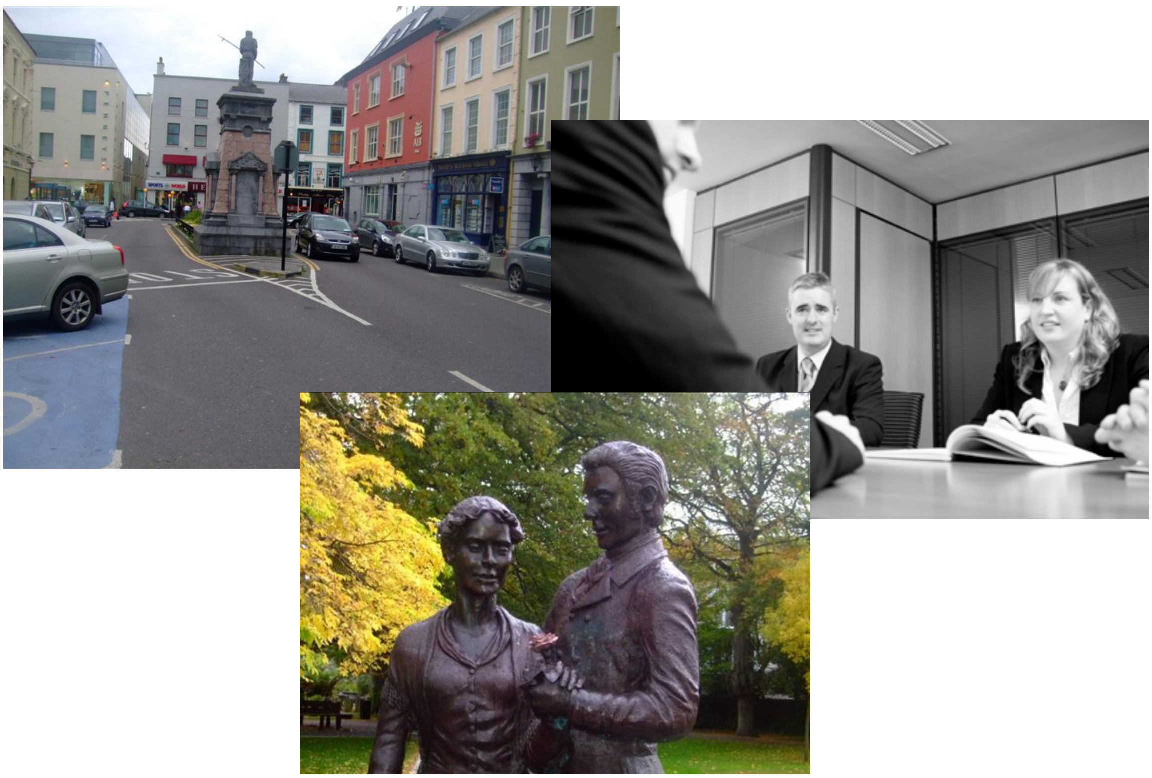
Appendix E – Base Year Model Validation Report

Appendix E

Tralee Transport Strategy - Base Year Model Validation Report

Report for Kerry County Council and Tralee Town Council

September 2010



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Contents

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Contents

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Tables

Figures

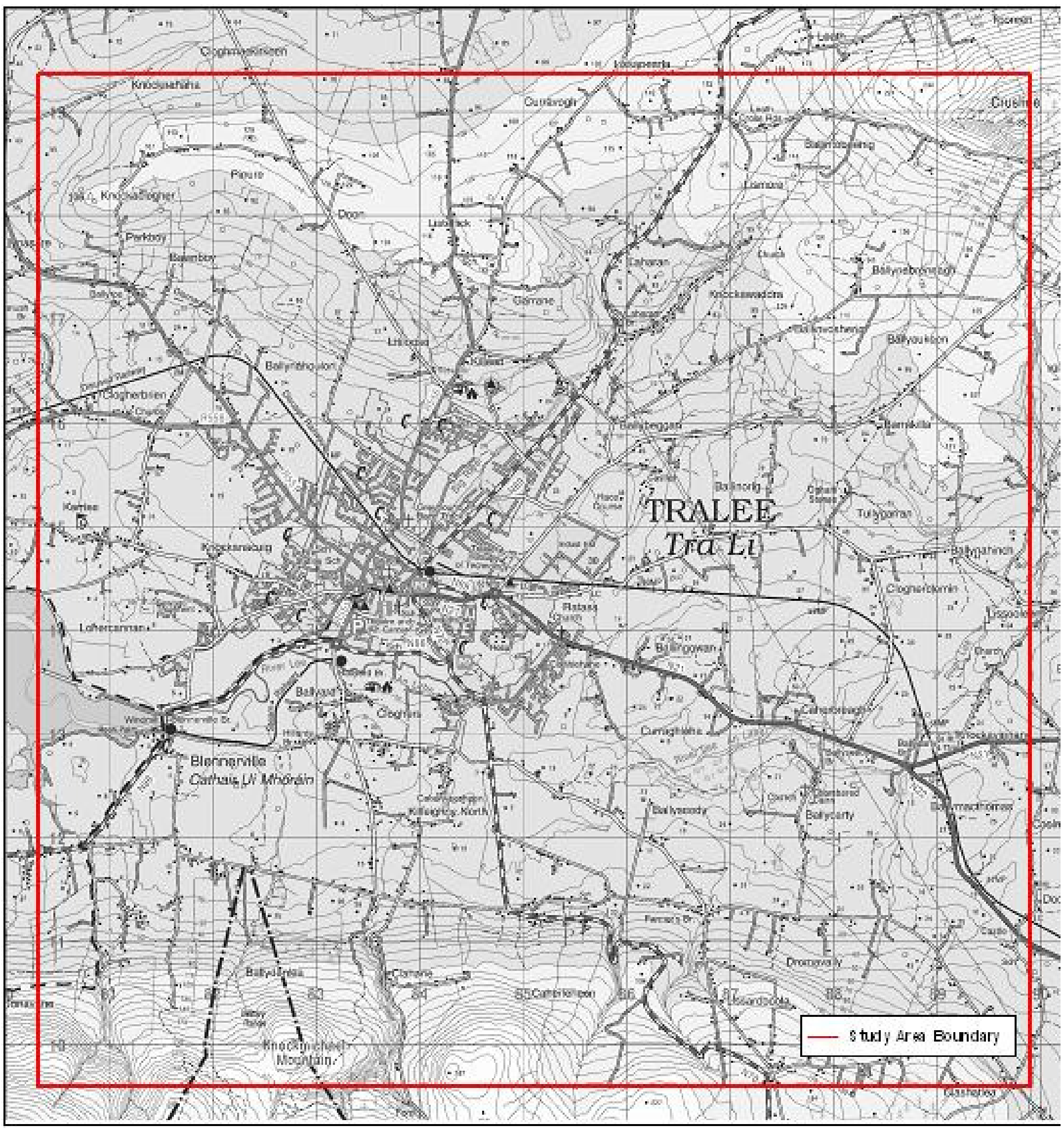
Appendices

1 Background

1.1 Introduction

1.1.1 MVA Consultancy, in conjunction with Healy Kelly Turner & Townsend (HKT&T) and Count on Us, was appointed by Kerry County Council to prepare a traffic management plan for Tralee Town and its environs. The study area is shown, below, in Figure 1.1. The initial task in developing a Traffic Management Plan is the determination of current traffic management arrangements in the town and the respective conditions experienced by each classification of road user. This will then inform the adequacy of the current traffic management arrangements, and assist in determining the interventions required to address any issues identified.

Figure 1-1 Study Area



1.1.2 As part of the assessment, a detailed traffic model was developed for the study area and is called the Tralee Traffic Model (TTM). The TTM represents the movement of traffic in Tralee and its environs for a typical AM, Inter-Peak (IP) and PM peak period for a base year of 2009.

1.2 Report Overview

1.2.1 In this report we describe the model development process used for the base year TTM, including a detailed description of the calibration process and validation statistics. Also described is the type of traffic modelling software used and the methodology used to develop the base year TTM.

1.2.2 At this stage a definition of what is actually meant by Calibration and by Validation should be given. Calibration involves the correction of network and demand errors to reduce discrepancy between measured data and modelled outputs. For the purposes of forecasting it is assumed that the parameters changed during calibration remain constant over time. Validation tests the ability of the model to predict observed travel behaviour. Validation involves testing some independent count data against flows obtained from the calibrated model.

1.2.3 The following sources on traffic model calibration/validation guidance have been used to inform the model development process and model robustness and reporting:

Model Calibration and Validation Guidance

- Highway Capacity Manual 2000 (US);
- DMRB Volume 12 Section 2 Part 1 (UK);
- National Roads Authority Project Appraisal Guidelines, Appendix 3, Traffic Modelling;
- National Transport Authority validation criteria; and
- SATURN manual validation guidelines.

1.3 Report Structure

Chapter 2 - TTM Description

In Chapter Two we give a high level overview of the modelling software platform employed and model dimensions such as the study area, time periods and vehicle types modelled within the TTM.

Chapter 3 – TTM Development

In Chapter Three the TTM development process is described in detail. We describe the survey data used to calibrate the TTM and how the road network in the Tralee area is redefined to the appropriate level of detail required by the transport assessment.

Chapter 4 – Demand Data Development

In Chapter Four we describe our use of the census data used to develop suitable trip matrices.

Chapter 5 - TTM Calibration Process and Results

Chapter Five outlines the calibration process adopted and the accuracy achieved. The calibration methods employed to ensure the TTM is 'fit for purpose' are presented.

Chapter 6 – TTM Validation

Chapter Six presents the validation statistics which demonstrate that the TTM is a suitable and robust tool to be used for the transport assessment of the Tralee area. The validation uses independent count, journey time and origin-destination data sets.

Chapter 7 - Conclusions

Finally, Chapter 7 summarises and concludes the main points in the report.

2 TTM Description

2.1 Introduction

2.1.1 This Chapter describes the TTM with reference to the various aspects below.

- Modelling software platform used;
- Extent of the model area;
- Time periods modelled;
- Vehicle types modelled; and
- The appropriateness of this model for the analysis required by the Transport Study.

2.2 Model Software Platform: SATURN

2.2.1 The model software used is the SATURN (Simulation Assignment of Traffic to Urban Road Networks) suite of transportation modelling programs.

2.2.2 SATURN has 6 basic functions:

1) As a combined traffic simulation and assignment model for the analysis of road-investment schemes ranging from traffic management schemes over relatively localised networks (typically of the order of 100 to 200 nodes) through to major infrastructure improvements where models with over 1000 junctions are not infrequent;
2) As a "conventional" traffic assignment model for the analysis of much larger networks (e.g., up to 6000 links in the standard PC version, 37500 in the largest)
3) As a simulation model of individual junctions;
4) As a network editor, data base and analysis system;
5) As a matrix manipulation package for the production of, for example, trip matrices; and
6) As a trip matrix demand model covering the basic elements of trip distribution, modal split, etc.

2.3 TTM Overview and Dimensions

Determination of Modelled Time Periods

2.3.1 The standard model time period for traffic simulation and assignment models is one hour as per the guidelines listed in section 1.2.3 above. At the outset of this project it was assumed that the TTM would also be a one hour model and initial model development and data collection was carried out based on this assumption. However at the point where we had developed a good information base in terms of traffic movements, patterns and journey times it became obvious that a one hour model was entirely unsuitable for the TTM.

2.3.2 Based on the traffic patterns that emerged from our initial analysis and data collection it emerged that there were issues regarding the following:

- POWCAR Journey Times: Assessment of POWCAR journey times revealed that the majority of journeys in Tralee were less than thirty minutes in duration.
- Departure Times: Assessment of departure times revealed that there was a large variance within the hour in terms of departure times. Our analysis revealed that the morning peak of departures was not spread over one hour but concentrated within a half an hour period.
- Observed Journey Times: MVA carried out a journey time assessment on three specified routes (described in detail in section 3). These independent tests supported the shorter half hour peak within Tralee.
- POWCAR Trip Distances: Journey distances in Tralee were notably shorter which would create an impact on journey time and departure time.

2.3.3 The combination of shorter journey times, a very narrow peak period and concentrated departure times needed to be replicated in the model. Had our survey data been evenly spread over a one hour peak period our model would have provided unrealistic diluted results. To realistically represent the delay that occurs in Tralee the decision was a made based on the above findings to develop a half hour model which would represent the actual network delay that occurs in the system during a shorter peak period. In essence this would allow us to capture all movements during the peak and replicate the areas impacted most by congestion in Tralee.

2.3.4 The TTM was developed and calibrated to represent the following half hour time periods:

- AM Morning peak period: 08h30 to 09h00;
- Inter-Peak Inter Peak period: 14h00 to 14h30; and
- PM Evening peak period: 17h00 to 17h30

2.3.5 To represent latest traffic movements within the Tralee Area for 2009, a series of surveys were conducted in November 2009 These surveys are described in detail in the network development (see Section 3).

2.3.6 The trip demand matrix representing a base year of 2009 was developed for the TTM using this survey data. The demand matrices are segregated into two vehicle types (or user classes), as follows:

- User Class One - Cars and light Goods Vehicles (LGVs). All cars and two axle trucks or other type commercial vehicles are considered LGVs; and
- User class Two - Heavy Goods Vehicles (HGV's). This user class is comprised of goods vehicles with 3 or more axles.

2.3.7 Bus flows in the Tralee area are also included as fixed flows in the modelled road network. Although there is no mode transfer calculated from car trips to bus trips, the road space occupied by the buses is taken account of in the traffic model by reducing the available road capacity.

2.4 Tralee Traffic Model Area

2.4.1 The modelled area under consideration as part of the Tralee traffic assessment is shown in Figure 1-1. The road network contained within the red border is included as part of the TTM local model. The area taken into consideration for the construction of this model expands well beyond the study area and takes into account movements originating within County Kerry and beyond. Section 2 explains in detail the extent of our model zones and how we developed our origin destination matrix.

2.4.2 The model area delineated in red has also been chosen to allow for testing the expansion of Tralees road network in future model years. Developments such as the proposed ring road and the expansion or improvement of existing primary roads linking Tralee need to be accounted given the impact the can have on the centre of the model area.

Appropriateness of TTM for the Tralee Area Traffic Assessment

2.4.3 For any model it is important to demonstrate that it is an appropriate tool for assessing the full range of traffic impact assessment types it is designed for. It is planned that the Tralee Traffic Model will be used to assess the impact of both local and strategic interventions. It is therefore crucial that the traffic model incorporates the level of detail required for localised analysis and that it demonstrates the anticipated responses to interventions upon their realisation.

2.4.4 This Validation Report will demonstrate that the TTM is an appropriate model for the Tralee Transportation Study by:

- Detailing that the model calibration achieved is of an acceptable standard; and
- Validating the calibrated model against measured journey times and other count data not used in the calibration.

2.4.5 Within the context of the range of analysis required of the model it must be understood that there is no one source that establishes the validation requirements of a general purpose model. Each such model must be considered with the context for which it will be used and validated accordingly, without sacrificing any of the desirable responses listed above in return for the perfect reproduction of observed volumes on link flows.

3 TTM Network Development

3.1 Introduction

3.1.1 The goal in developing the TTM was to develop a traffic model that accurately reflects current traffic conditions in the Tralee area for the 2009 base year and to a sufficient level of detail to allow assessments to be made on both local and strategic interventions. To achieve this goal the model must be defined in terms of road network and trip demand representation.

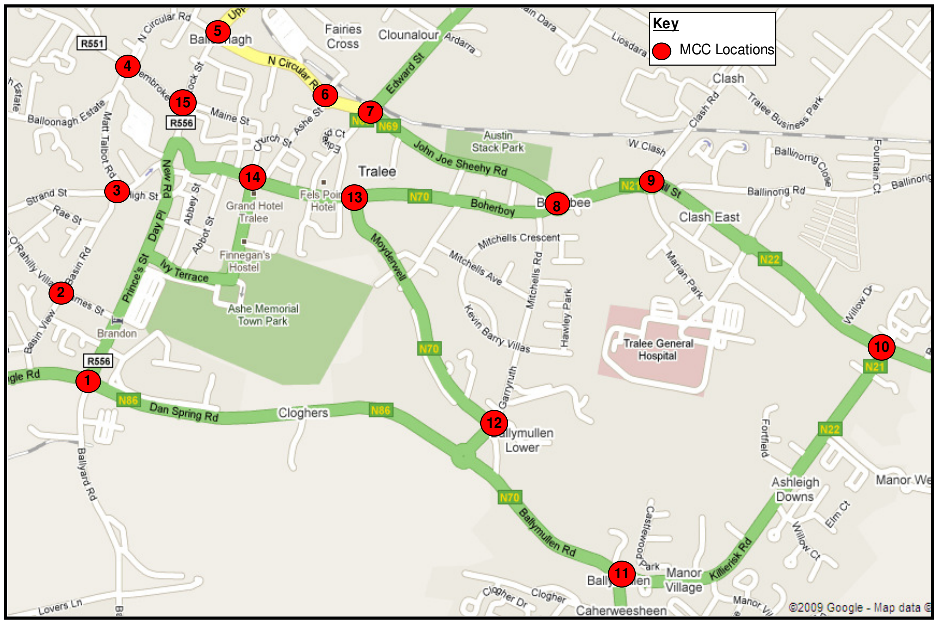
3.1.2 Accurate survey information that describes the road network and traffic observations are crucial inputs to the calibration and validation process. At the outset of the calibration process the following data inputs were obtained:

- **Road Network Data:** Initial base network data was gathered using digital mapping systems such as Google earth to get a high level view of the network. Following this detailed data was gathered from extensive site visits of Tralee. Junction layout details, such as allowed or banned turns, junction priority, and signal phase timings, were collected for all junctions within the simulation network of the TTM.
- **Survey Data**: Comprehensive surveys were undertaken in Tralee in order to fully understand traffic conditions as they currently exist. The following surveys were undertaken:
  - Junction turning counts at 15 locations;
  - Automated Traffic Counts (ATC's) over 7 days at 14 locations.
  - Bi-directional journey time surveys along three routes;
  - Origin /destination registration plate surveys at 12 locations;
  - Off-street car park surveys at 13 locations; and
  - On-street car park surveys within Tralee town centre;

3.1.3 A summary of Junction Turning Counts and Automated Traffic Counts is presented in sub Appendix A.

3.1.4 Shown in figure 3-1 below are the 15 junction turning count survey locations. Turning counts are taken at junctions and give us an exact knowledge of movements within a specified junction. This is crucial to identifying key junctions within a network and the actual movements that occur at them.

