validation Criteria**

Criteria	Acceptability Guideline
<b><i>Differences between modelled flows and counts across screenlines should be less than 15% of the counts</i></b>	95% of cases

TAG Unit M3-2, Section 7.1.3 sets out that validation of the network should include checks on:

- The geometry of the network (including the location of PT stops, access points); and
- Times/ speeds in the model (including, in-vehicle time, access and interchange times).

TAG Unit M3-2, Section 7.1.4 sets out that validation of the services should include checks on:

- Modelled versus observed number of PT vehicles; and
- Other service features, including stopping patterns for rail.

Table 5.2 outlines the PT assignment validation criteria as set out in TAG Unit M3-2, Section 7.1.5 and 7.1.6:

**Table 5.2 PT Assignment Validation Criteria**

Criteria	Acceptability Guideline
<b><i>Differences between modelled flows and counts by PT sub-mode across all screenlines (in total)</i></b>	Difference less than 15%
<b><i>Differences between modelled flows and counts on individual links should be less than 25% of the counts (unless observed flows are less than 150 passengers per hour)</i></b>	All links

In addition, checks should be made on passengers boarding and alighting in urban centres.

Guidance from the 2003 Modélisation des Déplacements Urbains de Voyageurs published by CERTU provides transfer ratio (total boardings over total trips) ranges based on the population of the modelled city (Table 5.3 below):

**Table 5.3 CERTU Guide 2003 – Transfer ratio range**

City Population	Transfer Ratio 2000	Transfer Ratio 1995
>300,000	1.05 to 1.65	1.05 to 1.55
100,000 to 300,000	1.02 to 1.33	1.1 to 1.34
<100,000	1.0 to 1.33	1.0 to 1.44

## 5.3 Observed data

Observed data has been collected from a number of different surveys undertaken on different dates, and has been processed to build a single database to define observed flows to use in the model validation. The following data sources have been used:

- Luas: 2012 survey

- Rail: Irish Rail 2013 survey
- Bus: different sources (see Table 5.4 below)

Table 5.4 Bus observed flows data sources

Screen line	Time Period	Data source		Comments
		Dublin Bus	Other Bus	
Canal Inbound	AM	Dublin Bus survey 2011	Dublin Bus survey 2011	2014 DublinBus survey doesn't include private bus
Canal Inbound	LT / SR	Dublin Bus survey 2014	NDC survey 2015	
Canal Inbound	PM	NDC survey 2015 (partial)	NDC survey 2015	Missing counts synthetized
Canal Outbound	AM	Dublin Bus survey 2011	Dublin Bus survey 2011	2014 DublinBus survey doesn't include private bus
Canal Outbound	LT /SR	Dublin Bus survey 2014	NDC survey 2015	
Canal Outbound	PM	Dublin Bus survey 2014	NDC survey 2015	
Outer Inbound	AM	Dublin Bus survey 2011	Dublin Bus survey 2011	2014 NDC outer counts 40% higher than 2011 counts
Outer Inbound	LT / SR	NDC survey 2014	NDC survey 2014	
Outer Inbound	PM	NDC survey 2014	NDC survey 2014	
Outer Outbound	AM	Dublin Bus survey 2011	Dublin Bus survey 2011	2014 NDC outer counts 40% higher than 2011 counts
Outer Outbound	LT/SR	NDC survey 2014	NDC survey 2014	
Outer Outbound	PM	NDC survey 2014	NDC survey 2014	

## 5.4 PT Trip Matrix Validation

Table 5.5 below summarises at the screenline level observed flows, modelled flows before factoring and modelled flows after the factoring process, by time period (further information on the factoring methodology is provided in Section 4.5.3 previously). More details on flows by sub-mode and by location are available in Appendix A1 and A2.

The results in Table 5.5 indicate that, with the exception of the SR and PM Outer cordons, all screenline flows are within +/- 15% observed flows validation criterion.

Table 5.5 Passenger flow validation summary table

Time Period	Cordon	Observed	Before Factoring			After Factoring		
			Modelled	Diff.	%Diff.	Modelled	Diff.	%Diff.
AM	Canal Inbound	40,671	46,424	+5,753	+14%	40,264	-407	-1%
AM	Canal Outbound	13,189	16,535	+3,346	+25%	13,973	+784	+6%
AM	Outer Inbound	28,169	36,713	+8,544	+30%	31,751	+3,582	+13%
AM	Outer Outbound	8,357	9,601	+1,244	+15%	8,458	+101	+1%
LT	Canal Inbound	12,110	12,128	+18	+0%	11,158	-952	-8%
LT	Canal Outbound	6,586	7,734	+1,148	+17%	6,457	-129	-2%
LT	Outer Inbound	8,070	9,304	+1,234	+15%	7,684	-386	-5%
LT	Outer Outbound	4,572	5,464	+892	+20%	4,509	-63	-1%
SR	Canal Inbound	10,083	11,442	+1,359	+13%	11,116	+1,033	+10%
SR	Canal Outbound	11,635	12,035	+400	+3%	12,872	+1,237	+11%
SR	Outer Inbound	5,059	7,938	+2,879	+57%	6,466	+1,407	+28%
SR	Outer Outbound	7,370	9,474	+2,104	+29%	9,574	+2,204	+30%
PM	Canal Inbound	15,251	16,300	+1,049	+7%	16,469	+1,218	+8%
PM	Canal Outbound	31,520	31,455	-65	-0%	32,633	+1,113	+4%
PM	Outer Inbound	7,178	10,350	+3,172	+44%	9,723	+2,545	+35%
PM	Outer Outbound	17,542	23,937	+6,395	+36%	23,859	+6,317	+36%

## 5.5 PT Network Validation

### 5.5.1 Observed data

Data to validate bus journey times produced by the PT Model came from two different sources: Automatic Vehicle Location (AVL) data and General Transit Feed Specification (GTFS) data.

