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Project Appraisal Guidelines Unit 5.1 - Construction of Transport Models

PE-PAG-02015
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PE Planning & Evaluation

Technical

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Sections 1 to 3 moved to Project Appraisal Guidelines Unit 5.0 – Scoping of Transport Modelling. New Sections 1 (Intro) and 6 (Variable Demand Modelling). Remaining chapters left in place and updated to provide improved reference to public transport/multi-modal modelling.

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1. Introduction

PAG Unit 5.0 provides an overview of transport models and specifies the process involved in the preparation of a transport model for use in the appraisal of transport infrastructure. This PAG Unit provides more detailed guidance on the development of transport models for use in the appraisal of transport infrastructure, focusing in particular on Variable Demand Models and Base and Future Year representations of the transport system.

2. Base Year Model Development

2.1 Overview

This section is generally focussed on the development of assignment models. Microsimulation modelling is not dealt with explicitly, however many of the principles of the following paragraphs are equally applicable.

2.2 Model Cordoning

Creating a cordon model from a strategic donor model is often the starting point in developing a local area assignment model. Cordon models are generally created from a larger strategic model e.g. the National Transport Model. Note that the road based travel element of the National Transport Model has been developed to represent the average AM Peak hour (07:00 – 09:00) and an average Inter Peak hour (12:00 – 14:00).

Prior to creating a cordon model, establishing the extents of the study area for the local assignment model is vital. The study area should be identified using for instance, the 2050 High Growth National Transport Model version within which a Do Something version (scheme in place) is tested. The extents of the cordon model should be defined by changes in link flows. Care should be taken to ensure the extents of the cordon model are not too tightly drawn and the resultant model is sufficiently large to assess all potential Do Something variants.

Following the cordoning process and due to the general nature of the strategic donor model, it is expected that the road network be further refined to ensure an enhanced reflection of the road network and its characteristics. It is also expected that the zoning system and demand matrices from the donor model also be refined to improve the representation of trip patterns.

Cordon models are typically created for the assignment stage only. The donor model typically includes a variable demand model and can therefore be used to calculate demand matrices with and without the scheme being assessed for application in the cordon model. This is the case where a cordon model is created from the National Transport Model.

2.3 Network Building

The level of network detail required will be greater in the core area close to the scheme and will decrease as the distance from scheme increases. In the core area it will be necessary to include all main roads and public transport routes, as well as those more minor routes that are likely to carry critical traffic movements, either in the base or future years. Capacity restraint should usually be applied throughout the core area and separate junction modelling will also be required in those parts of the model where junction capacities have a significant impact on drivers’ route choice, and where delays are not adequately included in the speed-flow relationships.

In the wider model area, the network description will need to cover all routes necessary to feed traffic and passengers to the boundary of the core area in a realistic way (i.e. with realistic distances and times). Care must be taken not to encourage unrealistic reassignments to routes that could avoid the core area, especially if fixed speeds are specified on external network links and no capacity restraint is applied, as is sometimes the case.

In most packages, special links (usually referred to as ‘zone connectors’) are used to load traffic and passengers onto the model network. The position of these connectors is often a critical factor in achieving realistic results from the assignment model. Zone connectors should not cross barriers to vehicular or passenger movement.

In the core area, they must be located as realistically as possible, and in particular must not be connected directly into modelled junctions, unless a specific arm exists to accommodate that movement. If zones are significantly larger than implied by the detail of the network, it will often be impossible to locate zone connectors realistically. This may lead to distorted traffic and passenger flows on nearby links, and turning movements at nearby junctions, which may themselves distort traffic patterns elsewhere in the network. In urban areas in particular, zones should be small enough to avoid this type of problem. As a consequence, efforts should be made to minimise the number of connectors from individual zones, multiple connectors can lead to assignment instability and model convergence problems. Connectors from adjacent zones should not connect to the network at the same point.

2.3.1 Highway

Network descriptions for highway assignment models will often need to include both link and junction details. Links are generally described in terms of:

- Nodes at each end of the link (i.e. junctions or changes in standard)
- Link length
- The speed-flow relationship (if any) appropriate for the link
- Link capacity (if not defined by speed-flow relationships or junction details)
- Any restrictions to particular vehicle types using the link

In urban areas it may also be necessary to consider the impact of traffic management measures such as bus lanes, traffic calming, parking controls and cycle lanes on the capacity and operating characteristics of individual network links. The usual requirements for junction coding, where this is required, are:

- Junction type (traffic signals, roundabouts, priority)
- Number of approach arms, and their order (in terms of entry link references)
- Number and width of traffic lanes on each junction approach, and the lane discipline adopted (including prohibited turns)
- Any additional data required to describe the operational characteristics of the junction (e.g. saturation flows, signal timings and phasing, turning radii and gap acceptance characteristics).