Figure 3-1 Junction Turning Count Locations

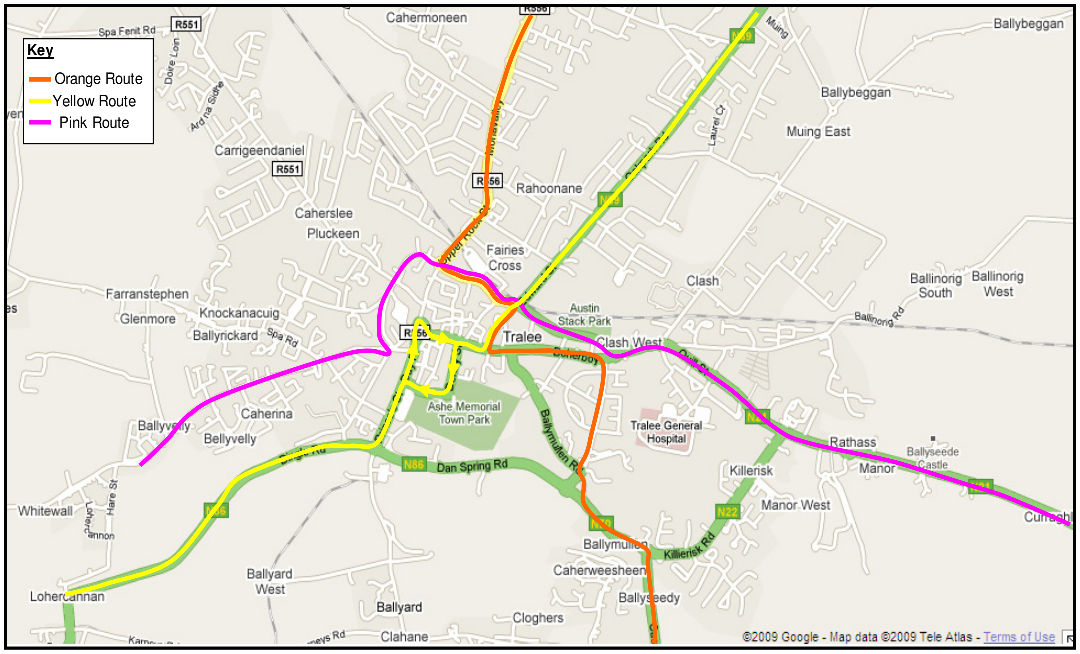


3.1.5 The following map indicates the 14 locations chosen for the ATC (Automated Traffic Count) surveys. These locations create a cordon around Tralee town centre and record all traffic which enters or exits Tralee town centre and its environs. Incorporating this information into the TTM will enable an accurate representation of through traffic flows within in the model.

Figure 3-2 ATC Locations

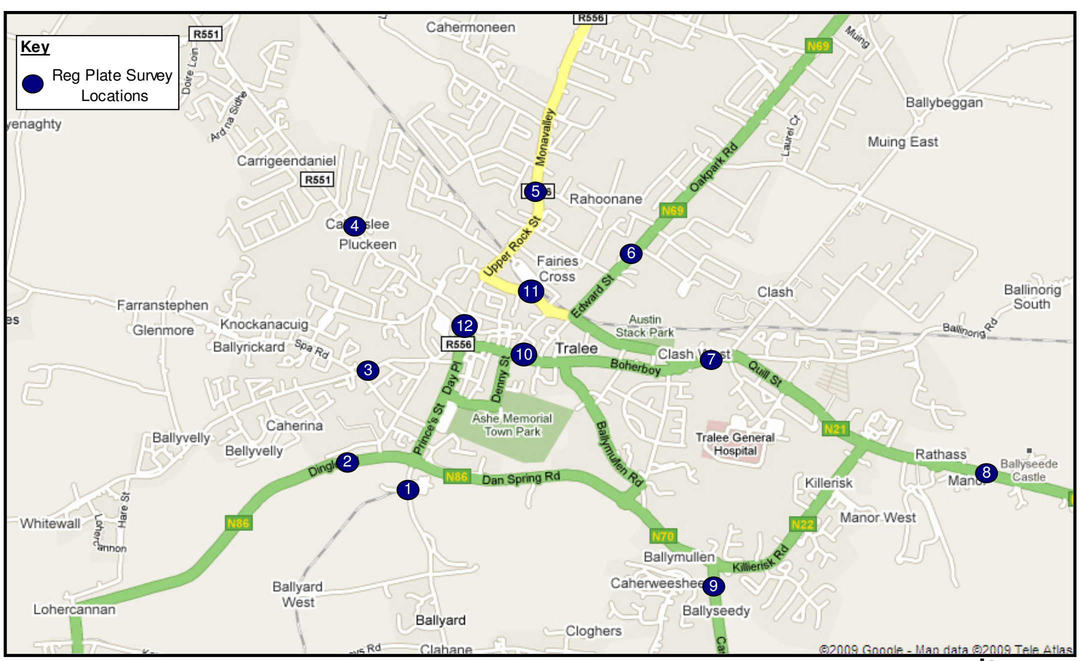
3.1.6 The journey time survey routes are shown in Figure 3-3. The journey time surveys were taken in both directions for the three routes. Journey times are used to validate modelled journey times against observed to ensure the model is outputting reliable results.

Figure 3-3 Journey Time Survey Routes



3.1.7 Figure 3-4 below shows the 12 locations where registration plate surveys were carried out. The registration plate surveys take note of all registration plates entering and leaving the study area and town centre. From this information it is possible to ascertain general travel patterns of traffic entering the study area. For example, we can tell whether a car which entered the study area on a particular road stayed inside the study area or passed through it and on what road that particular car exited the study area.

Figure 3-4 Registration Plate Survey Locations



3.2 Highway Network Development

3.2.1 All the above listed inputs were used when constructing the TTM to ensure it represented as accurately as possible the existing Tralee Road Network.

3.2.2 Shown below in Figure 3-5 is the model network as it exists in the TTM. Annotated in the figure are the major roads in the area.

Figure 3-5 TTM Network

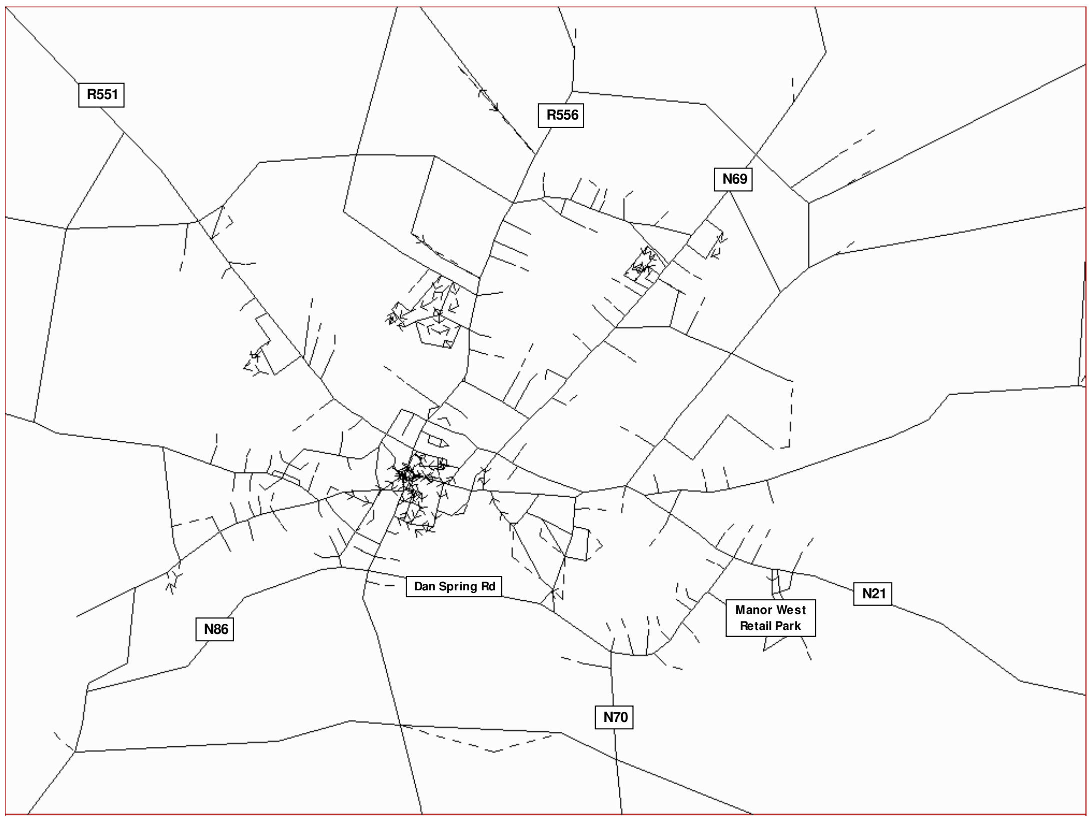
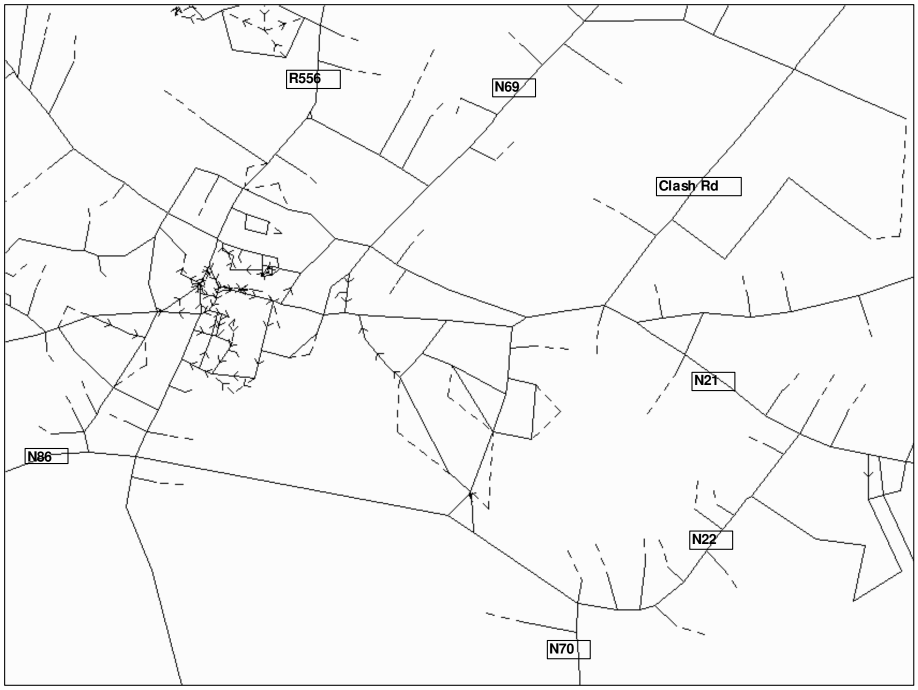


Figure 3-6 TTM Network, Town Centre



3.2.3 As can be seen from the above Figures 3-5 and 3-6, a very detailed highway network has been developed for the TTM. To ensure full network coverage and route choice all roads have been taken into account from the national primary routes to minor residential streets.

3.2.4 A detailed zoning system has been put in place to connect to the network. Major attraction zones such housing estates, shopping centres, schools, car parks and employment locations have all been designated individual zones to provide detail in trip distribution between zones and destination choice.

3.2.5 Combined the detailed network and zoning systems interact to provide a high level of detail, choice and accuracy in the model.

4 TTM Trip Matrix Development

4.1 Introduction

4.1.1 Central to the development of the TTM trip matrices was the use of the Census POWCAR (Place of Work Census Anonymised Records) data. POWCAR data is part of the Census program and provides geo-coded data of all employed persons who undertook a journey to work. This enables us to identify the exact origin and destination of each journey to work along with detailed travel, socio economic and demographic data.

4.1.2 This chapter explains how the POWCAR data is used, what we take form the POWCAR database and how we use it to create the initial trip matrices used for the calibration process.

4.2 POWCAR Data Set for Tralee

4.2.1 The basic form of the POWCAR data when processed is a set of home to work based trip movements by Electoral District.

4.2.2 The POWCAR data used for the TTM is derived from the 2006 Census and represents the data set of all trips made to work in Ireland between 07:00 and 09:30 on the day the census was taken. Every person trip made is represented by an I-J record of the trip with the origin and destination being allocated a DED (District Electoral Division) identifier. Each trip record also includes a description of the mode used in making the trip e.g. car, car passenger, bus etc.

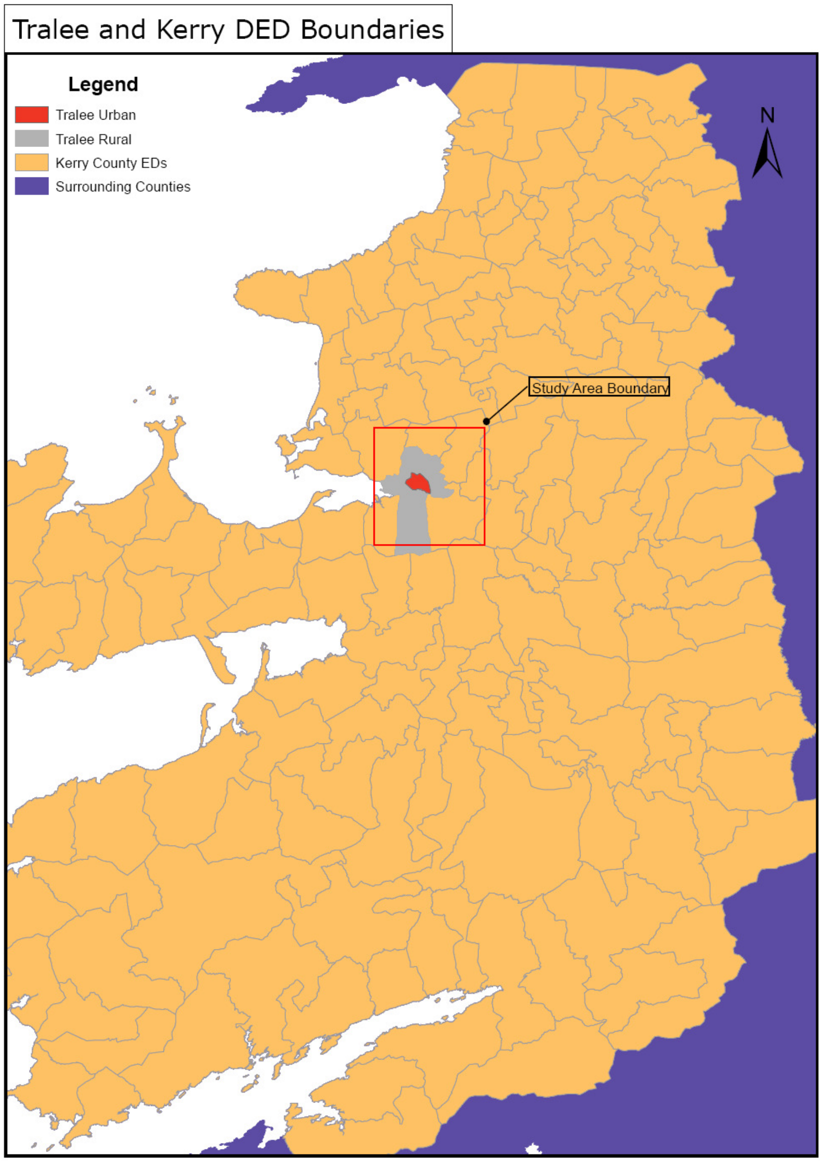
4.2.3 POWCAR provides, therefore, a fully observed sample of home to work trips at a high level of detail providing x,y coordinates which enable us to identify the location of the trip origin and destination. It was considered that the travel patterns in the area will not have changed significantly since the Census was taken between 2006 and the model base year, 2009. The data provided by POWCAR was used to create the base model and to determine base year mode split proportions.

4.2.4 Each trip record also includes a description of the time of day that the trip was made. It also includes information on whether the person had a car available to use for the trip regardless of whether they used car or other modes to make their trip. This information can give an idea of car availability for the selection of trip data extracted.

4.2.5 For the Tralee Transportation Study, POWCAR data was extracted for all DEDs in the study area and relevant neighbouring counties.

4.2.6 This area is shown below in Figure 4.1, overleaf.

Figure 4-1 DED's included in Tralee Traffic Model Zonal System



4.3 Zonal Aggregation and Disaggregation

4.3.1 Improvements to the network are not helpful unless accompanied by a finer representation of trip demand through the use of smaller zone sizes in the study area. Large zones within the study are broken up based on the identification of different land uses with the zone. Each land use is then given its own distinct zone to represent a proportion of trips from the disaggregated zone. Trip distribution for each such zone can be determined from either the original zone or a nearby zone.

4.3.2 For the areas shown above, POWCAR data was extracted for the 08:30 – 09:00hrs time period to provide origin destination data for the matrices. This covered a total of 164 DEDs.

The data at DED level needed to be fitted to the model zoning system, which, depending on location, has one of:

- A one to one relationship, i.e., the model zone and DED are the same - no aggregation or disaggregation required;
- A one to many relationship, i.e., one model zone equates to a number of DED zones - aggregation of DEDs required; or
- A many to one relationship, i.e., many model zones equate to one DED zone - disaggregation of DEDs required to fit model zoning system.