AVL data, dated from November 2012, contains average journey time between stops for each hour of the day on 17 different routes, distributed across the network (see Figure 5.1 below).

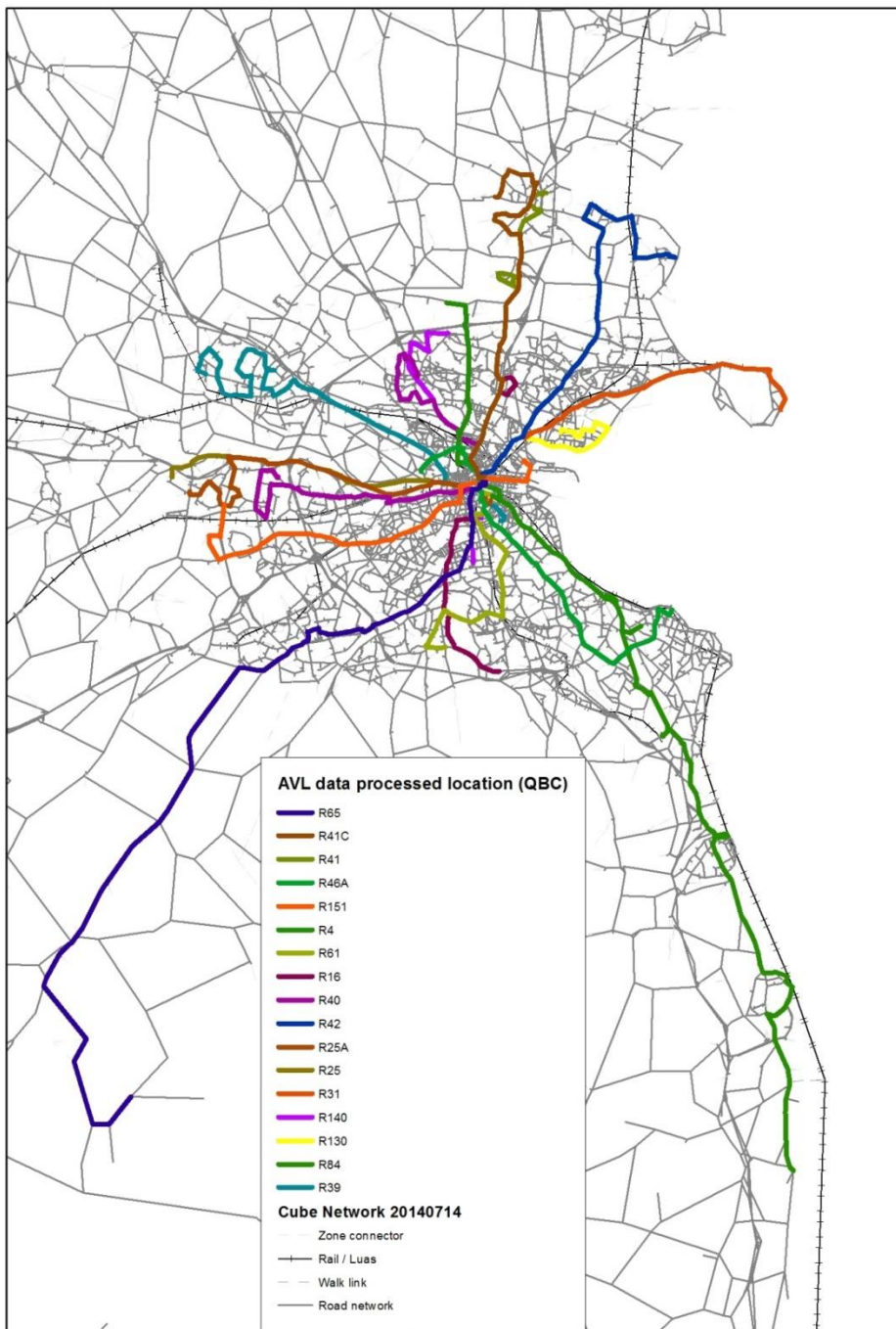


Figure 5.1 AVL data routes used in Journey Time validation

As the AVL data has only been processed for a limited number of bus lines, GTFS timetables are also used to check other bus lines' journey times. GTFS timetables are not observed data but planned journey times for each service.

### 5.5.2 Model validation – AVL data

A total of 69 services modelled journey times are compared against AVL data. Two indicators have been extracted, the ratio of services faster/slower than AVL data and the proportion of services within a relative range of observed journey times.

The first indicator summarised in Table 5.6 below measures the balance between services modelled too fast and services modelled too slowly. The objective is to have half of the services on each side of the balance. Results for the ERM model are provided in the table below, which shows that modelled services are slightly faster than observed data in all time periods.

**Table 5.6 Service classification by journey time comparison to AVL data and by time period**

	AM	LT	SR	PM
<b>Model faster than observed AVL data</b>	53 (77%)	48 (70%)	50 (72%)	57 (83%)
<b>Model within +/-10min of the observed AVL data</b>	46 (67%)	43 (62%)	41 (59%)	36 (52%)
<b>Model slower than observed AVL data</b>	16 (23%)	21 (30%)	19 (28%)	12 (17%)
<b>Average Journey Time difference</b>	-17%	-17%	-16%	-20%

The second indicator contains two levels of validation, based on the absolute relative difference between modelled and observed: less than 15% and less than 25%. Table 5.7 provides a summary of these figures for the four time periods.