2.3.2 Public Transport

Network descriptions for public transport assignment models comprise of links and services. Links are generally described in terms of:

- Nodes at each end of the link
- Link length
- Restrictions to use by particular public transport sub-modes or walk

The key parameters affecting the assignment are defined within the services. These include the definition of the crowding curve i.e. the relationship between levels of crowding and the perceived cost of crowding, headway, service capacity (which is used to define the level of crowding when compared with demand) and in-vehicle times. Services are generally described in terms of:

- Route code
- Route description
- Mode

- Operator
- Crowd Curve
- Headway
- Vehicle capacity (seated and total)
- Itinerary (or routing through the transport network as defined by the sequencing of nodes traversed)
- Stopping pattern
- Times between stops

2.4 Matrix Building

The production of base year trip matrices forms the foundation for the future year trip matrices used in scheme appraisal. They can be created from scratch but will often be based on:

- a cordon from a larger strategic model
- an existing model which may be an older one from the area
- from a regional model
- a model from an adjacent scheme

In the case of an older local area model, the trip matrix may need to be re-validated using more recent count data.

Mobile / Bluetooth and Automatic Number Plate Recognition surveys can aid the construction of matrices; trips are defined by the place of trip origin and the trip destination within the study area. This is known as an Origin-Destination (O/D) based matrix. Assignment models use this form of matrix.

An alternative way of looking at the pattern of trips is to consider the factors that produce or attract trips, i.e. on a Production-Attraction (P/A) basis, with home generally being treated as the "producing" end, and work, retail etc. as the "attracting" end. Trip production is usually defined as the home end of a home based trip or the origin of a non-home-based trip. Trip attraction on the other hand is defined as the non-home-based end of a home-based trip or the destination of a non-home-based trip. Changes in these P/A trip end forecasts over time or by scenario will lead to changes in the trip pattern. This definition of the trip matrix has normally been used in modelling travel demand and is a prerequisite for full variable demand modelling. It is not however, generally required, in the production of local area models.

Base year trip matrices are typically assembled using some combination of the following procedures:

- O/D data factoring, whereby old origin to destination data is scaled, preferably to new traffic and passenger counts at the old RSI locations or at screenlines
- Matrix construction, whereby new OD data is used to calculate the observed movements of a trip matrix
- Matrix infilling, which relates to the estimation of unobserved trip movements, either by using parts of another matrix, or by the use of a model (e.g. gravity model)
- Matrix manipulation where observed and infilled parts of a trip matrix are combined
- Other matrix manipulations required to obtain origin to destination matrices for assignment such as matrix estimation techniques

There is an important difference between these techniques. Matrix construction and infilling can be carried out separately for different trip purposes and/or vehicle types, but matrix updating based on count data can only be applied to vehicle types.

There are two main methods of deriving trip matrices for individual time periods:

- Constructing matrices directly from the origin to destination data relating to the specific period
- Constructing matrices by combining specified proportions of the all day (12 or 16-hour) Production/Attraction matrices for each trip purpose

2.5 Assignment of Trips to a Network

Once the network, zoning system and trip matrices for a model have been constructed, the next stage is to ‘assign’ or ‘load’ the trip matrices on to the network.

The aim of both highway and public transport assignment models is to reach equilibrium such that generalised costs and traffic (or passenger) flows are in balance, under the assumption that individual users will seek to minimise their own costs of travel through the network. The underlying principle is expressed as Wardrop’s First Principle of Traffic Equilibrium, which may be stated as:

“Traffic arranges itself on networks such that the cost of travel on all routes used between each OD pair is equal to the minimum cost of travel and all unused routes have equal or greater cost.”

A number of assignment procedures/algorithms are available within the various transport modelling packages designed to achieve Wardrop’s First Principle of Traffic Equilibrium. Further information can be obtained within the relevant user manuals for the various packages.

2.6 Measures of Convergence

In assignment models, the assignment of demand onto a network alters the condition of the network (the level of congestion or crowding and hence the journey or perceived journey time). Therefore, the network state is recalculated after each assignment and the assignment is repeated until a stable condition is reached.

The final assignment is defined as the point when the difference between subsequent assignments is below a specific threshold (convergence). In practice, perfect convergence will not usually be achieved in assignment models. Failure to achieve acceptable convergence to equilibrium can lead to highly misleading results.

The convergence indicators provided by a number of different software packages vary, as does the availability of a facility for the user to control the assignment process to ensure a given level of convergence. Common convergence indicators include:

- ‘Delta’ or ‘%GAP’: The difference between the costs along the chosen routes and those along the minimum cost routes, summed across the whole network, and expressed as a percentage of the minimum costs. This indicator is considered to be the most appropriate (truest) measure of assignment convergence.
- ‘P’ or ‘P2’: The percentage of links on which flows (given by ‘P’) or costs (given by ‘P2’) change by less than a fixed percentage between successive iterations. The percentage of links with minor changes in flow or cost provides an insight into the stability of the assignment as opposed to the degree of convergence. In other words these measures are not sufficient indicators of convergence in their own right.