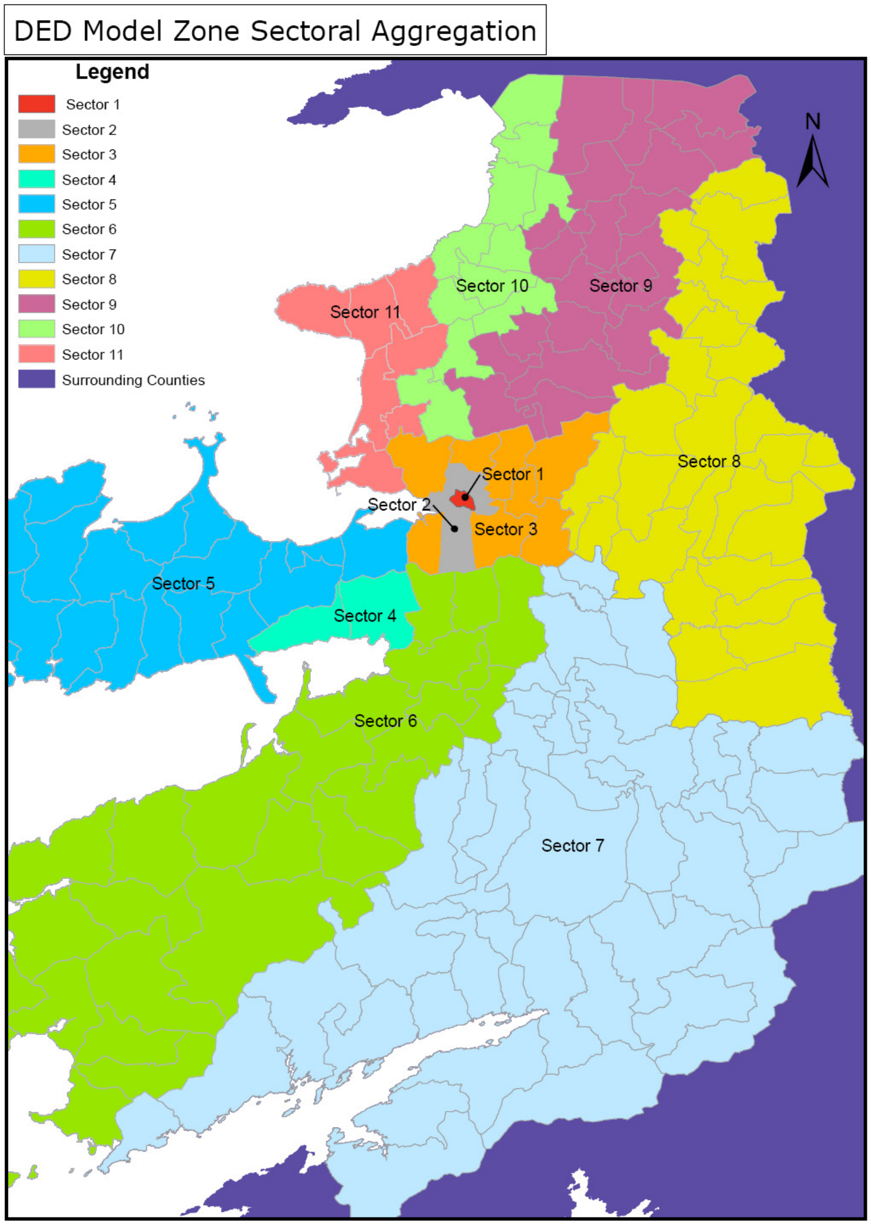
4.3.3 The DEDs for the Tralee urban and rural area (shown as Sectors 1 and 2 in **Error! Reference source not found.**2 below) were processed to fit the finer model zone detail in the TTM. In this area, two DEDs (Tralee Urban and Tralee Rural) were disaggregated into 41 model zones. The zonal disaggregation for these two DEDs was based purely on what was on the ground. Using a combination of GIS mapping and digital aerial photography all attraction zones such as employment locations, residential estates, schools colleges and shopping areas were identified and allocated a zone.

4.3.4 The DEDs immediately surrounding these central zones make up sector three. Here seven DEDs were disaggregated into 16 model zones again based on size and land use.

4.3.5 The DEDs contained in the study area outside of Tralee Urban, Rural and the immediate hinterlands of Tralee town were aggregated to fit the external zones contained in the TTM. For this purpose the 155 DEDs were aggregated into 8 external zones, which represent sectors four to 11 in Figure 4.2. These zones were aggregated using the primary road network as a relative boundary. For example Sector 6 is bound by the N86 and N70 while Sector 7 is bound by the N70 and N22. This methodology gives us a logical breakdown for our external zones both visually and in terms of zone loading and distribution.

4.3.6 Once the POWCAR data was formatted to fit the zonal system of the TTM, the data was imported into a SATURN matrix format.

Figure 4-2 Aggregated Model Zoning System



4.4 Pinpoint Zone Allocation

4.4.1 As mentioned in the previous section a detailed disaggreagtion of the two central DEDs was undertaken to ensure a comprehensive zonal system for the model. The allocation of trips to the correct zones was as equally important as the zone disaggregation

4.4.2 In order to allocate trips to zones the geo-coded locations of each employment destination were superimposed over a zone map of Tralee. As previously mentioned POWCAR data

provides geo-coded origin destination data. Geo-coded locations are addresses which are matched against the An Post Geo Directory. The An Post Geo Directory is a more detailed version of the Irish National grid offering 250Mx250M grid squares instead of 1000Mx1000m national grid squares.

4.4.3 This improved detail in work destination allowed us to accurately identify the primary employment attraction zones for which to allocate large numbers of trips during the calibration stages (section 5).

4.5 Educational Trips

4.5.1 Educational trips make up a sizeable portion of movement within the network. Given our trip matrix was made up of employment trips it was important that the educational trips were factored in order to represent this generator of traffic.

4.5.2 Education trips were factored in at two stages. Initially during our network development we identified the primary education destinations in Tralee and allocated these locations specific zones. Having specific educational zones within the network would allow us to add in network constraints during the matrix estimation stage. This would ensure that we could allocate sufficient trips to represent educational traffic within the network. Matrix estimation is discussed in greater detail in Chapter Five.

4.6 Non Work Trips

4.6.1 Similar to educational trips there are a number of other trip types that needed to be included within the matrix estimation process. Using the same methodology as education trips specific zones were identified and allocated to the car parks of Tralee, major shopping centres, hospitals and other trip generators such as the Aqua Park.

4.7 Inter Peak and PM Trip Matrix Development

4.7.1 As POWCAR data is only available for the AM period an alternative methodology had to be adopted when developing Inter-Peak and PM peak demand Matrices.

4.7.2 As the majority of trips in the PM peak are usually the reverse of AM peak trips (i.e. work to home as opposed to home to work), the PM peak demand matrix was derived by transposing the AM demand matrix. This is a standard modelling technique for developing PM matrices and converts all I-J trips in the AM matrix to J-I trips in the PM matrix and vice versa. This transposed matrix was then further refined using PM peak count information in a Matrix estimation process.

4.7.3 Inter Peak trips usually consist of various trip purposes. Trips such as shopping trips, hospital service and other work related movements occur not just home to work or home to education trips as is the case with AM and PM demand. It may therefore have a different overall trip distribution pattern to AM and PM demand. The Inter-Peak demand Matrix was derived by factoring the AM matrix so that the overall level of trips matched the observed amount of trips in the model area for the Inter-Peak period. This prior matrix was then further refined using inter-peak count information in a Matrix estimation process.

4.7.4 Further details on the matrix estimation process are explained in the following chapter of this report.

4.8 Summary

4.8.1 The construction of the base year TTM was simplified and enhanced by use of Census data to accurately reflect the population and employment in each of the model zones. Further census data from 2006 Place of Work - Census of Anonymised Records (POWCAR) provided a detailed breakdown of the trip distribution and mode choice in the Tralee area.

4.8.2 All Census data was processed into a matrix format suitable for input to the TTM. Thus, the base year Tralee Traffic Model incorporates a complete and comprehensive data set, and so accurately reflects the existing situation.

4.8.3 Inter-Peak and PM peak demand matrices were developed using a combination of standard modelling techniques including transposing matrices and matrix estimation.

5 TTM Calibration Process and Results

5.1 Calibration Process

5.1.1 Calibration is intended to improve agreement in the TTM between observed and modelled traffic characteristics.

5.1.2 Generally, the components of the model that may be adjusted on the demand side are trip distribution and trip production and generation rates. This adjustment usually involves trip matrix estimation.

5.1.3 On the supply side (network), modelled junction and link characteristics may be altered if sufficient new information is available to justify changes to the existing network.

5.1.4 Other aspects of the calibration are also detailed in this chapter, such as model convergence results, which determine the stability of modelled flows with respect to successive assignment iterations.

5.1.5 Additional parameters that must be assessed when judging the integrity of any changes made to the matrices include any changes made to trip length distribution given by origin-destination patterns in the matrix. Results for trip length distribution for both prior and post calibrated trip demand for all time periods modelled are given later in this chapter.

Initial Calibration Steps

5.1.6 As an initial calibration step, all modelled movements with a corresponding turning count were examined to determine if the count exceeded modelled capacity. Remedial steps were then taken to permit realistic flows in the model.

5.1.7 Similarly the capacity and speeds of modelled links were also checked to ensure they were broadly inline with survey information.

5.1.8 As the TTM was coded based on information gathered during extensive site visits to Tralee, it was felt that the network coded was an accurate and up-to date representation of the existing road network in Tralee so did not need to be altered significantly during the calibration process. As a result of this the most significant calibration adjustments taken were on the demand side, i.e. adjustments to trip distribution and trip production / generation. If required however the following model parameters may be adjusted if there is clear reason for doing so:

Network Adjustment Possibilities

- Junction type (Priority, Signalised, Roundabout);
- Road lengths;
- Signal timings;
- Link free flow travel speed;
- The number of approach lanes at each junction arm;

- Traffic lane width per junction approach, and the lane discipline adopted (including prohibited turns);
- Saturation flow through junctions;
- Assumed road capacities;
- Link based flow-delay relationships; and
- Any other traffic management measures that may impact on capacity, such as bus lanes, traffic calming, parking controls and cycle-lanes.

Network Adjustment Possibilities – Traffic Zones

- Zone co-ordinates; and
- Zone loading points (connections to the network).

5.2 Trip Demand Adjustment (Matrix Estimation)

AM Matrix

5.2.1 Trip demand is adjusted according to count data, so that there is an improved agreement between counts and modelled flows. For the AM time period The POWCAR matrix (described in Chapter 4) representing unadjusted demand is fed into a SATURN programme called ME2. This matrix is known as the prior matrix. ME2 then adjusts origin-destination patterns to produce a trip demand matrix that better replicates counts when assigned to the network. When this replication is satisfactory the matrix is said to be calibrated.

5.2.2 The prior matrix is adjusted only after all options for improving the network are exhausted. Any matrix adjustment must significantly improve the match between observed and modelled flows, and not introduce more trips into a zone than could realistically be expected. Controls are placed on zones to ensure that the trip demand generated by zones is sensible and in line with census population and employment statistics.

PM Matrix

5.2.3 For the PM time period a transposed AM matrix was used as the Prior matrix in the ME2 Process. As with the AM matrix ME2 then adjusted origin-destination patterns to produce a trip demand matrix that better replicated PM count data when assigned to the network. A number of iterations of the ME2 process were completed until the replication was satisfactory and meets guideline standards.

Inter Peak Matrix

5.2.4 To develop the Inter-Peak matrix the AM matrix was factored so that the level of traffic in the matrix matched the level observed in the inter-peak period survey data. This factored matrix then formed the prior matrix which was adjusted using the ME2 process so that origin-destination patterns matched those from traffic counts.

5.3 Matrix Adjustment Constraints

5.3.1 A key requirement in the Tralee study area is to ensure the proportion of through trips in the model remains accurate. The algorithm driving the ME2 estimation process tends to reduce such long trips in place of chains of short trips, especially when counts are spread over the entire area.

5.3.2 Constraints are therefore placed on the adjustment process to protect the number of movements and distribution of the through trips contained within the original car trip matrix.

5.3.3 By restricting such long through trips, the matrix adjustment algorithm is forced to create or re-distribute short trips.

5.3.4 Different sets of constraints were used for each time period. In summary:

- AM: HGV constraints on residential areas and unsuitable zones, destination constraints were placed on residential areas for car trips while employment zones were encouraged as destinations;
- Inter Peak: HGV constraints on residential areas and unsuitable zones, destination constraints were placed on residential areas for car trips were eased. School and retail zones received positive constraints; and
- PM: In line with the transposed matrix employment zones received constraints while residential zones had constraints lifted. HGV constraints for residential areas were maintained.

5.4 Traffic Flow Accuracy Measure: GEH

5.4.1 The GEH statistic is a measure that considers both absolute and proportional differences in flows. Thus for high levels of flow a low GEH may only be achieved if the percentage difference in flow is small. For lower flows, a low GEH may be achieved even if the percentage difference is relatively large. GEH is formulated as:

$$\text{GEH} = \sqrt{\frac{(\text{observed} - \text{modelled})^2}{0.5 \times (\text{observed} + \text{modelled})}}$$

5.4.2 The reason for introducing such a statistic is the inability of either the absolute difference or the relative difference to cope over a wide range of flows. For example an absolute difference of 100 pcu/h may be considered a big difference if the flows are of the order of 100 pcu/h, but would be totally unimportant for flows of the order of several thousand pcu/h. Equally a 10% error in 100 pcu/h would not be important, whereas a 10% error in, say, 3000 pcu/h might mean the difference between building an extra road lane or not.

5.4.3 In general the GEH parameter is less sensitive to the above statistical biases since a modeller would probably feel that an error of 20 in 100 would be roughly as bad as an error of 90 in 2,000, and both would have a GEH statistic of roughly 2.

5.4.4 As a rule of thumb in comparing assigned volumes with observed flows a GEH parameter of 5 or less would be an acceptable fit, while GEH parameters greater than 10 would require closer attention.

5.4.5 Two primary guideline documents have been used For the purposes of this validation to validate the TTM. The British Design Manual for Roads and Bridges (DMRB) Volume 12a and the NRA Project Appraisal Guidelines Appendix 3 were used as a basis for assessing the appropriateness of the highway model for traffic appraisal. The DMRB Volume 12a guidelines are a widely accepted standard in Ireland with the NRA basing their guidelines on this document and provide extremely robust validation criteria to which certain types of highway models should adhere.

DMRB Guidance on GEH Distribution

5.4.6 DMRB sets a guideline that 85% of links should have GEH less than 5 (when measured in vehicles per hour). In addition it is commonplace to establish that 90% of assessment links have a GEH of less than 10 and that 100% of validation links have a GEH less than 20.

5.5 Link Count Calibration

5.5.1 For the calibration process, the corresponding model junction was identified for each turning movement count survey site. Each individual turning movement was used in the calibration and so forcing the ME2 estimation process to derive a trip matrix that would fit each surveyed turning movement.

5.5.2 Further on in the validation of the model, these turning movements were aggregated to form link counts which are used to validate the network flows rather than turning movements.

5.5.3 The locations for the turning movement counts were outlined previously in Figure 3-1. As can be seen from the map a large proportion of the study area is covered by counts, which gives for a high degree of control in the matrix estimation.

5.5.4 Figure 3–2 indicates the locations of the 14 ATC (Automated Traffic Counts) counts used to cordon the primary routes which enter and exit Tralee. Validated external movements using ATC data allowed us to be specific in developing external/Internal movements and when limiting the exact number of movement in and out of Tralee.

5.5.5 A large proportion of the model network is therefore controlled for link flows, as illustrated in Figure 5-1 below. In total, 79 link counts were used to calibrate each time period.

Figure 5-1 Link Count Locations within the SATURN Network

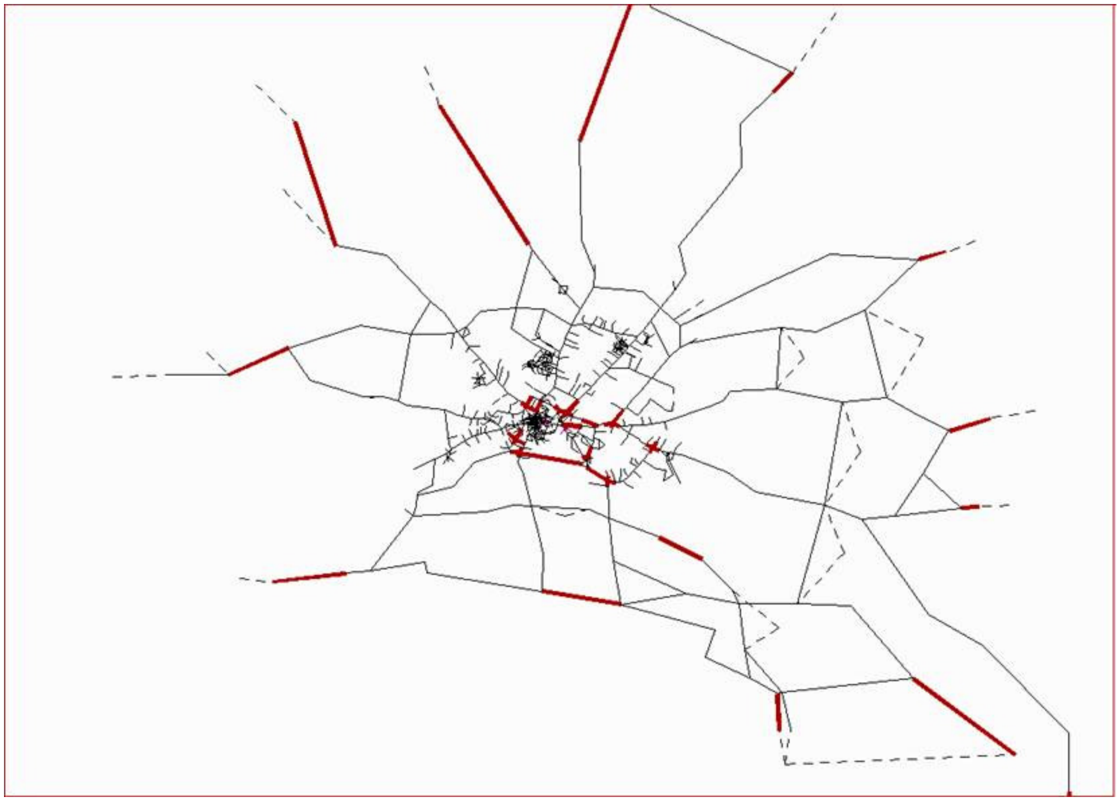
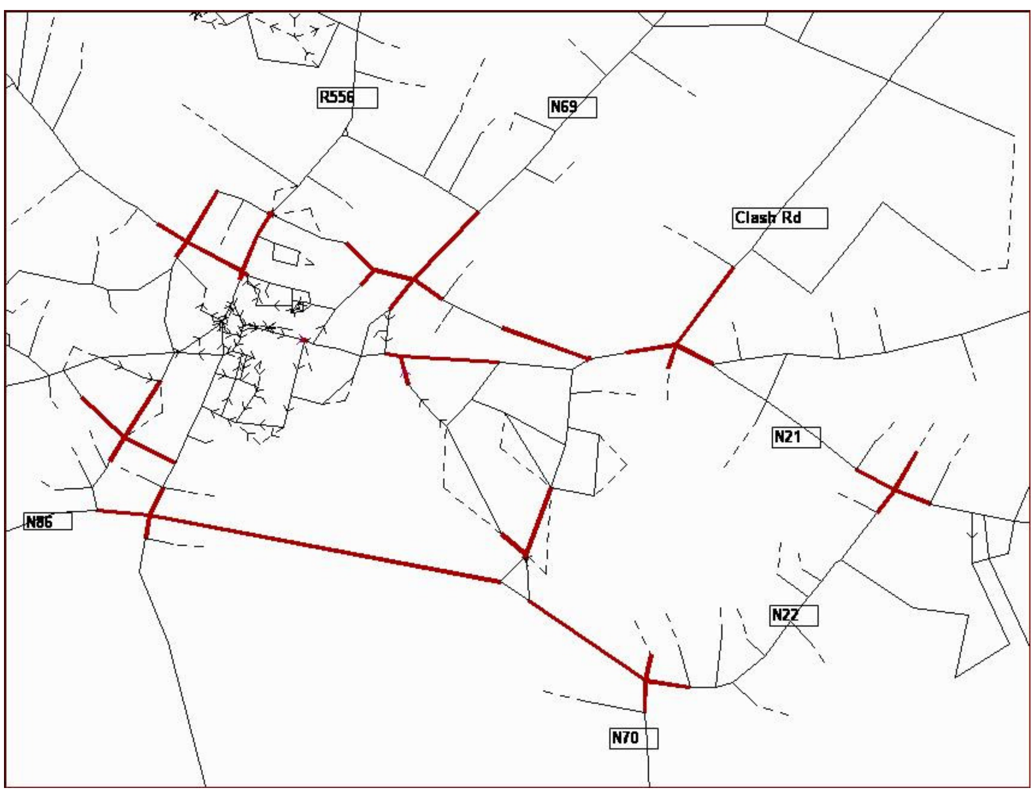


Figure 5-2 Link Count Locations within the SATURN Network, Town Centre



5.6 Model Fit to Counts (Prior to Calibration)

5.6.1 An initial test was performed to determine how well the existing disaggregated demand matrices assigned to the TTM replicated observed traffic volumes. Table 5-1 below details the model fit prior to undertaking the calibration process for each of the time periods modelled.