The results indicate that more than 70% of the modelled journey times are within +/- 25% the observed journey times for the AM, LT and SR time periods with this value dropping to 57% in the PM peak.

Table 5.7 Journey Time validation against AVL data – Summary table

Criteria		AM	LT	SR	PM
<15%	Bus services	35	28	31	29
	%	51%	41%	45%	42%
<25%	Bus services	50	48	50	39
	%	72%	70%	72%	57%
Total		69	69	69	69

AVL journey time detailed validation tables are available in Appendix B.

The figure below is a scatter plot that represents modelled and AVL observed data for the 69 services across the four time periods. It shows a good spread of services on each side of the line  $y=x$  which means a good balance between services modelled too slow and services modelled too fast.

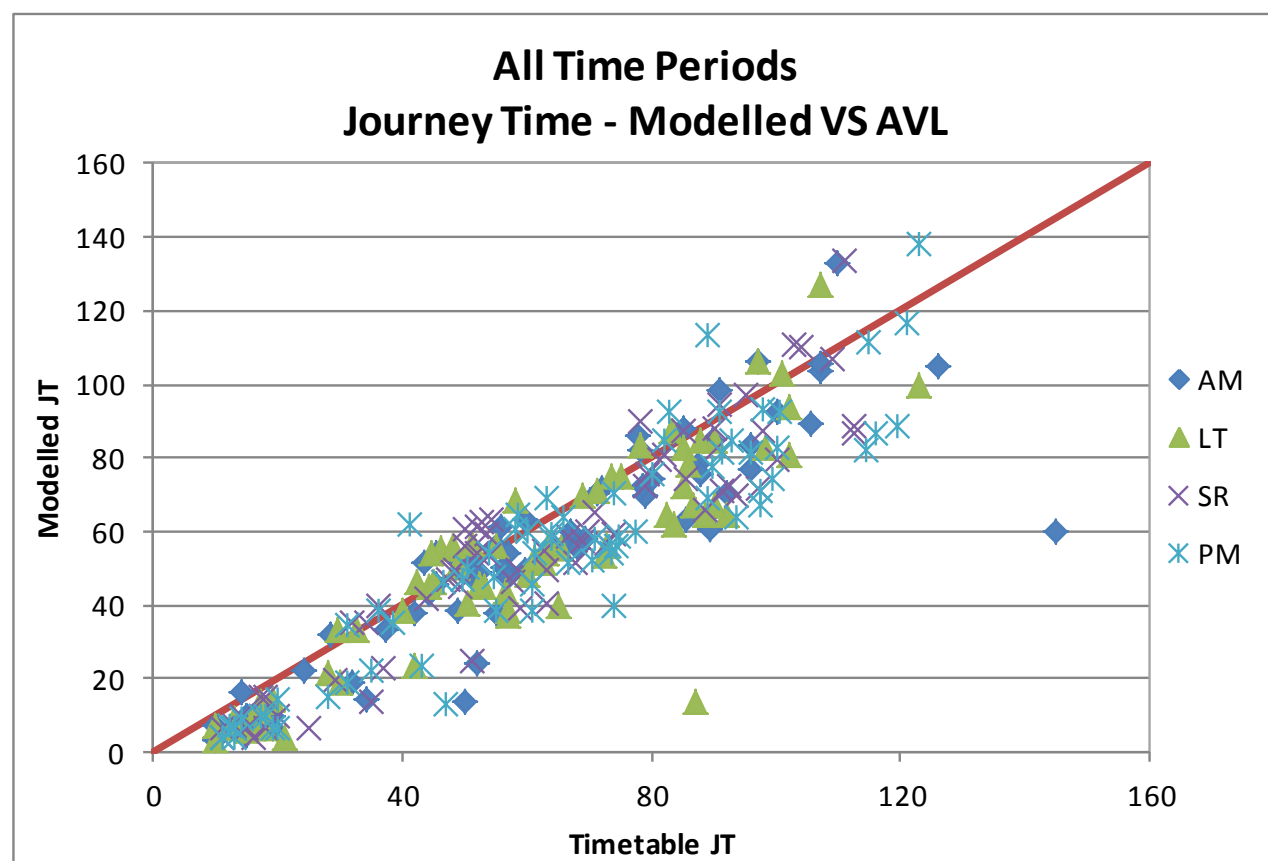


Figure 5.2 Bus times scatter plot – AVL Data

### 5.5.3 Model validation – GTFS data

The same indicators as for AVL data are produced with GTFS data in the tables below. The Journey Time validation process has focussed more on matching the observed AVL data rather than the GTFS data. This is due to the fact that GTFS data is not observed data but planned journey times for each service and does not take into account network delays, etc. Modelled journey times are expected to be slower than the timetabled GTFS data due to the impact of congestion.

**Table 5.8 Service classification by journey time comparison to GTFS data and by time period**

	AM	LT	SR	PM
<b>Model faster than observed AVL data</b>	214 (47%)	194 (51%)	214 (51%)	199 (47%)
<b>Model within +/- 10min of the observed AVL data</b>	297 (65%)	278 (73%)	292 (70%)	290 (69%)
<b>Model slower than observed AVL data</b>	240 (53%)	188 (49%)	205 (49%)	220 53%)
<b>Average Journey Time difference</b>	+2%	+2%	+1%	+2%

**Table 5.9 Journey Time validation against GTFS data – Summary table**

Criteria		AM	LT	SR	PM
<b>&lt;15%</b>	Bus services	269	249	261	268
	%	59%	65%	62%	64%
<b>&lt;25%</b>	Bus services	354	306	338	334
	%	78%	80%	81%	80%
Total		454	382	419	419