- ‘Epsilon’: The degree to which the total area under the cost/flow relationships is minimised.

The most appropriate convergence measures and the values generally considered acceptable for use in establishing a base model are provided in Table 5.1.1.

Table 5.1.1 Summary of Convergence Measures and Base Model Acceptability Guideline Values

Measure of Convergence	Base Model Acceptability Guideline Values
Delta and %GAP	< 0.1% or at least stable with convergence fully documented and all other criteria met
% of links with flow change (P)<1%	Four consecutive iterations > 98%
% of links with cost change (P2)<1%	Four consecutive iterations > 98%

2.7 Route Choice Analysis

Prior to calibration, it is important to check and document route choice for each user class within each modelled period. The ability of the model to accurately represent route choice within the network depends on the quality of network coding and capacity restraint procedures. Issues may be related to zone structure, zone connectors, link and accuracy of junction delays and the accuracy of trip matrices.

It is not possible to examine the routing of all zone pairs. However, movements between key zones should be assessed focussing on key areas of population and / or employment. Plots of minimum path routes are a useful way of identifying potential issues or demonstrating the plausibility of the transport model. An example of a Route Choice Analysis between Dublin and Ardee from the National Transport Model is shown in Figure 5.1.1.

Observations on route choice may not be available; therefore these checks should examine route choice based on plausibility and local knowledge. As such these checks cannot be regarded as true validation; nonetheless remedial action should be taken to address any instance of implausible route choices.

This analysis is equally applicable to highway and public transport assignment modelling. By comparing route choices consistently between highway and public transport assignment models, the modeller can also check mode split between key zone pairs.