Table 5-1 Count Validation Statistics (Pre-Calibration)

GEH	AM	IP	PM
GEH < 5	80%	80%	73%
5 < GEH < 10	92%	91%	95%
10 < GEH < 20	99%	99%	99%
Overall Average GEH	**12.9**	**14.6**	**7.2**

5.6.2 The percentage of total traffic at all count locations with a GEH less than 5 is as low as 73% (AM) this falls far short of DMRB guidelines.

5.6.3 The remaining course of action to improve the fit between model flows and assigned volumes was therefore to perform controlled adjustments to the prior matrix using matrix estimation techniques (described above in Section 5-2).

5.7 GEH Statistics for Calibrated TTM

5.7.1 Table 5-2 below summarises the GEH calibration results for the TTM after the matrix estimation process, for each of the three modelled time periods.

Table 5-2 Count Validation Statistics (Post-Calibration)

GEH	AM	IP	PM
GEH < 5	89%	91%	92%
5 < GEH < 10	100%	100%	100%
10 < GEH < 20	100%	100%	100%
Overall Average GEH	**2.6**	**1.4**	**3.8**

5.7.2 The figures demonstrate that an excellent calibration was achieved in the TTM for the morning, inter peak and PM peak periods, with all three time periods having an overall GEH of over ninety percent and falling well within DMRB Standards.

5.7.3 In no case are any GEH values above 10 or 20 present.

5.7.4 A detailed link by link breakdown of GEH statistics is located in appendix C.

5.8 Linear Regression of Counts and Modelled Flows

5.8.1 DRMB recommends a further check on flow validation: to fit a linear regression line through the origin with observed flow as the independent variable and modelled flow as the dependent variable. The slope and R^2 measure of goodness of fit for the pre-calibration and post-calibration are presented in Table 5.3 and Table 5.4

5.8.2 DMRB guidance is that the slope of the regression line is in the range 0.9 to 1.1 and that R^2 is greater than 0.95.

Table 5-3 Pre-Calibration Count Regression Analysis

Measure of Fit	All Trips (PCUs)		
	AM	IP	PM
Slope	0.938	1.039	1.01
R^2	0.54	0.75	0.75

Table 5-4 Post-Calibration Count Regression Analysis

Measure of Fit	All Trips (PCUs)		
	AM	IP	PM
Slope	0.988	0.987	1.022
R^2	0.89	0.94	0.94

5.8.3 Both slope and R^2 criteria are met in the post-calibration regression analysis.

5.8.4 The following charts show the correspondence between count and modelled flow data sets, with the best fit linear match plotted on each graph. The two graphs shown are for the prior and post calibration data sets, to show how the relationship between observed and modelled flows is improved by calibration.

5.8.5 Figures 5-3 to 5-8 illustrate the fit achieved between the modelled and measured link flow for the pre-calibration and post-calibration trip matrices for each of the time periods modelled. The data points are distributed closely to the y = x straight line without any significant outliers. This uniformity is reflected in the R^2 values detailed in Table 5-4 above.

Figure 5-3 Fit of Observed Vs Modelled Pre-Calibration AM

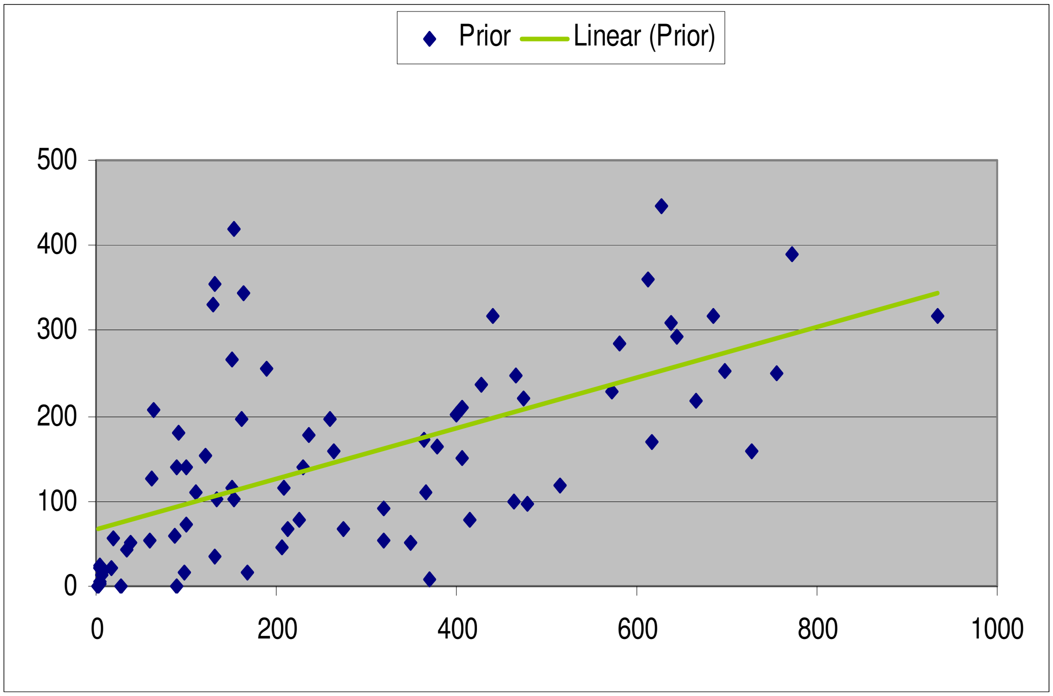


Figure 5-4 Fit of Observed Vs Modelled Post-Calibration AM

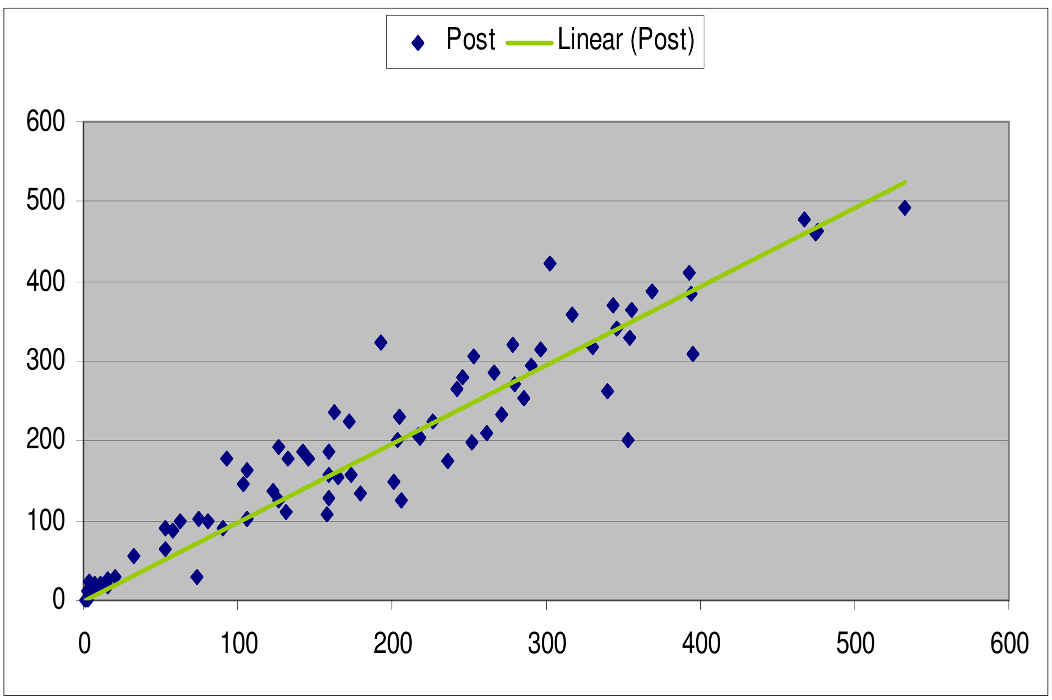


Figure 5-5 Fit of Observed Vs Modelled Pre-Calibration IP

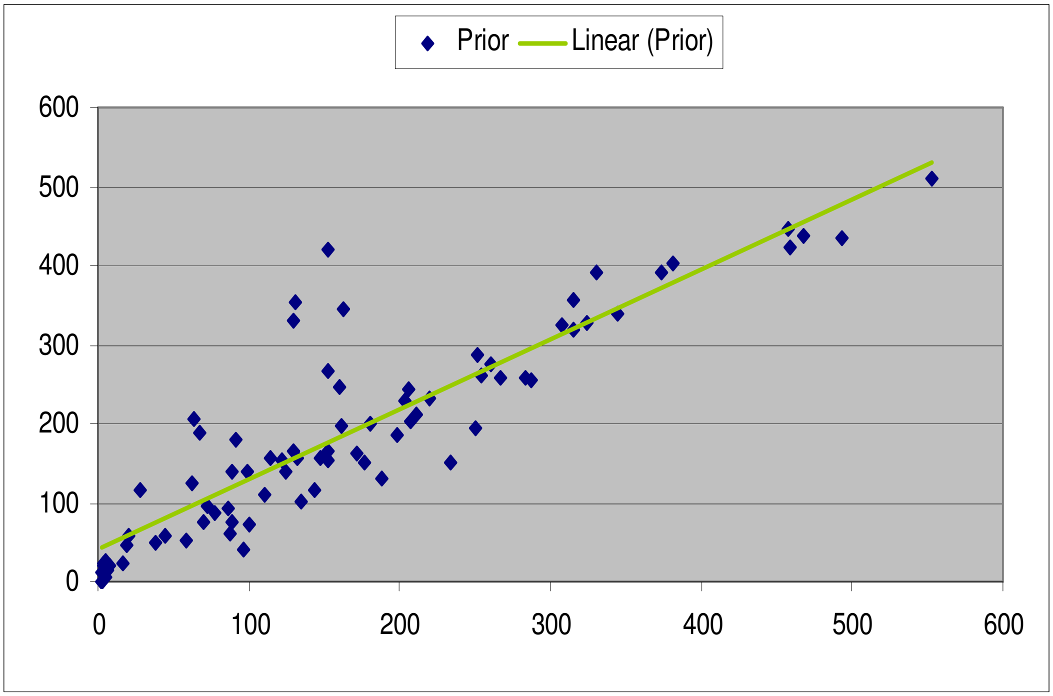


Figure 5-6 Fit of Observed Vs Modelled Post-Calibration IP

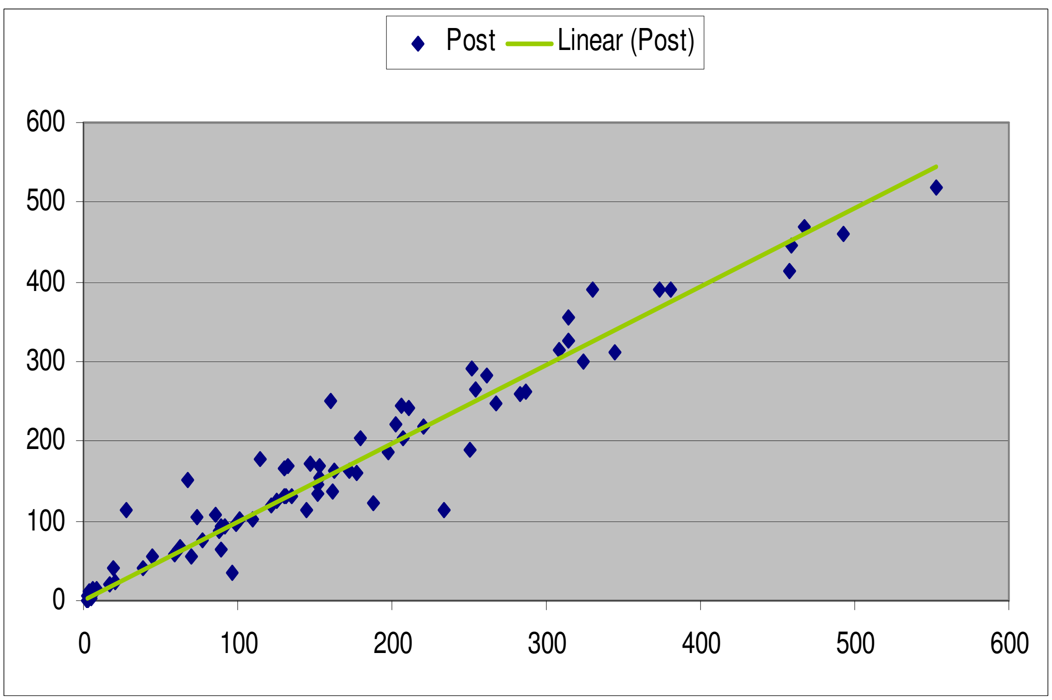


Figure 5-7 Fit of Observed Vs Modelled Pre-Calibration PM

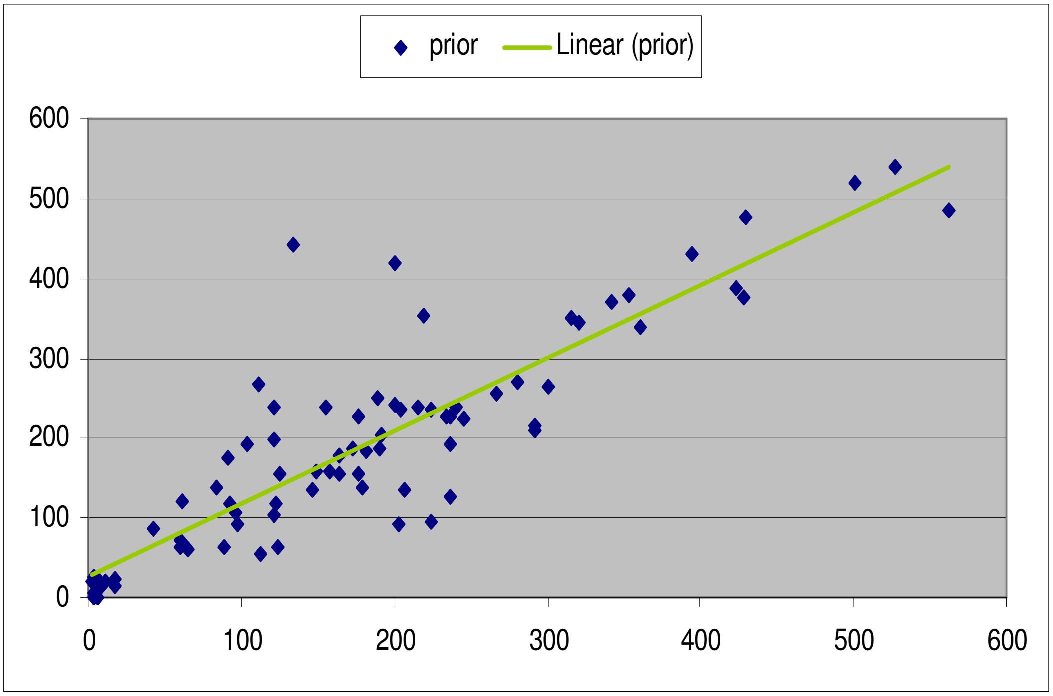
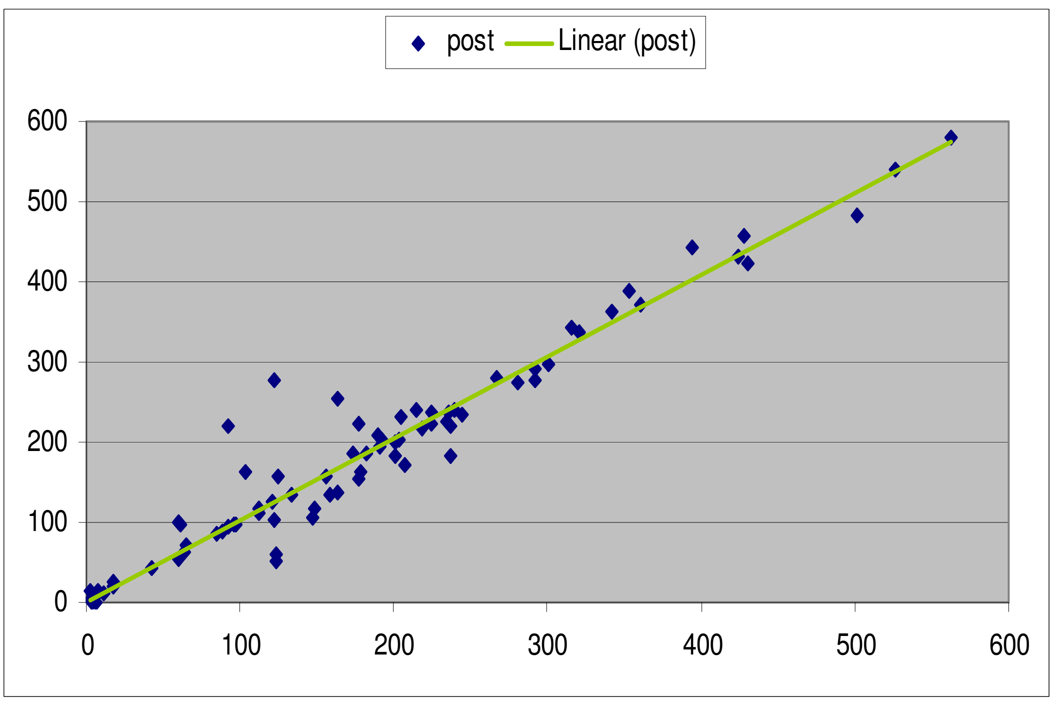


Figure 5-8 Fit of Observed Vs Modelled Post-Calibration PM



5.9 Model Convergence

5.9.1 The parameter used by Saturn to monitor the rate of convergence is the percentage of link flows which vary by less than a specified percentage between loop n and loop n-1.