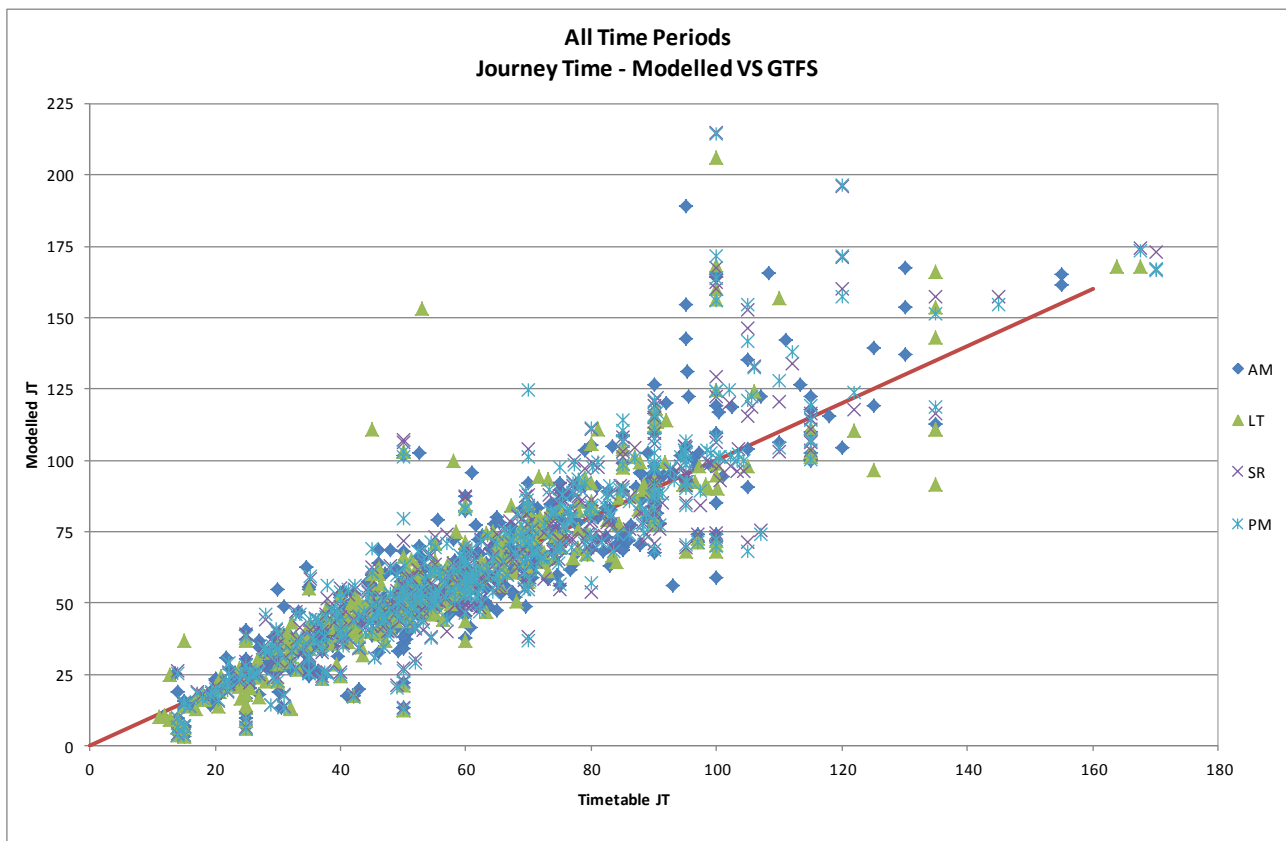


Figure 5.3 Bus times scatter plot – GTFS Data

## 5.6 PT Assignment Validation - Boarding and Alighting

### 5.6.1 Observed data

Boarding and alighting data was available for Luas and Rail from surveys carried out in 2012, and the 2013 Rail Census. As observed Bus passenger flow data partially includes boarding and alighting, a different source has been used for this validation i.e. Dublin Bus boarding by ticket type, stage and time band on a single day (Wednesday 14<sup>th</sup> May 2014).

Both Luas and Rail data sources have been processed at the station level and clustered by sector to facilitate the analysis. Observed Bus boarding data has also been processed at the sector level. As this data source represents a single day, checks against annual data<sup>6</sup> have been made to ensure reliability of the single day values. The annual boardings and annualisation factors for LUAS, Rail and Dublin Bus were as follows:

- Luas: 103,000 boarding (annual 29.32M – ratio of 280);
- Rail: 120,000 boarding (annual 36.74M – ratio of 306); and

<sup>6</sup> source: NTA statistical bulletin June 2014

- Dublin Bus: 365,000 boarding (annual 112.49M – ratio of 308).

## 5.6.2 Model validation

Observed and modelled boarding and alighting are summarised by time period in the tables below. In the AM and PM periods the model overestimates boardings (AM: +17% and PM: +14%), while underestimating in the LT and SR periods (LT: -12% and SR: -8%). Alighting in the model is overestimated in all periods apart from LT where it is very close to the observed data.

More details on boarding and alighting by location, sector and time period are provided in Appendix C.