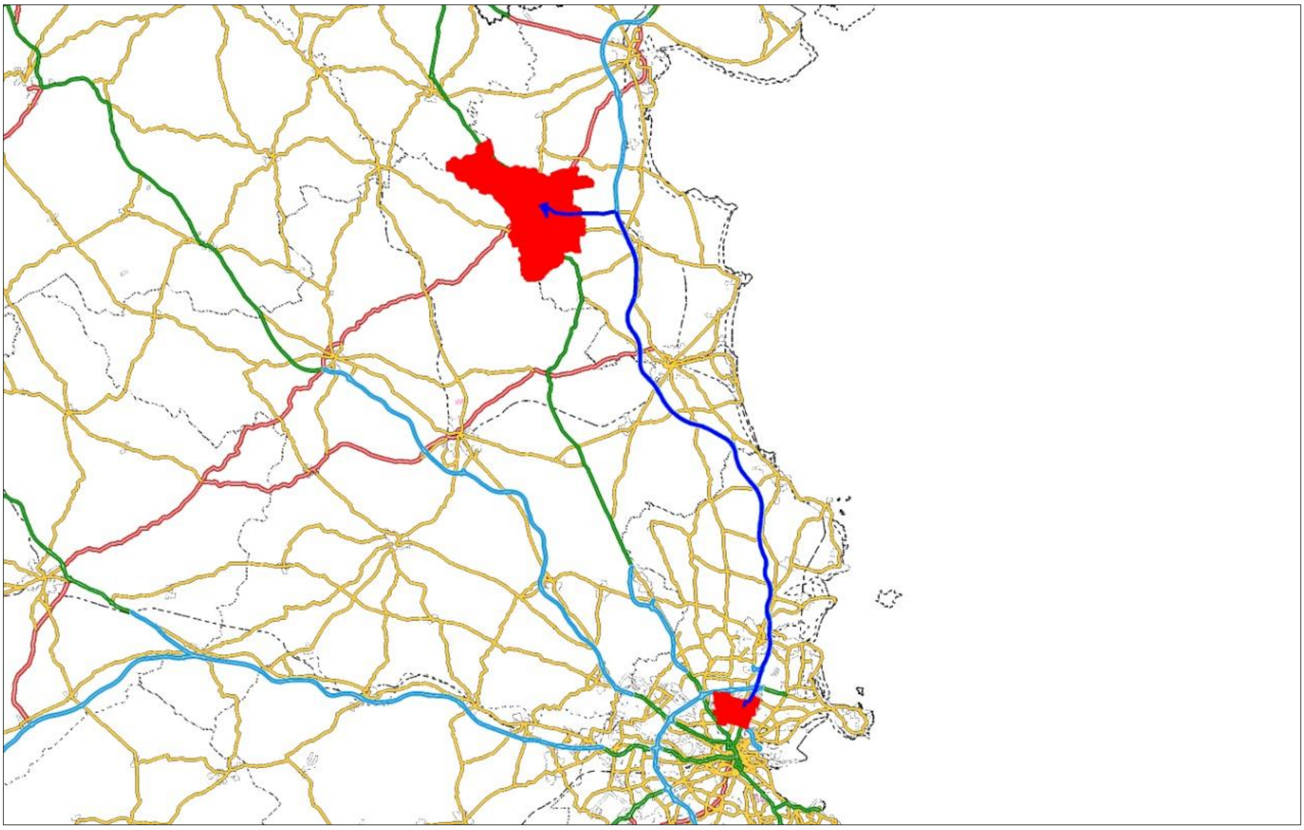

Figure 5.1.1 Route Choice Analysis – Dublin to Ardee (Example from National Transport Model)

3. Model Calibration and Validation

3.1 Overview

Validation and calibration are separate concepts although they are frequently confused with one another. Two accepted definitions are as follows:

- Calibration - the estimation of the parameters of a chosen model by fitting to observations
- Validation - the assessment of the validity of a calibrated model, either by the qualitative comparison of estimates produced by the model with information not used as a constraint in the model calibration, or by the direct estimation of the accuracy of model estimates

In advance of the calibration and validation processes, a comprehensive checking and cleaning process of observed datasets should be undertaken. It is important that the information used in calibrating the model, including count data for matrix estimation, is kept separate from that used for validation if the validation is to be a true independent test of the model.

In reality these two elements are part of an iterative process. If the results of the validation checks are not satisfactory, then the modeller will review the inputs and coding within the model and adjust as required in order to achieve a better representation of reality. The number of iterations required is usually proportional to the complexity of the model.

It is neither possible nor practical to produce a perfect model. However, it is also true to say that if a model cannot adequately reflect the existing situation, then any projections from that model should be treated with a high degree of scepticism.

The guidance supplied here applies to the calibration and validation of all model types, including simple, microsimulation and assignment models, whether they are constructed using macro-simulation, micro-simulation or junction modelling software. The model calibration and validation processes should be comprehensively documented within the Transport Modelling Report, in accordance with *PAG Unit 5.4 - Transport Modelling Report.*

3.2 Network Calibration

As briefly described above, the calibration process involves the estimation and subsequent adjustment of parameters used within a model to fit observations.

For a simple junction model, this may involve adjustments to theoretical saturation flows to ensure that observed queues and delays are reflected in the model. In the case of more complex assignment models the number of parameters and data elements clearly increases and the following represent some of the more common elements that may require adjustment:

- Route choice parameters (the balance of time versus distance)
- Link and service capacities
- Speed flow relationships
- Crowding curves
- Junction capacities
- Trip matrix elements

The final element (following adjustment of the network coding and relevant mathematical functions) is adjustments to the trip matrix i.e. matrix estimation (discussed in the following paragraphs).

This should only be undertaken once the modeller is assured that the network and mathematical functions within the model are operating correctly.

Care must be taken with this sort of approach as matrix estimation will almost inevitably result in a solution but it is rarely a unique one. It is therefore necessary to ensure that sufficient count data is held back from this process to enable an independent check to be undertaken as part of the validation process.

When comparing modelled and observed counts, the magnitude of the observed volume is clearly important when deciding on what is a reasonable error. Therefore, in addition to considering percentage or absolute differences, the GEH statistic (a form of the Chi-squared statistic) is also used as it incorporates both relative and absolute errors. The GEH statistic is:

$$GEH = \sqrt{\frac{(M - C)^2}{0.5 \times (M + C)}}$$

Where M is the modelled flow and C is the observed flow.

The criteria and associated acceptability guidelines to be used in the calibration of models are outlined in Table 5.1.2 and Table 5.1.3 for highway and public transport models respectively. Comparisons should be presented for each user class and each modelled period.

Table 5.1.2 Highway Calibration Criteria

Criteria and Measures		Acceptability Guideline
Assigned hourly flows compared with observed flows		
1	Individual flows within 100 v/h for flows less than 700 v/h.	More than 85% of cases
2	Individual flows within 15% for flows between 700 & 2,700 v/h.	
3	Individual flows within 400 v/h for flows greater than 2,700 v/h.	
4	GEH statistic: individual flows – GEH < 5	More than 85% of cases
Modelled journey times compared with observed times		
5	Times within 15% or 1 minute if higher.	More than 85% of cases

Table 5.1.3 Public Transport Calibration Criteria

Criteria and Measures		Acceptability Guideline
Assigned hourly flows compared with observed flows		
1	Individual flows within 25% of counts except where observed hourly flows are less than 150 passengers per hour.	More than 75% of cases
2	Across modelled screenlines total modelled flows within 15% of observed	95% of cases

3.3 Matrix Estimation

Matrix estimation is the process by which the number of trips between zone pairs is adjusted to improve the match between assigned and observed flows along a modelled link. It is good practice to avoid manipulation of the demand matrices until all other possible modifications have been made. In this way the modeller can be assured that the network coding and relevant mathematical functions are operating correctly. This will avoid a situation when a matrix manipulation seeks to find a matrix that hides errors in the network coding or assignment functions.