5.9.2 The values used in each assignment during calibration are that 98% of links should differ by less than 5% between subsequent iterations.

5.9.3 This convergence criterion is achieved for all assignments carried out in calibrating the TTM. See Appendix B for a detailed breakdown of convergence results for the AM Peak, Inter Peak and PM Peak periods.

5.10 Trip Length Distribution – Calibration Impact

5.10.1 As a further calibration step is to compare trip length distributions for the prior and post calibrated matrices to ensure they have not been distorted in any way by the ME2 process.

5.10.2 Trip length distribution is compared below for the LV matrix for all modelled time periods. The number of trips made is shown on the y-axis. Distance bands are shown on the x-axis. The data shows there is little difference evident in terms of how trip distribution was adjusted by the overall matrix adjustment process.

5.10.3 The trip length distribution of the pre and post-calibration matrices of each modelled time period are shown below in Figures 5.9 to 5.11. The pre calibration line (blue) in the diagrams below indicates the trips in the model before we have applied our matrix constraints, factors and run matrix estimation. The pink line indicates our matrix trips post matrix estimation. The non work and education trips have now been factored into the trip matrix. This is most evident by looking at the increase in trips for the inter peak period where work trips would be low and all other trips high. The diagram clearly shoes that matrix estimation has worked on this occasion.

Figure 5-9 Car length Trip Distribution AM Peak

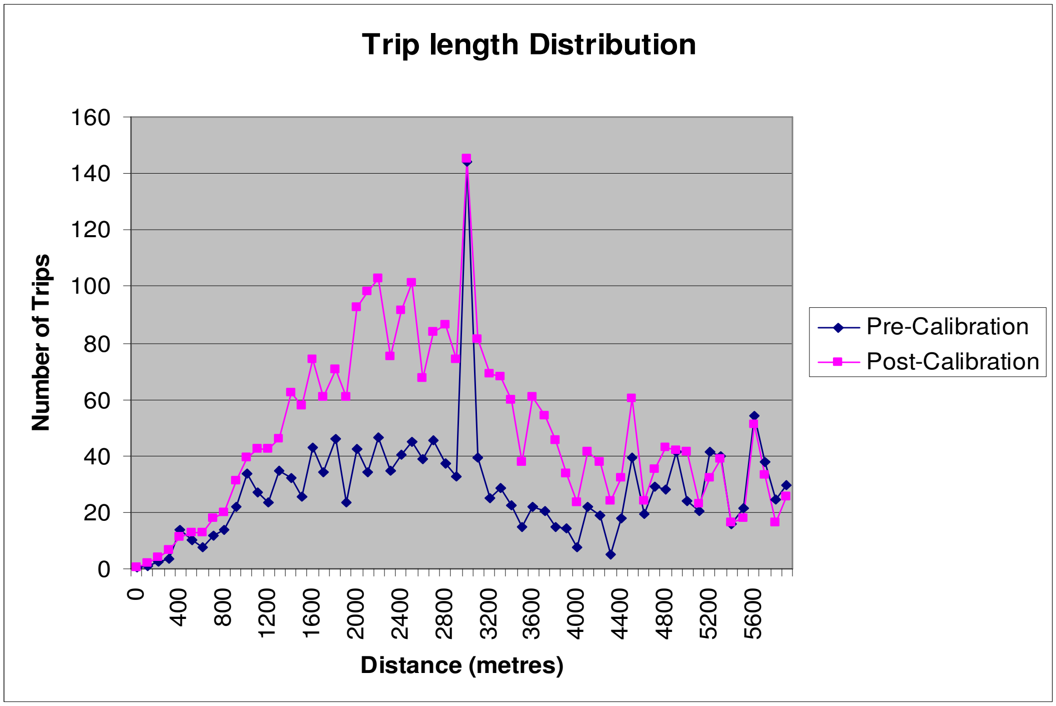


Figure 5-10 Car length Trip Distribution Inter Peak

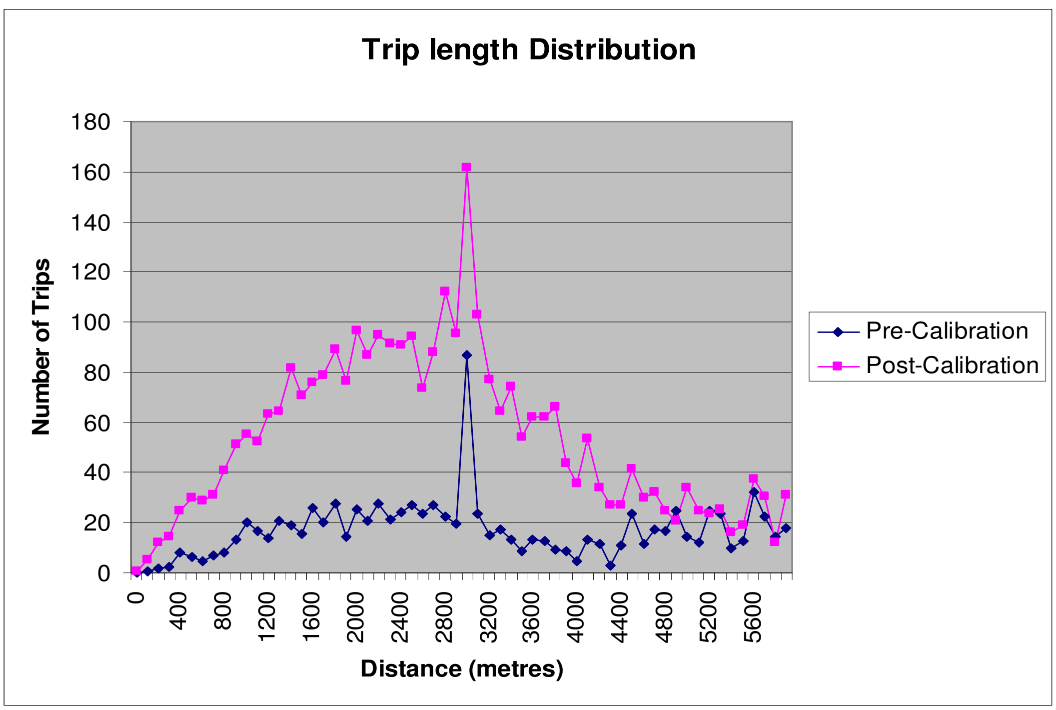
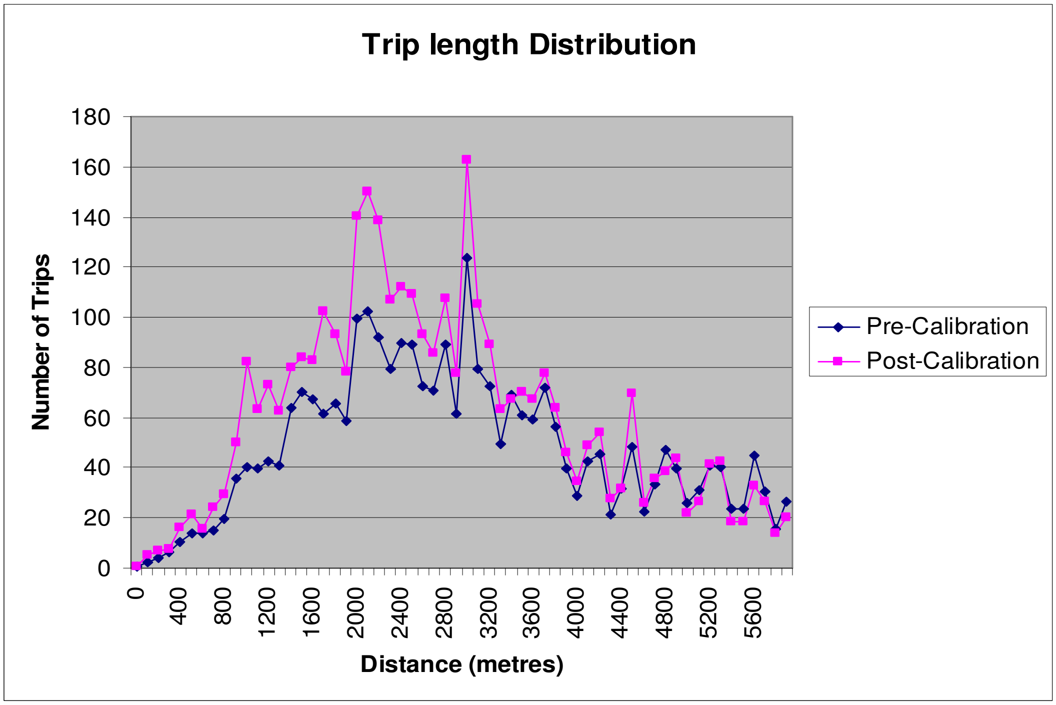


Figure 5-11 Car length Trip Distribution PM Peak



5.11 Summary of Calibration Actions

5.11.1 To improve the agreement between the observed and modelled traffic characteristics a number of calibration steps were taken for the Tralee Traffic Model.

- The first and most significant of these was to carry out a matrix estimation for each of the modelled period matrices to ensure origin-destination patterns in the model were consistent with those observed during traffic count surveys.
- Following on from the matrix estimation process a link count calibration was carried out. During this stage modelled flows for each time period were compared with actual flows for 79 locations. The results of these comparisons outlined in Table 5-4 show an excellent calibration between modelled and observed flows with all time periods falling well within DMRB and NRA Project Apprisal guidelines.
- Further calibration checks carried out on the Tralee Traffic Model include linear regression analysis, origin destination testing and trip length distribution analysis. All of which demonstrated that the Tralee traffic Model is very stable and meets all DMRB criteria for model calibration.

6 TTM Validation

6.1 Introduction

6.1.1 This section sets out additional comparative measures by which the robustness of the calibrated model may be judged. The following model performance characteristics are detailed:

- Comparison of modelled traffic flows to each individual survey location;
- Comparison of modelled journey times to observed journey times; and
- Comparison of observed origin destination movements against modelled

6.2 Individual Survey Location Validation

6.2.1 Modelled flows were compared with 79 link flows at the 29 surveyed junctions. These junctions were chosen to provide a wide geographical spread of validation locations around the modelled area of interest.

6.2.2 DMRB presents additional guidelines for traffic flow validation[1], these are:

- flows within 100 for links with flow less than 350 vehicles per half hour;
- flows within 15% for links with flow between 700 and 1,350 vehicles per half hour; and
- flows within 200 for links with flow over 1,350 vehicles per hour.

6.2.3 The results in Table 6-1 below were obtained when testing all individual link counts throughout the model under the three criteria set out above.

Table 6-1 Turning Count Validation– % Links Satisfying Alternative DMRB Criteria

DMRB Condition	AM	IP	PM
Flow < 350; modelled within 50	88%	93%	94%
350 < Flow < 1350; modelled within 15%	81% (2 links)	100%	100%
1350 < Flow; modelled within 200	N/A	N/A	N/A

6.2.4 All of the alternative DMRB criteria are well met for the post-calibration trip matrix.

[1]Note: DMRB conditions have been halved to take into account half hour model

6.3 Journey Time Validation

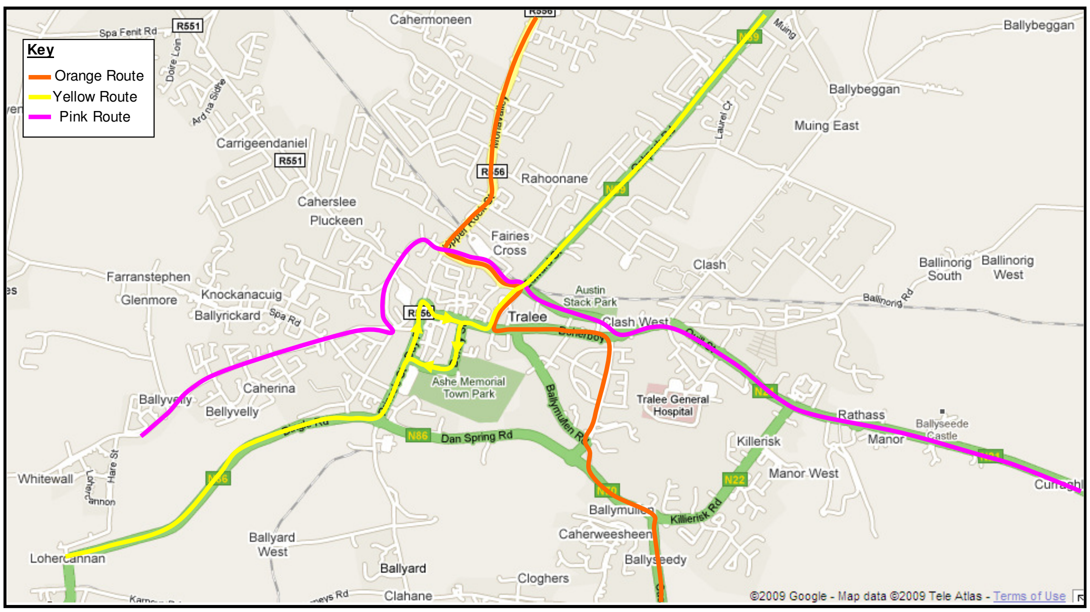
6.3.1 Travel time surveys were commissioned by MVA as part of this study. Survey times were taken along three routes in both directions. Along each route, the journey time was taken at a series of different survey points in order to properly observe the journey time along stages of the route.

6.3.2 The journey time survey routes were as follows:

- Orange Route : R556 /Collinswood to Castlemaine Rd/ Caherweesheen;
- Yellow Route: Oakpark Rd (N69)/Dromtracker Rd to Dingle Rd/Basin View; and
- Pink Route: N21 Manor West Retail Park to Ballyvelly Rd/ Ashgrove Estate.

6.3.3 Figure 6-1 below shows the survey routes and the survey stages that were used to record the stage journey times.

Figure 6-1 Journey Time Survey Routes



6.3.4 Tables 6.2 to 6.4 below summarises the journey travel times against the model times for the same routes for each of the modelled time periods.

6.3.5 It should be noted that for certain time periods we have not included a full set of journey time comparisons. The decision to create a half hour model instead of a one hour model limited the number of journey time runs available for comparison. As a result we have omitted occasional results as they do not provide us with a realistic basis for comparison.

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Table 6-2 AM Peak Observed Vs Modelled Journey Times

Route	Observed Time (Seconds)	Modelled Time (Seconds)	% Difference
Orange Route SB	N/A	N/A	N/A
Orange Route NB	533	680	28 %
Yellow Route SB	615	614	-0.1 %
Yellow Route NB	804	685	-11 %
Pink Route EB	647	713	10 %
Pink Route WB	845	800	-5 %
Routes Combined	**3444**	**3492**	**1%**

Table 6-3 Inter Peak Observed Vs Modelled Journey Times

Route	Observed Time (Seconds)	Modelled Time (Seconds)	% Difference
Orange Route SB	N/A	N/A	N/A
Orange Route NB	677	731	7 %
Yellow Route SB	617	635	3 %
Yellow Route NB	770	688	-10 %
Pink Route EB	656	772	17 %
Pink Route WB	975	817	-16 %
Routes Combined	**3695**	**3643**	**-1%**

Table 6-4 PM Peak Observed VS Modelled Journey Times

Route	Observed Time (Seconds)	Modelled Time (seconds)	% Difference
Orange Route SB	734	670	8 %
Orange Route NB	800	760	-5 %
Yellow Route SB	540	578	7 %
Yellow Route NB	705	680	-3 %
Pink Route EB	N/A	N/A	N/A
Pink Route WB	730	793	8 %
Routes Combined	**3509**	**3481**	**-1%**

6.3.6 The DMRB guidelines advise that modelled journey times should be within 15% of the observed time. For the PM peak period five out of five of the journey time routes satisfy these criteria.

6.3.7 Three out of five of the routes surveyed in the inter-peak and four out of five of those surveyed in the AM peak satisfy these criteria. However, as the average difference of the surveyed routes is well within the DMRB guidelines, this difference in the route time is acceptable.

6.3.8 Figures 6-2 to Figure 6-16 below plot time elapsed to each survey stage on each route for both the post-calibrated models for all time periods modelled. The charts demonstrate a clear correlation between observed and modelled delay in every case.