**Table 5.10 Boarding and alighting validation by mode – AM time period**

Mode		Observed	Modelled	Diff.	% Diff.
<b>Rail</b>	Board	16,869	21,311	4,442	26%
	Alight	17,636	21,591	3,955	22%
<b>Luas</b>	Board	11,651	11,869	218	2%
	Alight	11,413	11,868	456	4%
<b>Bus</b>	Board	39,463	46,609	7,147	18%
	Alight	No data	N/A	N/A	N/A
<b>All modes</b>	Board	67,983	79,789	11,806	17%
	Alight	29,049	33,460	4,411	15%

Table 5.11 Boarding and alighting validation by mode – LT time period

Mode		Observed	Modelled	Diff.	% Diff.
Rail	Board	3,388	4,433	1,045	31%
	Alight	3,830	4,482	652	17%
Luas	Board	4,820	4,142	-678	-14%
	Alight	4,775	4,142	-633	-13%
Bus	Board	17,739	14,153	-3,586	-20%
	Alight	No data	N/A	N/A	N/A
All modes	Board	25,946	22,728	-3,218	-12%
	Alight	8,605	8,624	19	0%

Table 5.12 Boarding and alighting validation by mode – SR time period

Mode		Observed	Modelled	Diff.	% Diff.
Rail	Board	4,541	6,287	1,746	38%
	Alight	3,975	6,112	2,137	54%
Luas	Board	6,039	5,777	-263	-4%
	Alight	5,889	5,777	-112	-2%
Bus	Board	24,118	19,806	-4,312	-18%
	Alight	No data	N/A	N/A	N/A
All modes	Board	34,698	31,869	-2,829	-8%
	Alight	9,864	11,889	2,025	21%

Table 5.13 Boarding and alighting validation by mode – PM time period

Mode		Observed	Modelled	Diff.	% Diff.
Rail	Board	13,584	15,669	2,085	15%
	Alight	12,751	15,430	2,679	21%
Luas	Board	11,687	11,702	15	0%
	Alight	11,759	11,702	-57	-0%
Bus	Board	32,271	38,419	6,148	19%
	Alight	No data	N/A	N/A	N/A
All modes	Board	57,541	65,790	8,249	14%
	Alight	24,510	27,132	2,622	11%

## 5.7 PT Assignment Validation - Line profiles

### 5.7.1 Observed data

A representation of boarding, alighting and passenger flows on a single graph provides a useful validation tool and allows the modeller to spot local issues at stations. Both Luas lines (Green and Red) and the Dart are considered in this analysis and observed data has been extracted from the following sources:

- Luas: 2012 survey; and
- Rail: Irish Rail 2013 survey.

### 5.7.2 Model validation

Line profile charts have been extracted for three lines, in both directions over the four time periods – and all 24 charts are shown in Appendix D. In order to keep this report concise, only AM peak directions are shown below.

#### ***Luas Green line Northbound***

Figure 5.4 below represents the Luas Green line Northbound in the AM peak period. The modelled line profile is slightly below the line from the observed data, but follows a similar shape. The gap between the two curves is mainly due to an underestimation of boarding at Stillorgan and Sandyford stations, and an overestimation at The Gallops and Glencairn.