Using transportation modelling software, it is possible to perform this operation at numerous locations in a single matrix estimation run, thus adjusting sections of the trip matrix to match observed demand. In the case of VISUM this matrix estimation tool is referred to as ‘TFlow Fuzzy’, in the case of SATURN it is referred to as 'ME2’.

The general process across all transportation modelling packages requires the setting of numerical parameters and constraints including tolerance values (calculated as a percentage of observed volumes) in order to ensure accuracy within the subsequent matrix estimation process. A cautious approach should be adopted when undertaking matrix estimation and the changes brought about by the process should be monitored, refer to the following paragraphs for further detail.

3.4 Trip Matrix Calibration

3.4.1 Trip Length Distribution Check

An assessment of trip length distributions should be undertaken to ensure they have not been adversely affected by the matrix estimation (ME) process. This assessment should examine the prior and post (ME) matrices for the each of the user classes within all modelled time periods. This assessment will identify whether the matrix estimation process has targeted certain movements. An example of a trip length distribution check is illustrated in Figure 5.1.2.

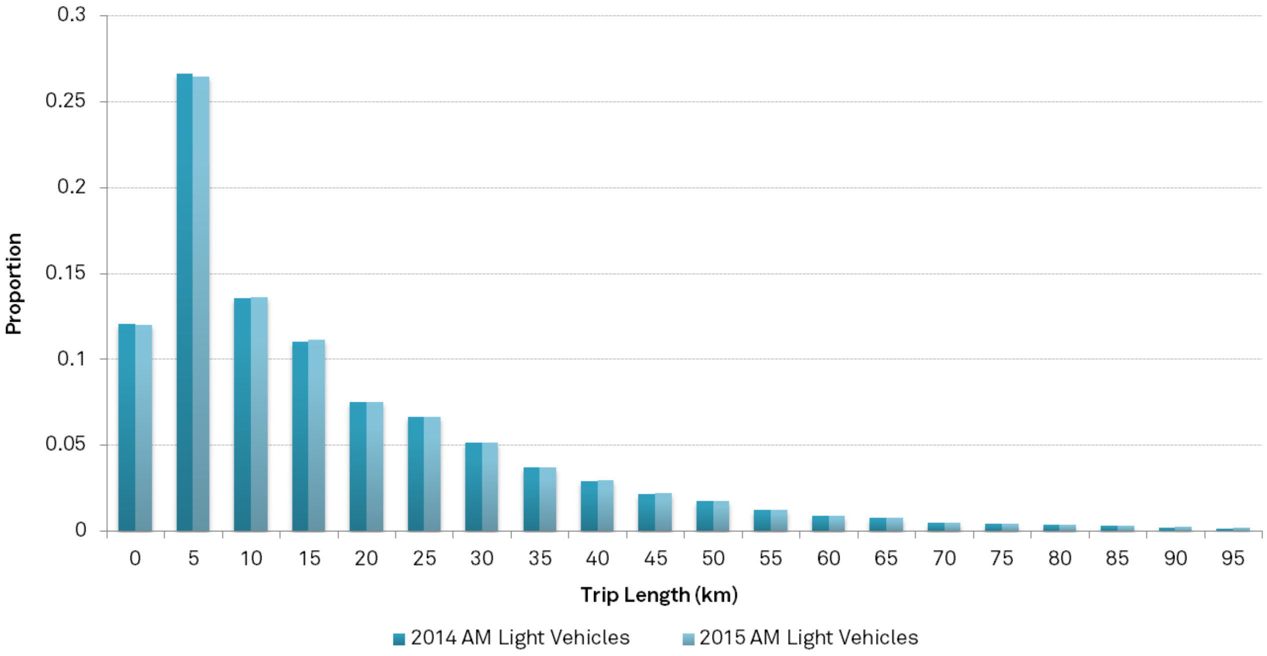

Figure 5.1.2 Sample Trip Length Distribution

Any significant variations in trip length potentially brought about by matrix estimation should be examined further, in order to establish whether such variations are important or statistically significant. In such instances, the post calibration matrix should be revisited.

A coincidence ratio can be used to compare two distributions by examining the ratio of the total area of those distributions that coincide. The coincidence ratio is defined as:

$$\mathrm{CR} = \frac{\sum\{\mathrm{Min}\ (\mathrm{TLDs}, \mathrm{TLDf})\}}{\sum\{\mathrm{Max}\ (\mathrm{TLDs}, \mathrm{TLDf})\}}$$

Where TLDs is the source trip length frequency and TLDf is the final trip length frequency. A desirable range for the coincidence ratio is between 0.7 and 1.0 where a ratio of 1.0 suggests an identical distribution.