Figure 6-2 Journey Time: Orange Route Northbound AM

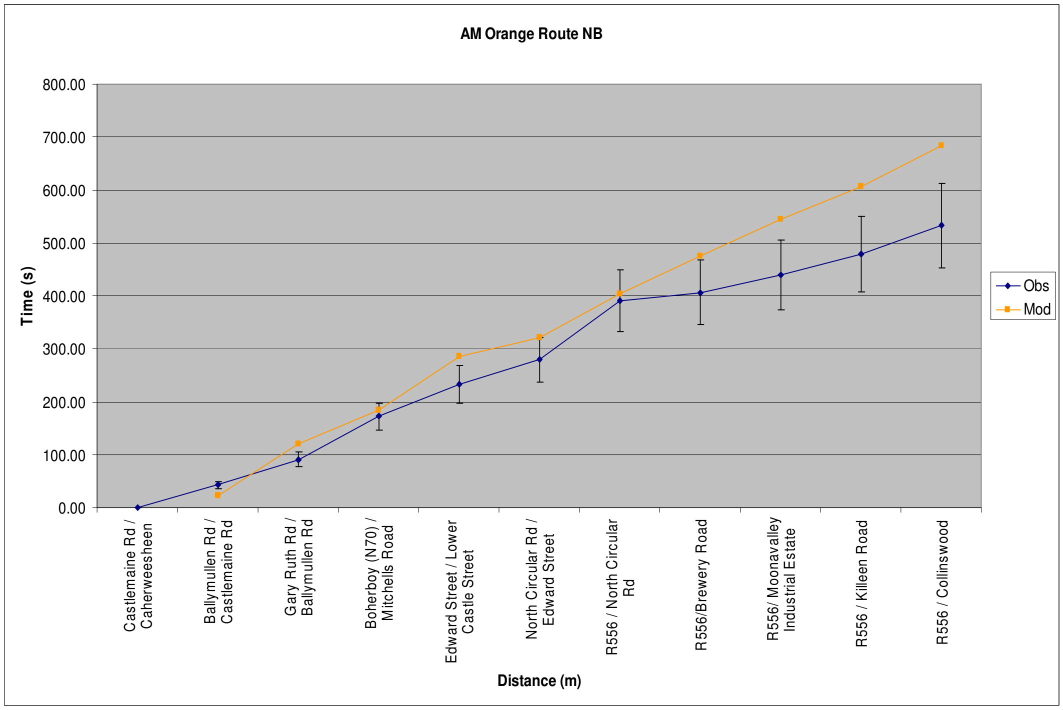

Figure 6-3 Journey Time: Pink Route Eastbound AM

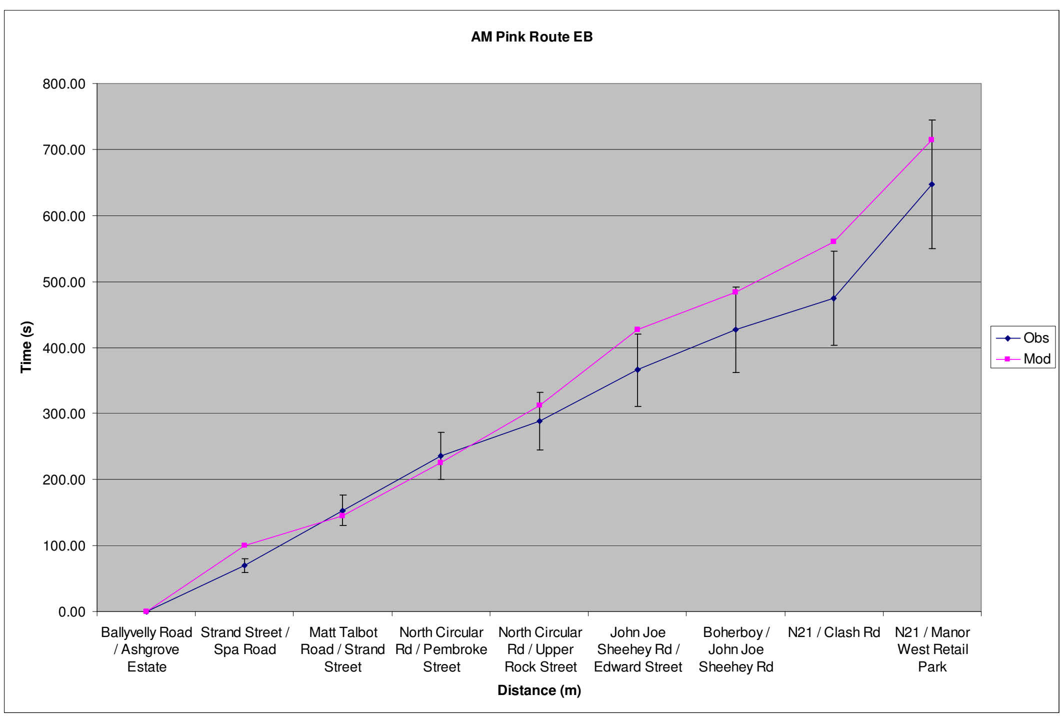

Figure 6-4 Journey Time: Pink Route Westbound AM

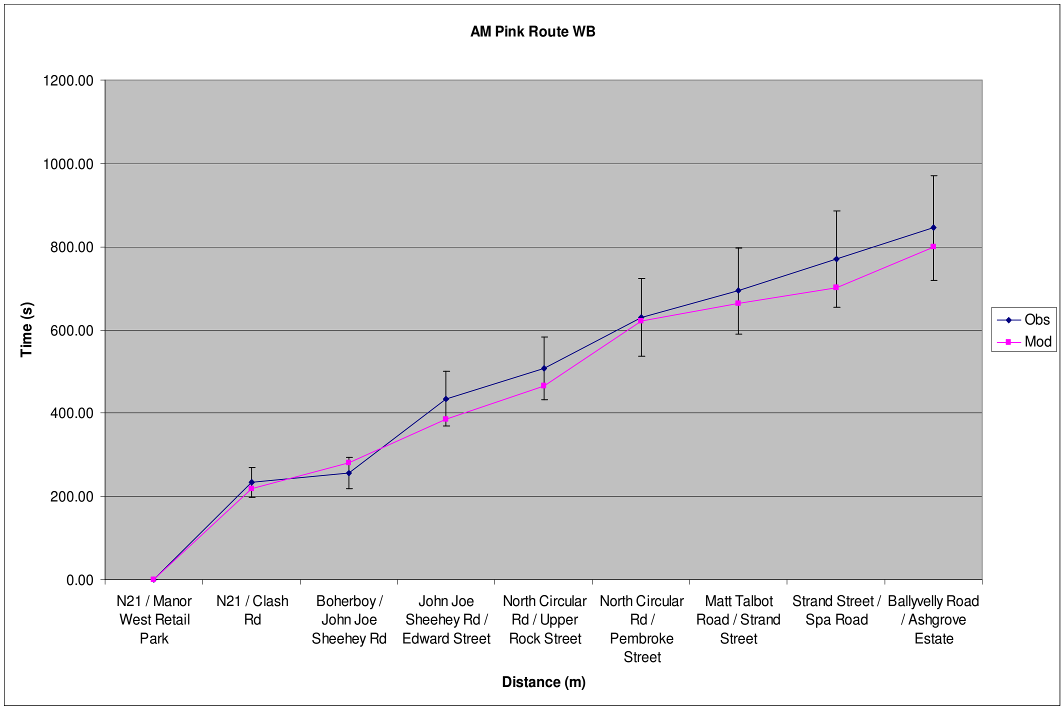

Figure 6-5 Journey Time: Yellow Route Southbound AM

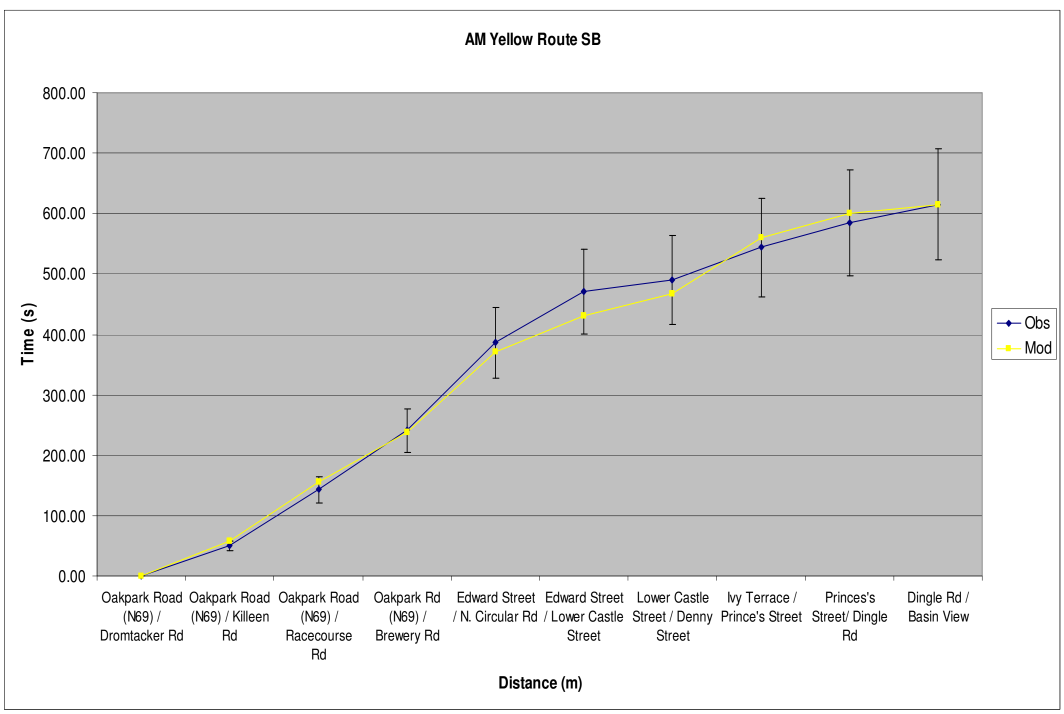

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Figure 6-6 Journey Time: Yellow Route Northbound AM