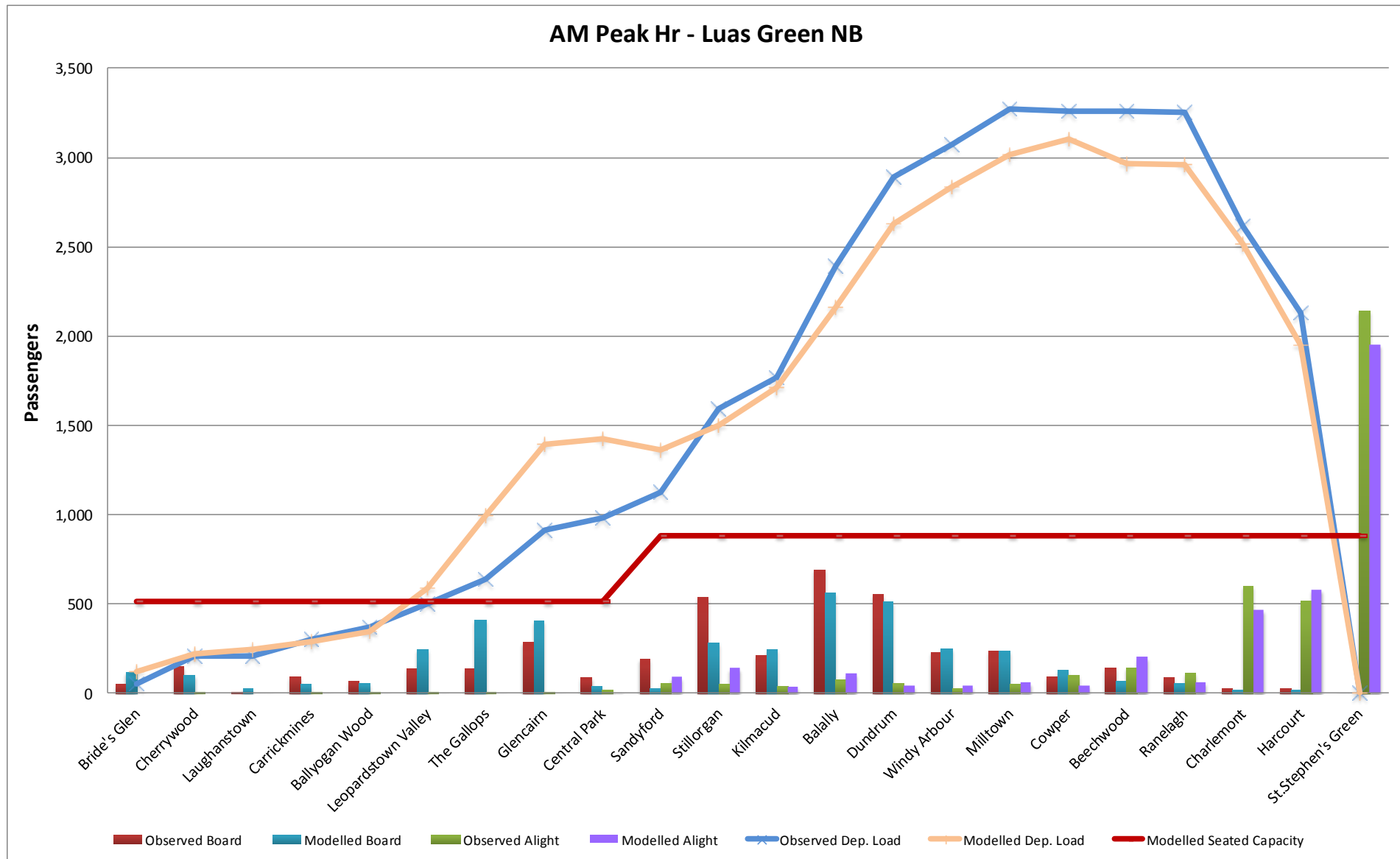


Figure 5.4 Luas Green line profile – Northbound – AM peak

## Luas Red Line Eastbound

Figure 5.5 below illustrates the line profile for the Luas Red Line travelling towards the city centre in the AM peak period. The results indicate that the modelled profile follows a similar trend to the observed with an overestimation of passenger flows, mainly between the Red Cow and Fatima stations.

At key stations such as Hueston, Bus Áras and the Red Cow, modelled boardings and alightings are very close to observed values. The other key stations identified in Figure 5.5 are Jervis and Abbey Street. The model underestimates alightings at Jervis and provides an overestimate at Abbey Street. However, the combined total number of people modelled as boarding and alighting at these city centre stops is very close to observed data.

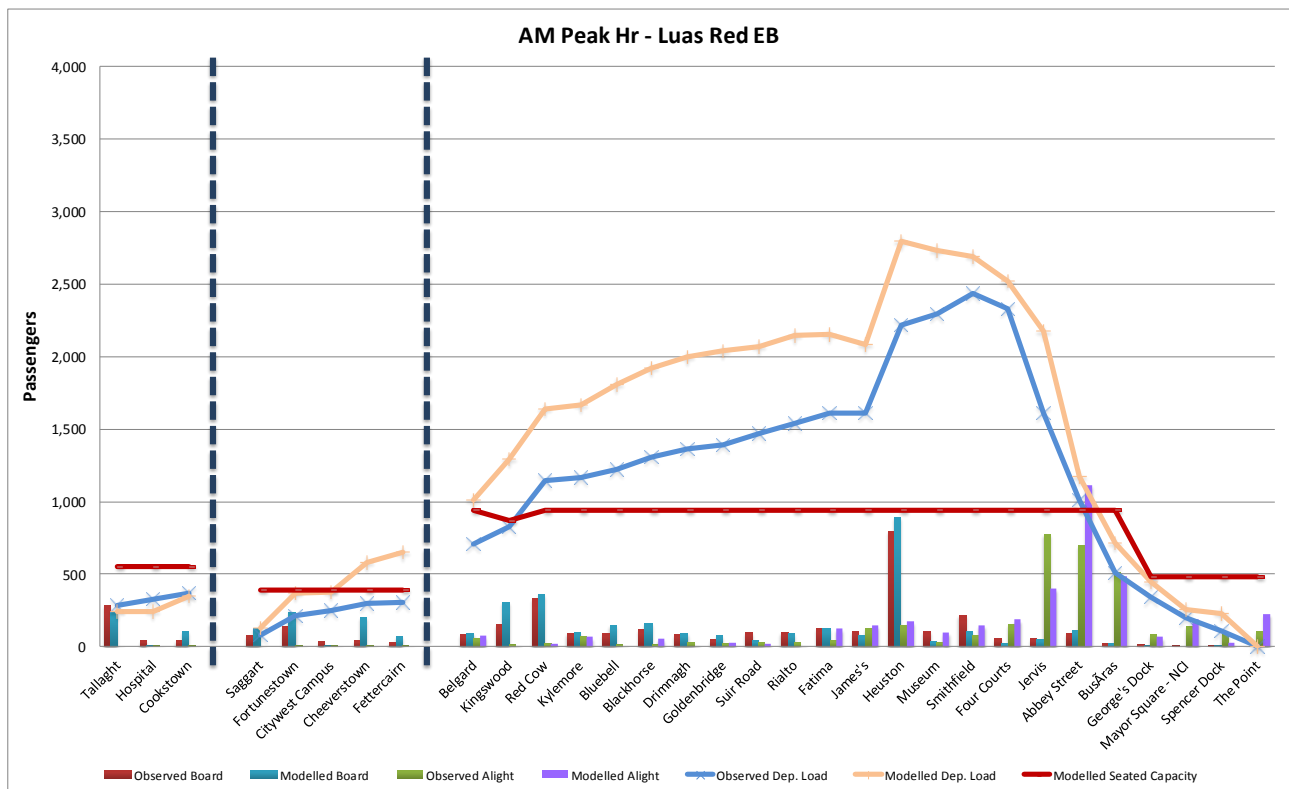


Figure 5.5 Luas Red line profile – Eastbound – AM peak

## DART Northbound

Figure 5.6, overleaf, displays the modelled and observed line profiles for the DART service travelling northbound from Greystones to the City Centre and Malahide. The results indicate that the modelled profile is quite similar to the observed trend with the main differences due to an overestimation of boarding at Bray and an underestimation of alighting at Lansdowne Road station.

Figure 5.6 indicates that the model represents an incorrect balance of flows between Pearse and Tara Street stations, with too many passengers alighting at Tara Street when

compared to observed data. However, the combined total number of people modelled as boarding and alighting at these city centre stops is very close to observed data.