3.5 Screenline Analysis

An additional check on the quality of trip matrices should be undertaken by comparing modelled and observed flows (both highway and public transport) across screenlines by vehicle type/public transport sub-mode and modelled time period. The criteria and associated acceptability guidelines to be used in relation to screenlines are outlined in Table 5.1.4.

Table 5.1.4 Calibration Criteria

Criteria and Measures	Acceptability Guideline
Total screen line flows (> 5 links) to be within 5%.	More than 85% of cases
GEH statistic: screenline totals < 4	
Across public transport screenlines total modelled flows within 15% of observed	95% of cases

Notes: Screenlines containing high flow routes (such as motorways) should be presented both with and without such routes.

3.6 Origin-Destination & Desire Line Analysis

A validation of modelled trip matrices can be undertaken at a sector to sector level (e.g. collection of zones forming areas within the transport model), with additional detail at a zonal level if necessary, using origin-destination data for each modelled time period. This demonstrates whether a model presents a good understanding of travel patterns within the study area. Origin-destination data collated through Bluetooth or Automatic Number Plate Recognition surveys should be utilised in this regard. The results of the origin-destination analysis should be presented in a tabular format.

It is recommended that modelled origin-destination patterns are compared against measured patterns based on the percentage split of destinations from each origin-destination survey location. A target deviation limit of ± 25% within more than 85% of samples should be attained.

As a final high level check on the trip matrices, a review of travel patterns within the modelled study area should also be undertaken to understand the dominant movements. This can be attained through an analysis of the key desire lines within the transport models. This analysis may highlight dominant demands and by-pass movements during each of the modelled peaks. These diagrams should use colour and bandwidth thickness to illustrate compatibility between observed and modelled desire lines. An example is provided in Figure 5.1.3.