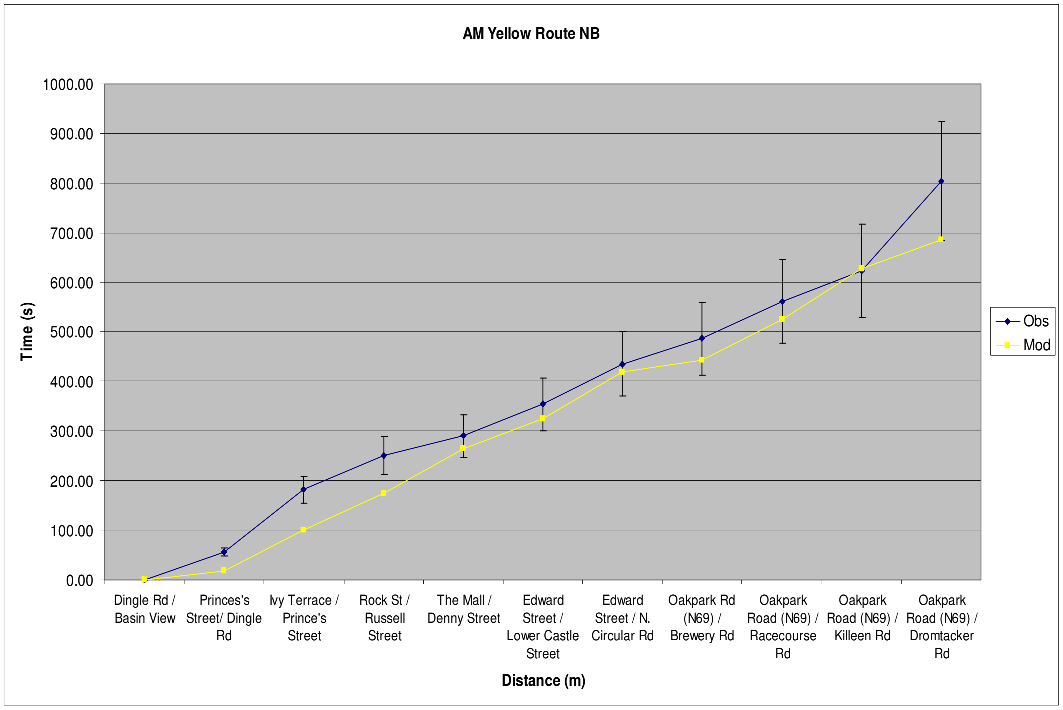

Figure 6-7 Journey Time: Orange Route Northbound IP

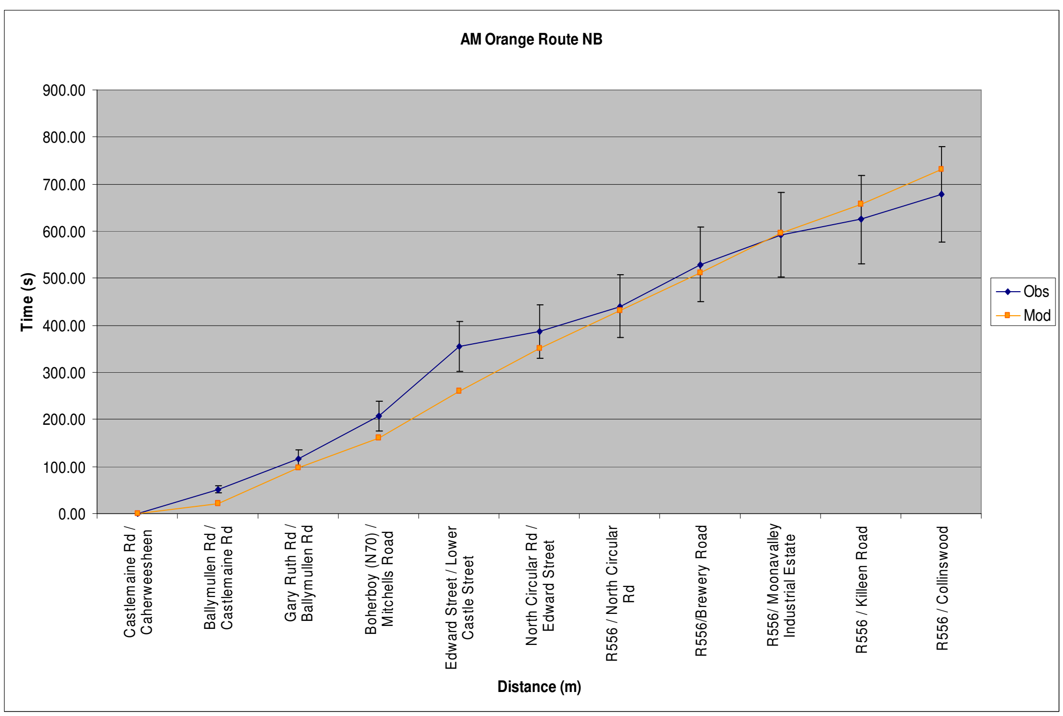

Figure 6-8 Journey Time: Yellow Route Southbound IP

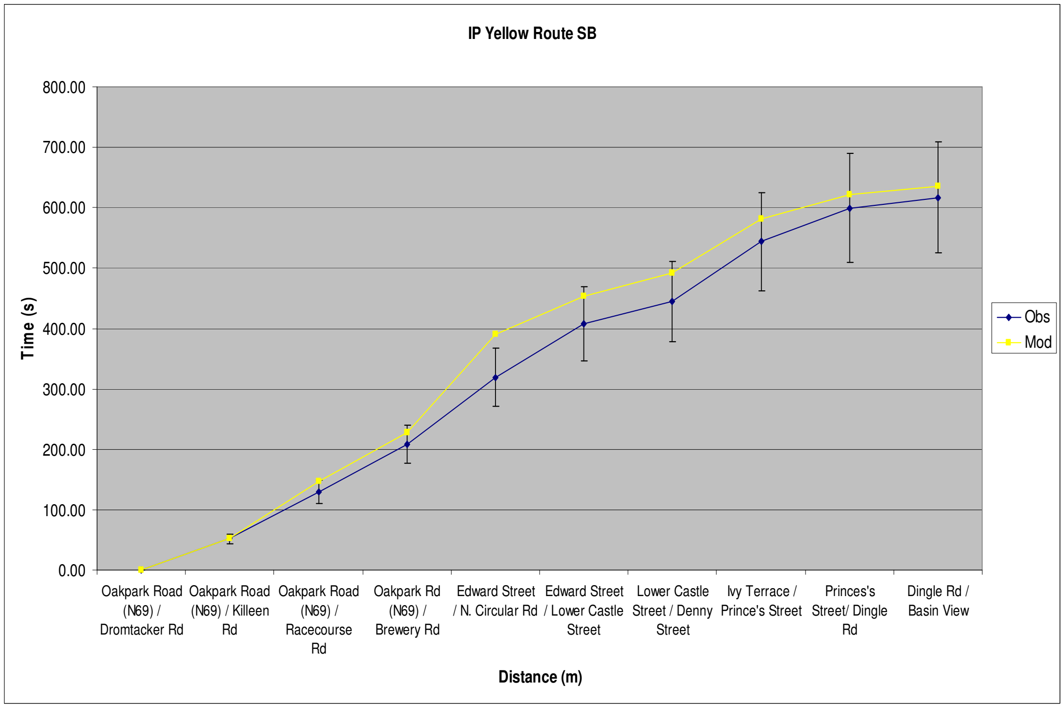

Figure 6-9 Journey Times: Yellow Route Northbound IP

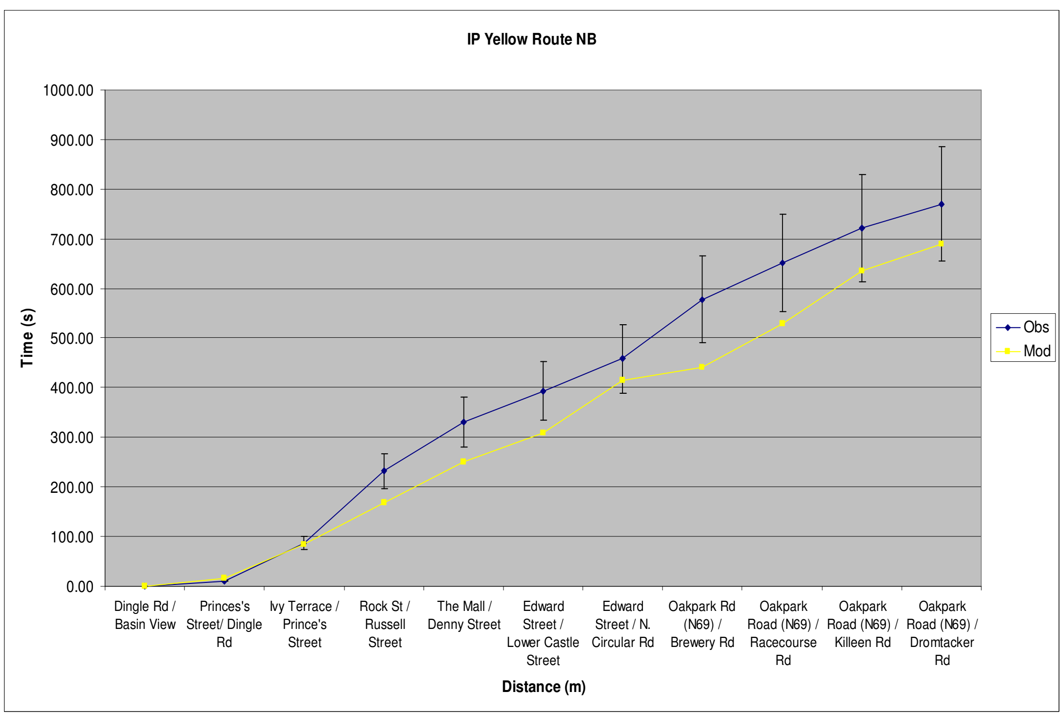

Figure 6-10 Journey Times: Pink Route Westbound IP

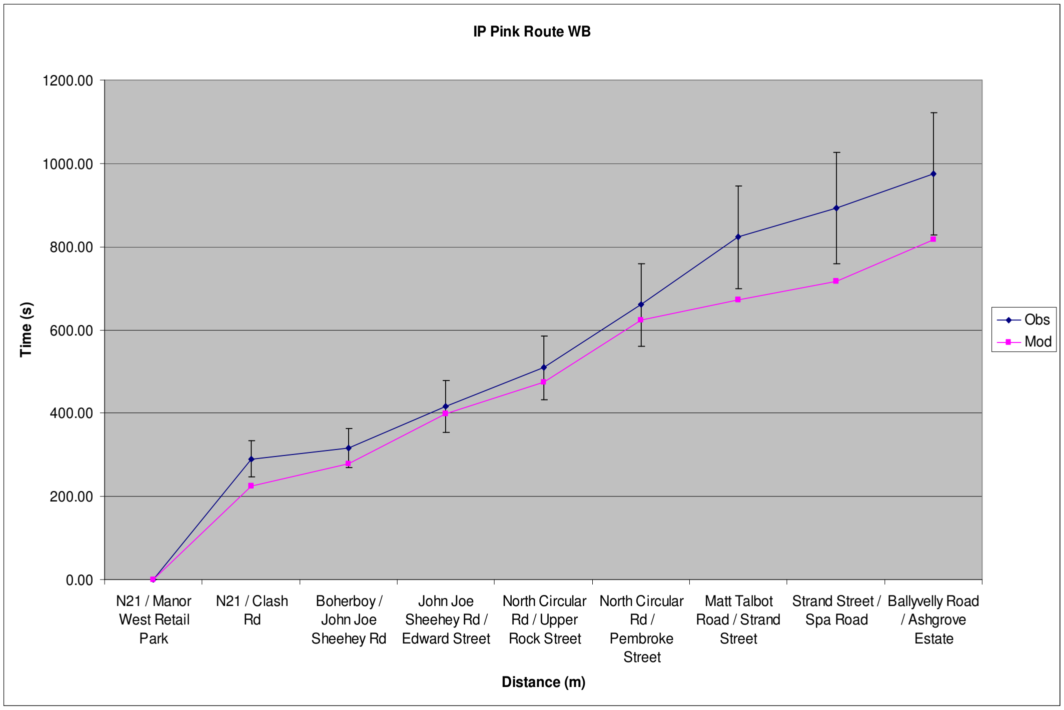

Figure 6-11 Journey Times: Pink Route Eastbound IP

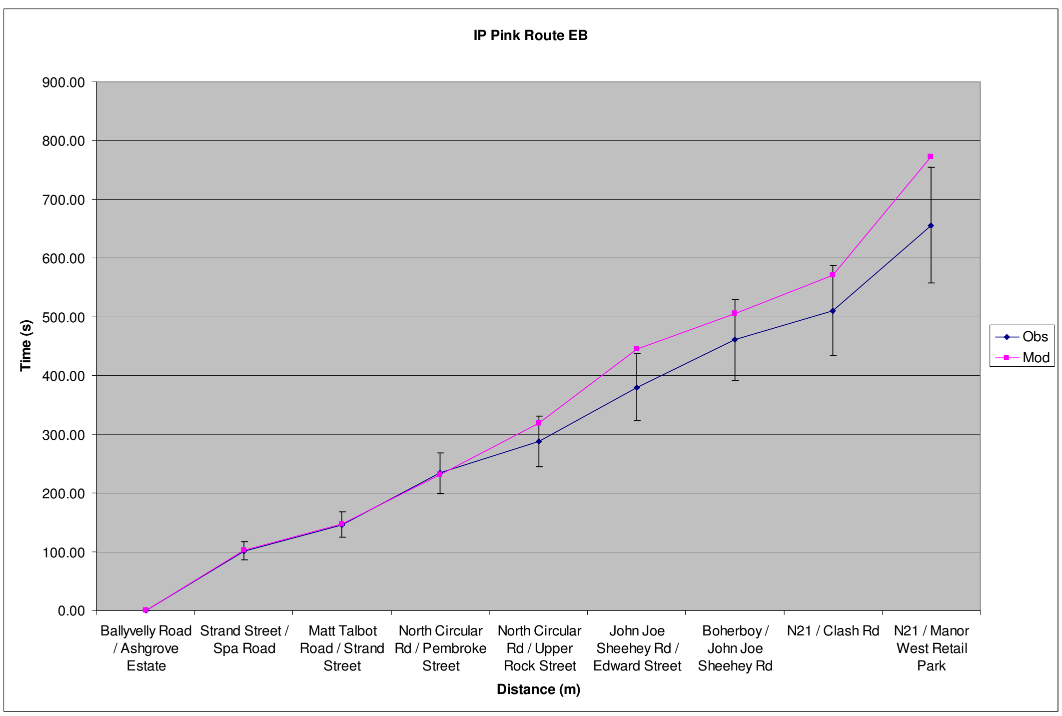

Figure 6-12 Journey Times: Orange Route Northbound PM

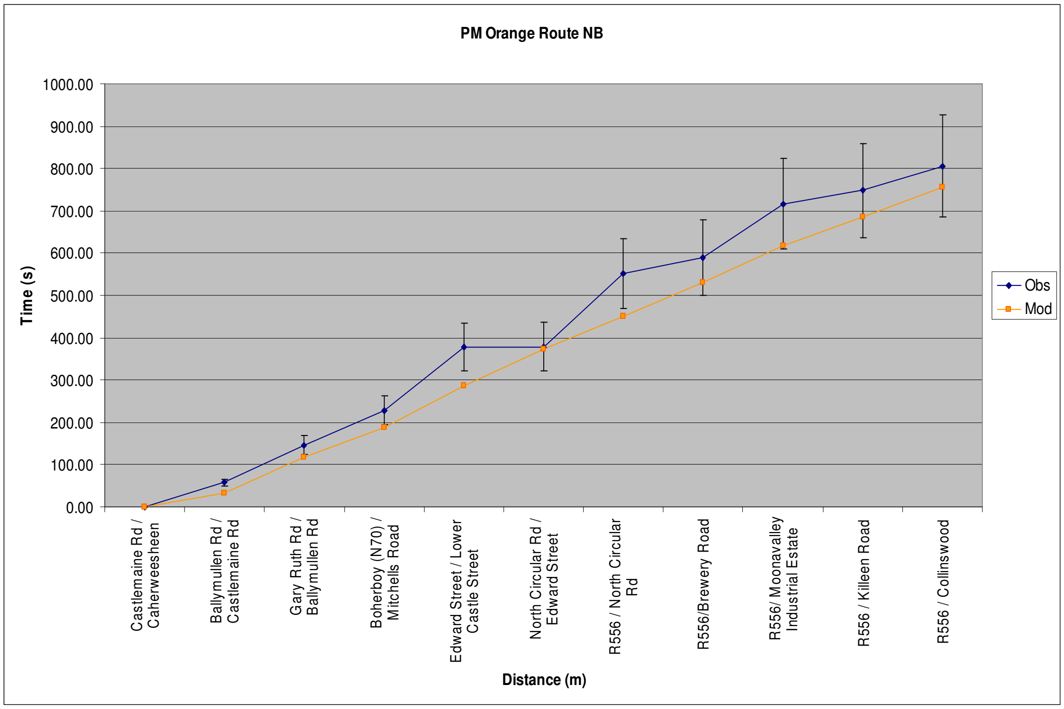

Figure 6-13 Journey Times: Orange Route Southbound PM

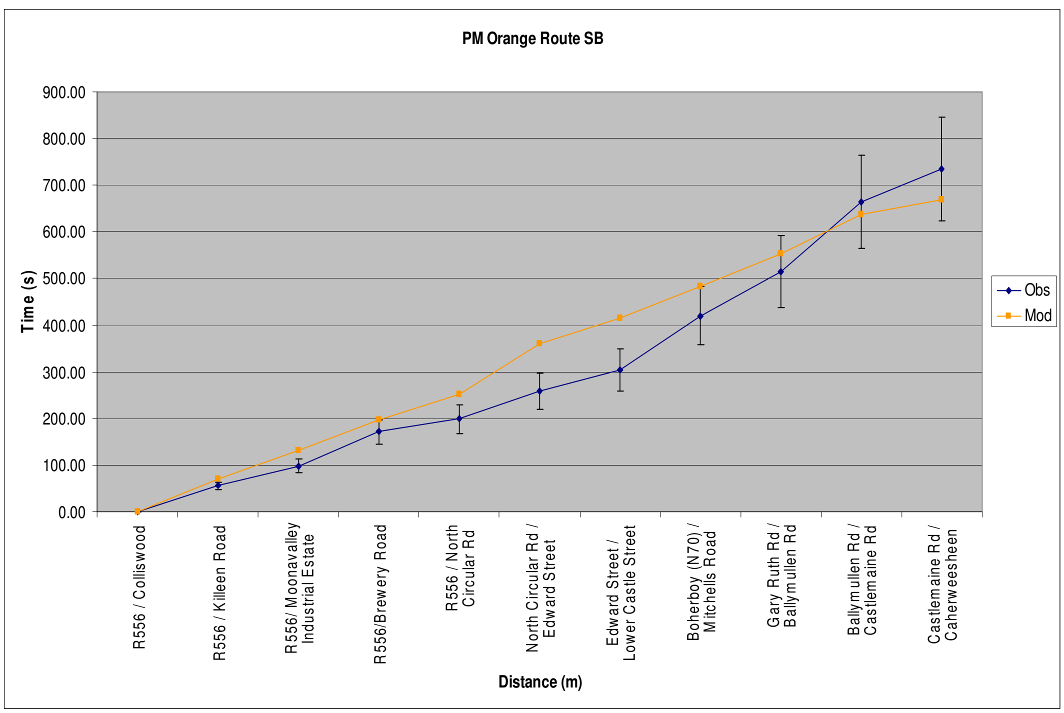

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Figure 6-14 Journey Times: Yellow Route Northbound PM

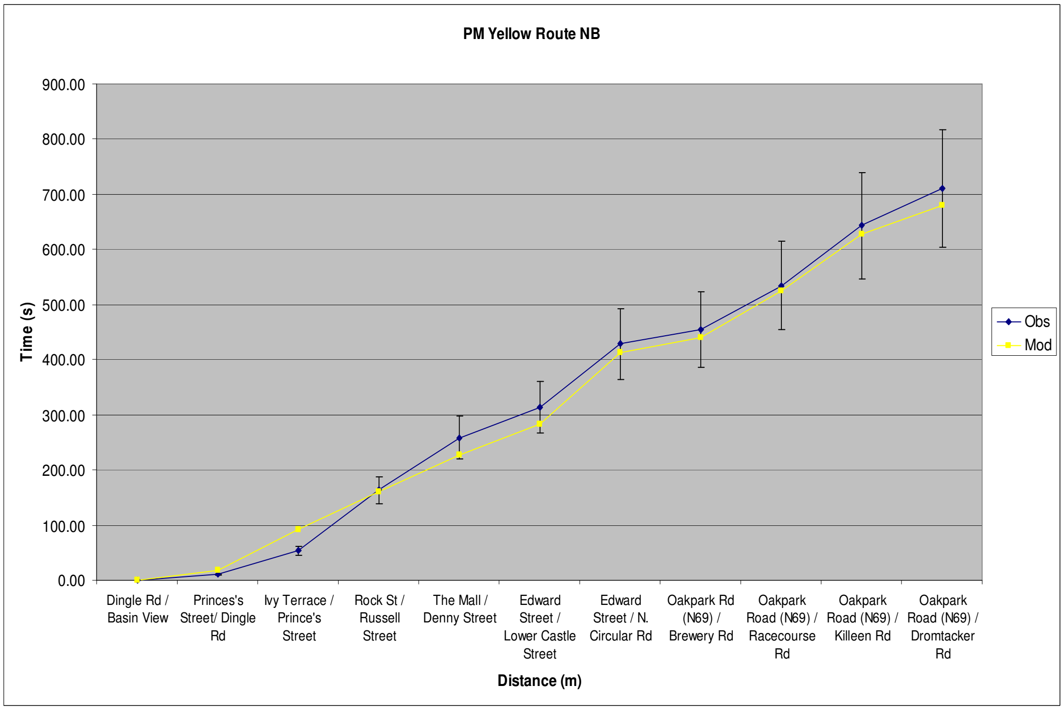


Figure 6-15 Journey Times: Yellow Route Southbound PM

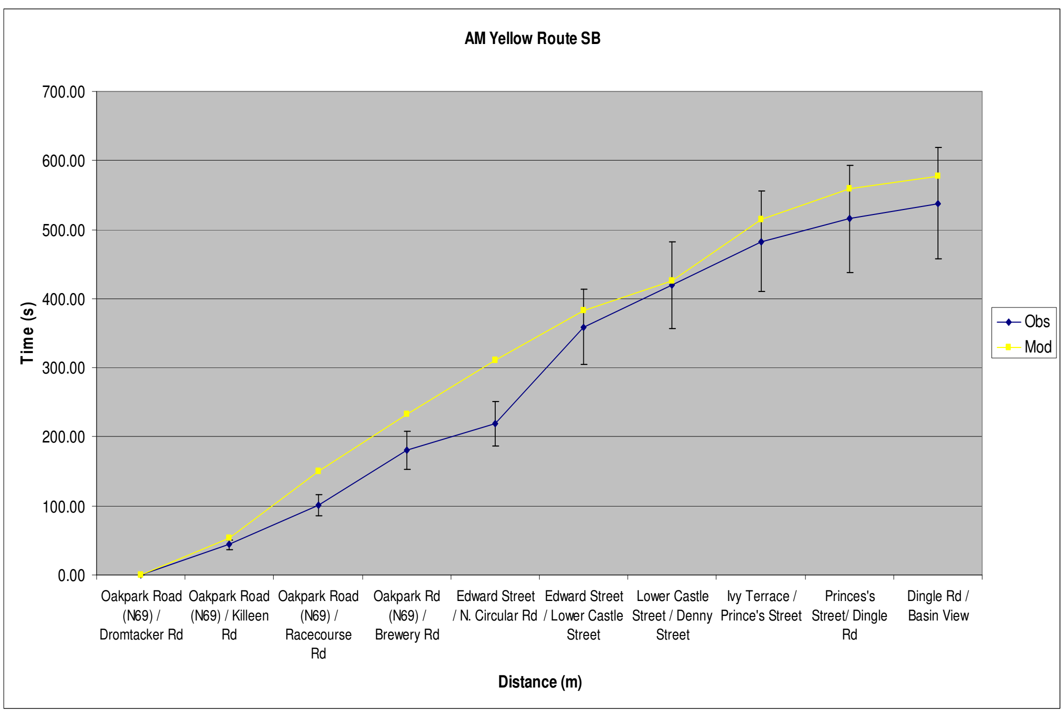
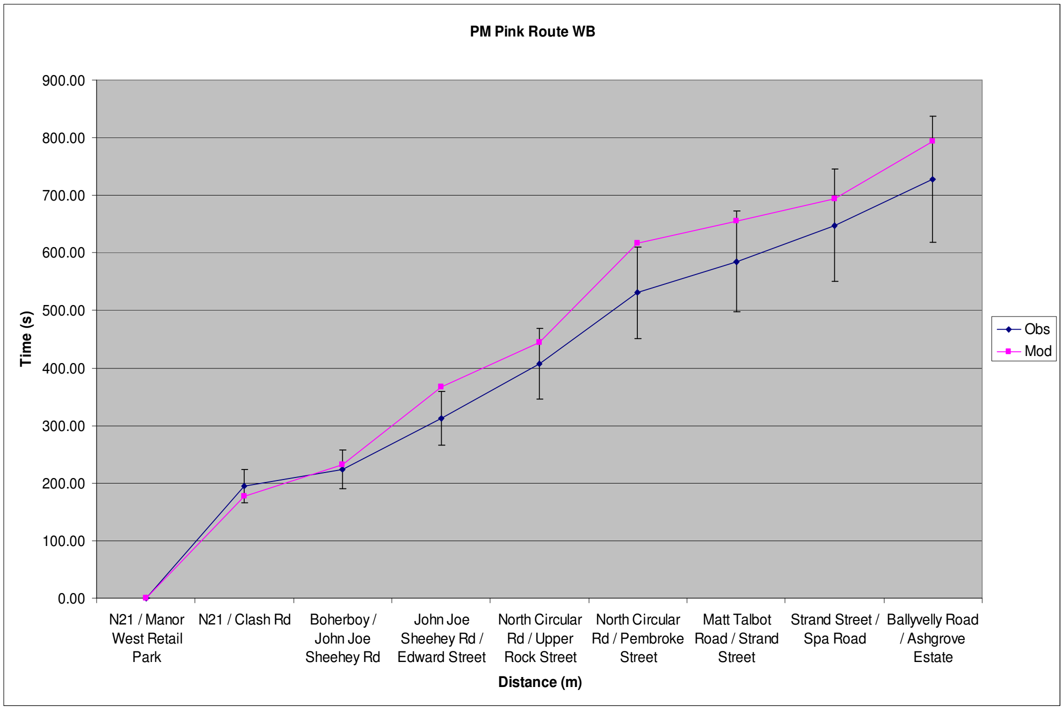


Figure 6-16 Journey Times: Pink Route Westbound PM



6.4 Origin Destination Testing

6.4.1 Origin-Destination testing provides us with another testing option to ensure the model is providing sensible movement patterns and flows throughout the network. OD testing works by comparing origin/destination movements observed during registration plate surveys, with origin destination movements in the model.