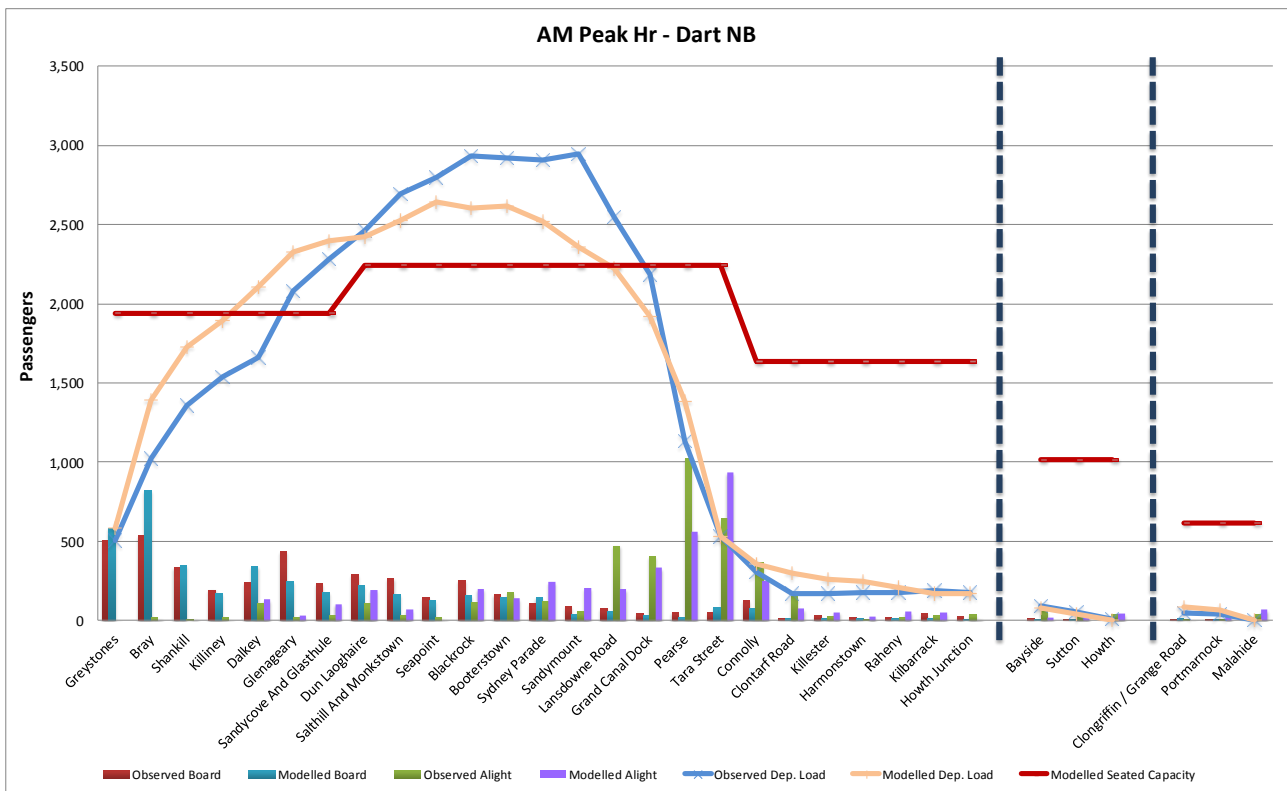


Figure 5.6 DART line profile – Northbound – AM peak

### ***DART Southbound***

Figure 5.7 below illustrates the modelled and observed line profiles for the DART service travelling southbound from Malahide in the AM Peak hour. Similar to the other services, the modelled line profile follows a similar trend to the observed with peak passenger loads experienced at Killester and Clontarf Road stations.

The model overestimates passenger demand with approximately 1,500 additional passengers modelled at Killester station. This is due to an overestimation of passenger boardings at Kilbarrack, Raheny, Harmonstown and Killester.

The results in Figure 5.7 indicate that the model provides a good representation boarding and alighting at Connolly station with an incorrect balance of flows at Tara Street and Pearse Stations i.e. too many passengers alighting at Tara Street and too few at Pearse when compared to modelled data.