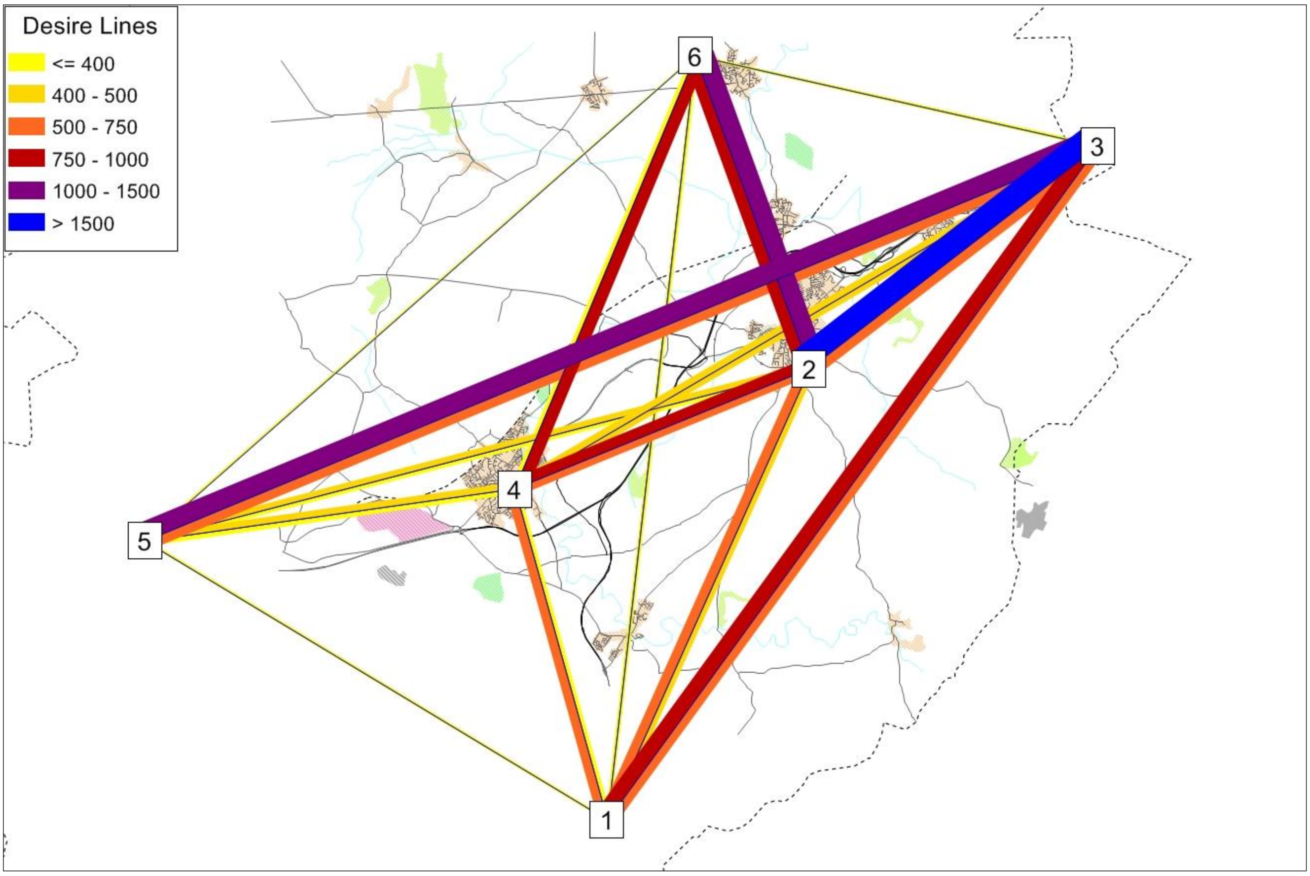

Figure 5.1.3 Sector Desire Lines Example

3.7 Network Validation

The process of model validation determines how well the model estimates compare with reality as reflected by independent observations made on the ground. Care should be taken to ensure that sufficient quality count data is retained for the validation process, that is not used in the process of calibrating the model.

In order to determine a model's suitability, clear thinking is required about the intended use. The accuracy of any model, indeed even count data, cannot be expected to represent reality except within a range or tolerance. Moreover, it is often not necessary to go to great lengths to reduce that range and seek apparently greater precision.

In light of the above, it is important to ensure that:

- The degree of accuracy is adequate for the decisions which need to be taken
- The decision makers understand the quality of the information with which they are working
- That they take the inherent uncertainties into account in reaching decisions

The type of validation checks which may be undertaken on a model are dependent on the model form but typical examples include the comparison of model outputs and observed data for:

- Turning proportions at junctions
- Highway and public transport flows on individual links
- Highway and public transport flows across screenlines or cordons

- Queues at junctions
- Highway and public transport journey times along critical routes
- Public transport boarding and alighting at stops/stations.

3.8 Validation Standards

The output from an assignment model can be used to assess the performance of the whole modelling process although it should be remembered that any poor performance may be due to a number of factors including:

- Errors in the trip matrix
- Coding errors in the network
- Incorrect route choice parameters

Comparisons of link flows, journey times and turning movements at junctions are key validation exercises and form a check on the quality of the network and assignment. The count comparisons can also be done at an individual link level or by looking at groups of links as screenlines. The criteria associated with the validation of transport models are outlined in Table 5.1.5 and Table 5.1.6 for highway and public transport models respectively. Comparisons should be presented for each user class and each modelled period.

Table 5.1.5 Highway Validation Criteria

Criteria and Measures		**Acceptability Guideline**
Assigned hourly flows compared with observed flows		
1	Individual flows within 100 v/h for flows less than 700 v/h.	More than 85% of cases
2	Individual flows within 15% for flows between 700 & 2,700 v/h.	
3	Individual flows within 400 v/h for flows greater than 2,700 v/h.	
5	GEH statistic: individual flows – GEH < 5	More than 85% of cases
Notes: Screenlines containing high flow routes (such as motorways) should be presented both with and without such routes.		
Modelled journey times compared with observed times		
6	Times within 15% or 1 minute if higher.	More than 85% of cases

Table 5.1.6 Public Transport Validation Criteria

Criteria and Measures		**Acceptability Guideline**
Assigned hourly flows compared with observed flows		
1	Individual flows within 25% of counts except where observed hourly flows are less than 150 passengers per hour	More than 75% of cases
2	Across modelled screenlines total modelled flows within 15% of observed	95% of cases

The onus is on the modeller to use the Transport Modelling Report as a means of making the case to the sanctioning authority that the results of the modelling work are robust and fit for purpose.

Fitness for purpose will be influenced by the stage the project has reached. As an example, at route selection, the model must be capable of providing a platform whereby a variety of schemes can be assessed on a consistent basis but it may not be necessary to be of sufficient quality that it could provide robust detailed turning movements at the scheme junctions.

Conversely, when the model is to be used to determine the preliminary design, and the requirements of land acquisition, the ability to identify the detailed impacts of the scheme will be important.

Fitness for purpose does not imply that the validation standards displayed in Tables 5.1.3 to 5.1.5 need to be strictly adhered to. This will be more important at the preliminary design stage than at the route selection stage. Emphasis should be on setting criteria which is suitable for the project context and scale of model.

In all cases, data used for model calibration and validation should be distributed across all road types and classifications with particular focus on those areas with high volumes or expanding congested conditions.