6.4.2 Comparisons of observed and modelled OD movements showed an extremely close match between what was observed and what was modelled adding further confidence to the Tralee Traffic Model.

6.4.3 Table 6-5 below summarises the findings of the OD movement comparison. Using the observed matrix summarising the OD movements and locations observed during the registration plate survey (summarised in Figure 3-4, the same OD movements were replicated in the SATURN model using Select Link Analysis. This method allows us to replicate OD movements from a single point which enables us to compare modelled and observed flows.

6.4.4 The analysis compares the percentage difference between observed and modelled. Summarised below is the percentage of findings within and outside a 25% limit. The findings are very positive with the bulk of comparisons fitting falling within the 25% cut off margin across all time periods.

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Table 6-5 Origin Destination Analysis

	Time Period		
	AM	IP	PM
Percentage movements within 25% of observed	89%	84%	100%
Percentage movements outside 25% of observed	11%	16%	0%

7 Conclusions

7.1 Introduction

7.1.1 This report documents the development, calibration, and validation of the Tralee Traffic Model (TTM) for a base year of 2009. The area of the model covers Tralee town and hinterlands and is shown above in Figure 1.1.

7.1.2 Three time periods were modelled, calibrated and validated. These are the AM peak period from 08:30 to 9:00, the Inter-Peak Period from 14:30 to 14:00 and the PM peak period from 17:00 to 17:30.

7.1.3 Traffic flow calibration and validation indicates that the correlation between modelled and observed flows is excellent for the Tralee area for all periods modelled.

7.1.4 The traffic flow validation of 79 individual link flows is acceptable using both the standard guidelines and the alternative criteria outlined by the DMRB. The regression analysis also indicates that there is no strong bias in the modelled flows.

7.1.5 We consider that the highway assignment model is fit for purpose. It represents AM, IP and PM peak period base year traffic conditions well, as demonstrated statistically in Chapters 4 and 5. It provides a robust basis for assessing impacts on the road network with the introduction of large scale developments as:

- The model realistically represents journey times;
- The study area is covered by a large number of counts for both calibration and validation; and
- Regression analysis indicates a high correlation between modelled and observed flows and no strong biases.

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Validation Report Appendix A – Survey Locations

Automated traffic Counts by Count on Us

Site	Location	Exact	Direction	Start Date	End Date
1	N86 near Blannerville	Sign Post	Eastbound	23/11/09	29/11/09
			Westbound	23/11/09	29/11/09
2	R558 between Tralee and an spa	Telegraph Pole	Eastbound	23/11/09	29/11/09
			Westbound	23/11/09	29/11/09
3	R551 near Ardrert	Telegraph Pole	Northbound	23/11/09	29/11/09
			Southbound	23/11/09	29/11/09
4	Unnamed Road North west of Lisloose	Telegraph pole	Eastbound	01/12/09	07/12/09
			Westbound	01/12/09	07/12/09
5	R556 near Collinswood	Sign Post	Northbound	23/11/09	29/11/09
			Southbound	23/11/09	29/11/09
6	N69 between Listowel And Tralee	Sign Post	Northbound	23/11/09	29/11/09
			Southbound	23/11/09	29/11/09
7	Tralee near dromtuckeer road	Sign Post	Eastbound	23/11/09	29/11/09
			Westbound	23/11/09	29/11/09
8	Between Ballinorig Road	Telephone	Northbound	23/11/09	29/11/09

	and Caherwisheen Road	Pole	Southbound	23/11/09	29/11/09
9	N21 at Maglass	Crash Barrier	Eastbound	23/11/09	29/11/09
			Westbound	23/11/09	29/11/09
10	N22 North Of Faranfore	Crash Barrier	Northbound	23/11/09	29/11/09
			Southbound	23/11/09	29/11/09
11	Unnamed road at Mountnicholas	Telegraph pole	Northbound	01/12/09	07/12/09
			Southbound	01/12/09	07/12/09
12	N70 at Garaun	Telegraph pole	Northbound	23/11/09	29/11/09
			Southbound	23/11/09	29/11/09
13	Unnamed road between Ballyseedey and N70	Lamp post	Northbound	23/11/09	29/11/09
			Southbound	23/11/09	29/11/09
14	Unnamed Road Between Caherleheen and Curragraigue	Lamp Post	Eastbound	23/11/09	29/11/09
			Westbound	23/11/09	29/11/09

Manual Turning Counts by Count on Us

Site	Location	Date	Day
1	Dan Spring Rd / Dingle Rd Roundabout	Thursday	26/11/2009
2	Basin Rd / James Street	Thursday	26/11/2009
3	Strand Street / Matt Talbot Rd	Thursday	26/11/2009
4	Matt Talbot Rd / R551	Thursday	26/11/2009
5	Upper Rock Street / North Circular Road	Thursday	26/11/2009
6	N. Circular Rd / Ashe Street	Thursday	26/11/2009
7	Edward Street / N. Circular Rd	Thursday	26/11/2009
8	N69 / N70	Thursday	26/11/2009
9	Clash Road / Quill Street	Thursday	26/11/2009
10	N21 / Killerisk Rd	Thursday	26/11/2009
11	Killerisk Rd / Castlemaine Rd	Thursday	26/11/2009
12	Stephens Terrace / Garry Ruth Rd	Thursday	26/11/2009
13	Moyderwell / Upper Castle Street	Thursday	26/11/2009
14	Lower Castle Street / Denny Street	Thursday	26/11/2009
15	Rock Street / Pembroke Street	Thursday	26/11/2009

Validation Report Appendix B – Convergence Statistics

Am Peak Convergence Stats

Summary of the Main Convergence Statistics AM Peak	
Number of Ass-Sim Loops	9
Assignment Delta (%)	0.01
Number of Ass Iterations	50
Simulation Convergence	0.0014
Number of Sim Iterations	3
% of OK Flows < 5.00%	99.62
Mean GEH Flow Statistic	0.018
Mean Abs Flow Difference %	0.22
Rel Mean Abs Flow Diff. %	0.57
Rel Mean Standard Dev. %	0.2
% of OK Turn Delays	99.87
Mean Abs Diff in Ass/Sim Del	0.03
Relative to mean delay:(%)	0.33
Convergence Gap (%)	0.052
Variational Inequality (%)	0.003
Change in ASS-HRS (%)	0.019
Loop n - 1	-0.005
Loop n - 2	0.023
Loop n - 3	-0.024

Change in PCU-KMS (%)	0.024
Loop n - 1	0.029
Loop n - 2	0.01
Loop n - 3	-0.001
No of calls to MAXQCT	0
No of calls to MAXDTP	0
Delta (%) on the .UFC file	0.032
Total CPU time (seconds)	46.8

Inter Peak Convergence Statistics

Summary of the Main Convergence Statistics Inter Peak	
Number of Ass-Sim Loops	9
Assignment Delta (%)	0.0094
Number of Ass Iterations	50
Simulation Convergence	0.003
Number of Sim Iterations	3
% of OK Flows < 5.00%	99.46
Mean GEH Flow Statistic	0.016
Mean Abs Flow Difference %	0.2
Rel Mean Abs Flow Diff. %	0.48
Rel Mean Standard Dev. %	0.16
% of OK Turn Delays	100

Mean Abs Diff in Ass/Sim Del	0.02
Relative to mean delay:(%)	0.23
Convergence Gap (%)	0.028
Variational Inequality (%)	0.002
Change in ASS-HRS (%)	0.016
Loop n - 1	-0.002
Loop n - 2	0.16
Loop n - 3	-0.07
Change in PCU-KMS (%)	0.006
Loop n - 1	0.004
Loop n - 2	-0.007
Loop n - 3	-0.107
No of calls to MAXQCT	0
No of calls to MAXDTP	0
Delta (%) on the .UFC file	0.029
Total CPU time (seconds)	43.9

PM Peak Convergence Statistics

Summary of the Main Convergance Statistics PM Peak	
Number of Ass-Sim Loops	8
Assignment Delta (%)	0.015
Number of Ass Iterations	50
Simulation Convergence	0.0008
Number of Sim Iterations	3
% of OK Flows < 5.00%	97.78
Mean GEH Flow Statistic	0.051
Mean Abs Flow Difference %	0.65
Rel Mean Abs Flow Diff. %	1.9
Rel Mean Standard Dev. %	0.58
% of OK Turn Delays	99.62
Mean Abs Diff in Ass/Sim Del	0.11
Relative to mean delay:(%)	1.06
Convergence Gap (%)	0.146
Variational Inequality (%)	0.008
Change in ASS-HRS (%)	-0.313
Loop n - 1	0.21
Loop n - 2	-0.396
Loop n - 3	0.353

Change in PCU-KMS (%)	0.091
Loop n - 1	-0.053
Loop n - 2	0.105
Loop n - 3	-0.04
No of calls to MAXQCT	0
No of calls to MAXDTP	0
Delta (%) on the .UFC file	0.03
Total CPU time (seconds)	39.7

Validation Appendix C - Calibration Links (GEH Stats)

PCUs Combined 8:30-9.00

Observed (PCUs)	Model (PCUs)	Difference	% Difference	GEH
201	149	-52	-26%	3.9
75	101	26	34%	2.8
242	264	22	9%	1.4
165	154	-11	-7%	0.9
81	100	19	23%	2.0
346	340	-6	-2%	0.3
93	177	84	90%	7.2
290	294	4	2%	0.3
217	206	-11	-5%	0.8
252	199	-53	-21%	3.5
131	111	-20	-15%	1.8
73	29	-44	-61%	6.2
476	463	-13	-3%	0.6
395	308	-87	-22%	4.6
158	107	-51	-33%	4.5
133	177	44	33%	3.5
236	174	-62	-26%	4.3
159	127	-32	-20%	2.7
159	159	0	0%	0.0
343	370	27	8%	1.4
532	494	-38	-7%	1.7
146	177	31	21%	2.4
261	209	-52	-20%	3.4
353	202	-151	-43%	9.1
475	462	-13	-3%	0.6
330	316	-14	-4%	0.8
296	314	18	6%	1.0
354	329	-25	-7%	1.4
393	412	19	5%	0.9
16	27	11	69%	2.4
369	389	20	5%	1.0
227	223	-4	-2%	0.3
285	253	-32	-11%	2.0
106	101	-5	-5%	0.5
159	186	27	17%	2.0
180	133	-47	-26%	3.8
106	162	56	53%	4.8
21	29	8	38%	1.6
4	11	7	186%	2.7
173	157	-16	-9%	1.2
205	231	26	13%	1.8
279	272	-7	-3%	0.4
271	234	-37	-14%	2.3
127	125	-2	-2%	0.2
340	263	-77	-23%	4.4
467	477	10	2%	0.4
218	205	-13	-6%	0.9
246	278	32	13%	2.0
253	304	51	20%	3.1

394	385	-9	-2%	0.4
317	359	42	13%	2.3
204	200	-4	-2%	0.3
63	99	36	56%	4.0
163.2	235	72	44%	5.1
52.8	64	11	22%	1.5
277.8	321	43	15%	2.5
90.6	92	1	1%	0.1
53.4	91	38	71%	4.4
16.2	18	2	9%	0.4
58.2	87	29	50%	3.4
205.8	127	-79	-38%	6.1
303	424	121	40%	6.3
123	138	15	12%	1.3
7.8	20	12	152%	3.2
7.8	16	8	103%	2.3
11.4	21	10	88%	2.5
3	11	8	256%	2.9
141.6	186	45	32%	3.5
355.8	364	8	2%	0.4
192.6	323	130	68%	8.1
266.4	285	19	7%	1.1
3	0	-3	-100%	2.4
1.2	0	-1	-100%	1.5
103.2	146	43	42%	3.9
172.2	225	52	30%	3.7
126.6	194	67	53%	5.3
32.4	56	23	72%	3.5
3	4	1	41%	0.6
4.2	24	20	480%	5.3

PCUs Combined 14:00-1430

Observed (PCUs)	Model (PCUs)	Difference	% Difference	GEH
172	162	-10	-6%	0.8
73	106	33	46%	3.5
160	252	92	57%	6.4
207	204	-3	-2%	0.2
77	75	-2	-3%	0.3
254	266	12	5%	0.8
114	177	63	55%	5.2
261	282	21	8%	1.3
198	187	-11	-6%	0.8
220	220	0	0%	0.0
89	64	-25	-28%	2.9
96	34	-62	-64%	7.7
315	326	11	4%	0.6
381	391	10	3%	0.5
70	55	-15	-22%	1.9
125	124	-1	-1%	0.1
177	160	-17	-10%	1.3
188	123	-65	-34%	5.2
132	170	38	29%	3.1
468	468	0	0%	0.0
553	517	-36	-6%	1.5
211	241	30	14%	2.0
287	262	-25	-9%	1.5
251	190	-61	-24%	4.1
374	391	17	4%	0.9
324	300	-24	-7%	1.4
493	461	-32	-7%	1.5
458	414	-44	-10%	2.1
267	246	-21	-8%	1.3
44	55	11	25%	1.6
308	314	6	2%	0.3
153	170	17	11%	1.3
344	312	-32	-9%	1.7
147	172	25	17%	2.0
28	115	87	310%	10.3
234	112	-122	-52%	9.2
67	153	86	128%	8.2
19	40	21	112%	3.9
2	7	5	258%	2.4
180	203	23	13%	1.6
86	109	23	26%	2.3
152	146	-6	-4%	0.5
130	167	37	28%	3.0
144	113	-31	-21%	2.7
283	261	-22	-8%	1.4
330	392	62	19%	3.2
203	220	17	9%	1.2
206	244	38	18%	2.5
252	292	40	16%	2.4

459	444	-15	-3%	0.7
315	355	40	13%	2.2
99	97	-2	-2%	0.2
110	102	-8	-8%	0.8
92	93	1	1%	0.1
101	101	0	0%	0.0
152	135	-17	-11%	1.4
135	131	-4	-3%	0.3
20	22	2	10%	0.4
17	19	2	12%	0.5
88	88	0	0%	0.0
89	92	3	3%	0.3
130	130	0	0%	0.0
122	119	-3	-2%	0.3
4	12	8	211%	2.9
8	15	7	88%	2.1
4	6	2	45%	0.8
6	14	8	129%	2.5
161	138	-23	-14%	1.9
153	153	0	0%	0.0
163	163	0	0%	0.0
131	132	1	1%	0.1
2	0	-2	-100%	2.0
2	0	-2	-100%	2.0
62	63	1	2%	0.1
63	66	3	4%	0.3
59	58	-1	-2%	0.1
38	42	4	10%	0.6
5	4	-1	-21%	0.5
5	5	0	-3%	0.1

PCUs Combined 15:00-15:30

Observed (PCUs)	Model (PCUs)	Difference	% Difference	GEH
173	186	13	7%	1.0
96	97	1	1%	0.1
177	223	46	26%	3.2
192	202	10	5%	0.7
60	55	-5	-8%	0.7
224	237	13	6%	0.8
125	157	32	26%	2.7
189	208	19	10%	1.4
237	219	-18	-8%	1.2
164	137	-27	-17%	2.2
147	107	-40	-28%	3.6
124	51	-73	-59%	7.7
394	443	49	12%	2.4
527	539	12	2%	0.5
149	117	-32	-22%	2.8
122	102	-20	-16%	1.9
191	195	4	2%	0.3
177	154	-23	-13%	1.8
164	254	90	55%	6.2
424	431	7	2%	0.3
563	580	17	3%	0.7
122	277	155	127%	11.0
267	279	12	5%	0.7
292	278	-15	-5%	0.9
430	424	-6	-1%	0.3
281	276	-5	-2%	0.3
501	483	-18	-4%	0.8
361	371	10	3%	0.5
240	240	0	0%	0.0
60	101	41	68%	4.5
321	338	17	5%	1.0
245	233	-12	-5%	0.8
353	388	35	10%	1.8
92	220	128	140%	10.3
158	136	-22	-14%	1.8
207	170	-37	-18%	2.7
64	64	0	-1%	0.0
18	25	7	38%	1.5
2	13	11	550%	4.0
182	186	4	2%	0.3
61	96	35	58%	4.0
123	60	-63	-51%	6.6
104	163	59	57%	5.1
179	162	-17	-9%	1.3
237	182	-55	-23%	3.8
316	343	27	8%	1.5
234	227	-7	-3%	0.5
215	239	24	11%	1.6
204	232	28	14%	1.9

428	456	28	7%	1.3
342	362	20	6%	1.0
97.28	96	-1	-1%	0.1
200.32	184	-16	-8%	1.2
64.64	70	6	9%	0.7
120.96	126	5	4%	0.4
224	222	-2	-1%	0.1
112	112	0	0%	0.0
17.92	20	2	12%	0.5
42.88	43	0	0%	0.0
92.16	93	1	1%	0.1
202.88	203	0	0%	0.0
236.16	237	1	0%	0.1
133.76	133	-1	-1%	0.1
7.68	15	7	89%	2.1
11.52	12	0	4%	0.1
7.68	15	7	94%	2.1
6.4	8	2	25%	0.6
218.88	216	-3	-1%	0.2
292.48	292	0	0%	0.0
300.8	297	-4	-1%	0.2
200.96	201	0	0%	0.0
5.76	0	-6	-100%	3.4
3.2	0	-3	-100%	2.5
155.52	157	1	1%	0.1
84.48	85	1	1%	0.1
88.96	87	-2	-2%	0.2
112.64	118	5	4%	0.5
3.84	6	2	51%	0.9
3.2	4	1	18%	0.3