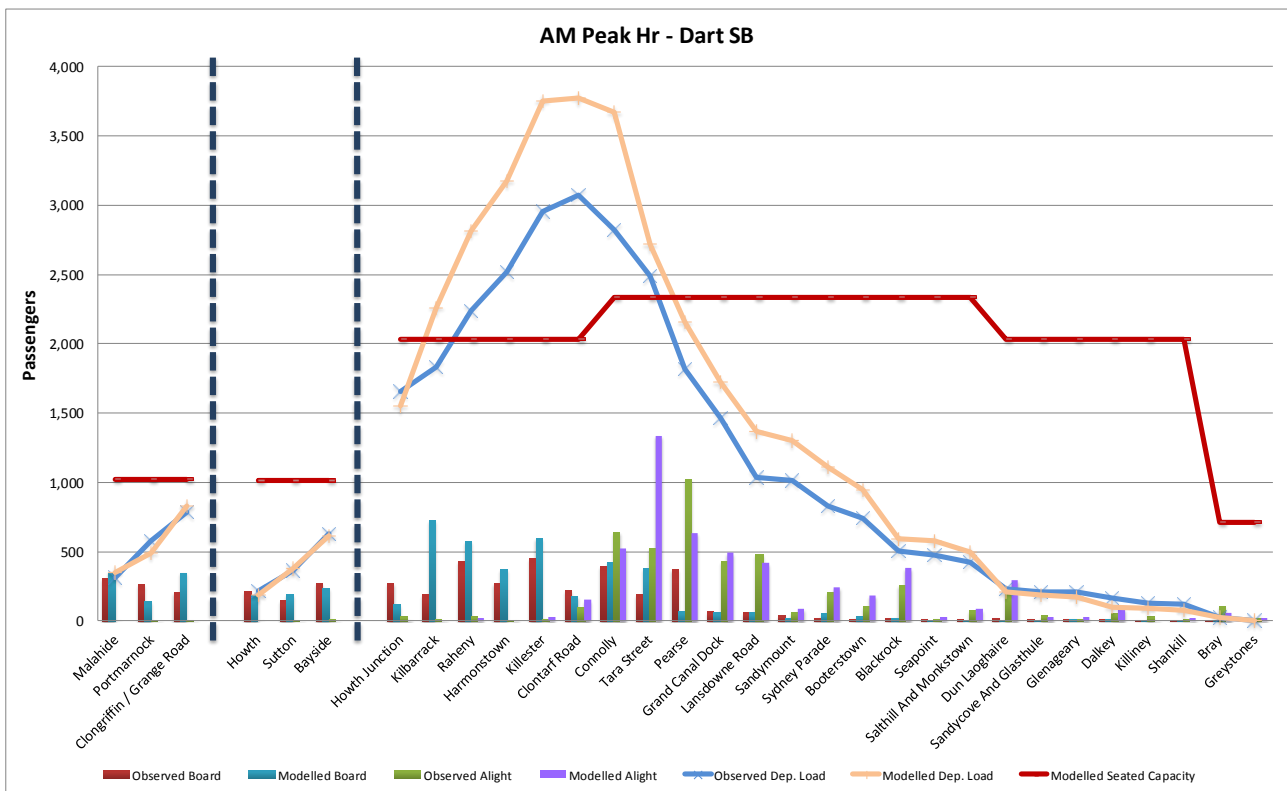


Figure 5.7 DART line profile – Southbound – AM peak

## 5.8 Interchange

### 5.8.1 Observed Data

French transport modelling guidance (2003 Modélisation des Déplacements Urbains de Voyageurs – CERTU) has been used to validate interchange in the ERM PT Model. The French guidance gives transfer ratio (total boardings over total trips) ranges based on the population of the modelled city (see Table 5.3 previously).

### 5.8.2 Model Validation

ERM PT Model transfer ratio by time period is within guideline ranges provided in Table 5.3 for a city of Dublin's size (as shown in Table 5.14 below). The relatively low transfer ratio for the ERM could be explained by a bus dominant PT network that requires less transfer than a light/heavy rail dominant PT network.

Table 5.14 Overall PT transfer ratio by time period

	AM	LT	SR	PM
<b>Total Trips</b>	80,778	23,257	33,840	63,505
<b>Intrazonal</b>	4,600	1,567	2,350	1,607
<b>Trips Assigned</b>	76,178	21,690	31,490	61,898
<b>Total Boarding</b>	94,328	28,015	39,093	78,196
<b>Transfer Ratio</b>	1.24	1.29	1.24	1.26

## 6 Conclusion and Recommendations

### 6.1 Summary

This report has described the development, calibration and validation of the Public Transport Assignment Model component of the Eastern Regional Model. This section summarises the key points of the model development, the strength and weakness of the model revealed by the validation process and a set of recommendations for further enhancements.

### 6.2 Model Development – Key points

As the PT network is the aggregation of different networks (road, rail, Luas, walking), a node convention and a link convention have been defined to facilitate output analysis and provide a framework for any additional network coding.

Bus network speeds are derived from road network congested speed. Factors based on link characteristics have been calibrated to represent relative bus speed to car speed on different road types. Bus speeds on bus lanes are defined as car speed on an uncongested network (or low flow assignment), to take account of traffic light delays.

All PT lines files are automatically derived from General Transit Feed Specification data, using a bespoke process developed for this model.

Fares are included in the PT assignment model. Separate fare models have been built by operator, based on ticketing data, to calculate average fare by user class.

### 6.3 Model Validation

Modelled flows for the two cordon screenlines (canal cordon and outer cordon) are within the acceptance criterion ( $\pm 15\%$ ) for the AM period. Canal cordon modelled flows validate against the acceptance criterion for LT, SR and PM periods. However, the Outer Cordon flows are overestimated in the SR and PM time periods.

Modelled bus journey time calibration is reasonably good when compared to actual AVL data with the majority of routes modelled within  $\pm 10$  minutes of observed journey times with a good balance between services which are too slow and too fast. The results indicate that more than 70% of the modelled journey times are within  $\pm 25\%$  of observed for the AM, LT and SR time periods with this value dropping to 57% in the PM peak

In the AM and PM periods the model overestimates boardings (AM: +17% and PM: +14%), while underestimating in the LT and SR periods (LT: -12% and SR: -8%). Alighting in the model is overestimated in all periods apart from LT where it is very close to the observed data.

Modelled line profiles correspond reasonably well with observed data line profiles. The main differences between the model and observed data are due to under or over estimation at a limited number of stations.

The interchange ratio is within the recommended thresholds for a city of Dublin's size.

## 6.4 Recommendations

Following the development and the calibration/validation of the ERM PT Model, some areas have been identified where potential improvements could be made.

### 6.4.1 Analysis of Crowding

Cube Voyager software does not allow direct visualisation of crowding. Discussions with the Citilabs development team are on-going to allow further analysis.

### 6.4.2 Accessibility for Rural Areas

The motorised access mode for PT (mode 96) tends to create long drive access legs. This can also have an impact on sub-mode choice, particularly in more rural areas of the model. Re-analysing the motorised access parameters may allow this to be improved.

### 6.4.3 Additional Surveys

Further actions to improve both the calibration and validation processes should be considered. This could include a more extensive PT survey process to collect more information on bus, rail and Luas flows at various locations across the entire day and revenue information to calibrate the fares models.



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