3.9 AADT and Annual Public Transport Demand Estimates

A lot of time is concentrated on the generation of transport models which produce a reflection of peak hour conditions. However, an important additional element of information generated by transport models is estimates of AADT or annual public transport demand. The estimates of AADT and annual public transport demand are generally produced by applying expansion factors to the modelled period flows which generally comprise of one or both of the AM and PM peak hours, and the Inter peak. These expansion factors are derived from traffic and passenger data within the model study area. Further detail in relation to the development of expansion factors for short period traffic counts is provided in PAG Unit 16.1: Expansion Factors for Short Period Traffic Counts.

The resultant AADT flows will be utilised within the safety appraisal process (see PAG Unit 6.4: Guidance on Using COBALT for further detail) and will also likely be referred to within model related publications. Furthermore, AADT flows may form inputs to environmental models such as air and noise assessments; and are also utilised to determine road cross section and road make up. In light of this, it is important that the modelled AADTs match observed volumes in the ‘base case’ as closely as possible. Therefore, there is a need to validate the accuracy of the modelled AADTs against count data from which AADT values can be derived.

Therefore, it is recommended that modelled AADT flows are compared against measured AADTs using a suitable tolerance e.g. ± 15% (where observed AADT flows are greater than 700) within more than 85% of samples. Instances where observed AADTs are less than 700, modelled AADTs within ± 100 vehicles are considered acceptable. If comparisons of AADT show a high level of correlation between modelled and observed values, then model adjustment may not be necessary. However, if comparisons of AADT show unexpected variations between modelled and observed values, it may be necessary to make adjustments to the peak hour models in order that more accurate AADT estimates are produced.

3.10 Junction Model Validation

Should a simple junction model be developed in support of the appraisal of a TII scheme, there is a need to ensure that such a model is also calibrated and validated, although these processes can be combined into a single procedure for models of this type. A number of criteria should be used including, at a minimum, those in Table 5.1.7.

The comparison of stopline flows is particularly important for junction models, particularly where congested conditions exist in the base year.

Where stopline flows are validated, but with significantly lower levels of queuing in the models as compared to surveys, it is likely that observed stopline flows (actual flows) are being used to reflect upstream flows (demand flows) in the modelling, and that the much higher demand flow in reality is not being captured. In such situations, the modelled flows should be increased until the measured level of queuing is reflected in the models, as this will allow upstream demand flows to be approximated.

Note that ‘optimising’ the signal settings of a junction cannot be deemed to be a mitigation measure in itself if the signal settings are already deemed to be optimised by an Urban Traffic Control (UTC) system – as the theoretical optimisation as dictated by a junction modelling programme can be difficult to achieve.

Table 5.1.7 Junction Model Validation Criteria

Criteria and Measures	**Acceptability Guideline**
Mean Maximum Queue length (m) per traffic lane	± 15%
Signal timings and Intergreen periods (s)	Modelled = Observed
Stopline traffic flows (passenger car units) per arm	± 2%
Journey Time (for linked junction models)	±10%

4. Treatment of Future (Opening & Horizon Year) Networks

Projecting the usage and performance of transport networks is a critical component of transport appraisal. Transport models are also used to assign transport demand projections with a view to estimating how travel patterns of demand will change over time. The development of transport demand projections for application within transport models is discussed separately in *PAG Unit 5.3: Travel Demand Projections.*

Figure 5.1.4 shows the transport model structure necessary to assign transport projections and inform a transport appraisal. The process begins with the development of a ‘reference case’ (Do-Nothing scenario) by factoring the base year demand to each future year required.

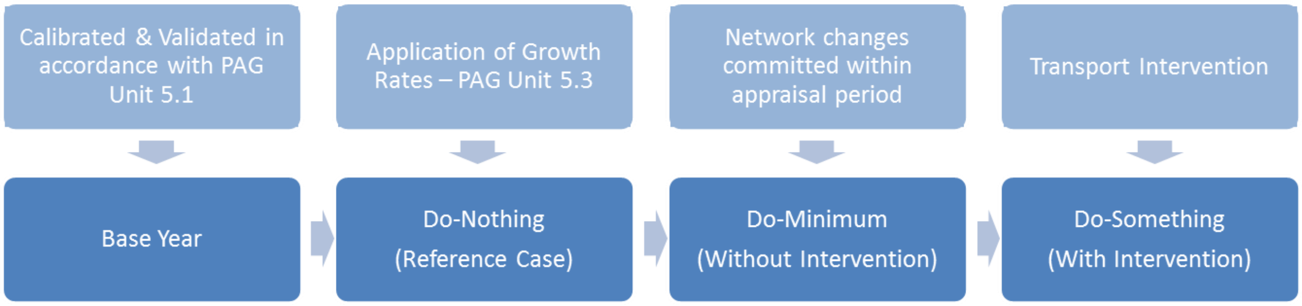

Figure 5.1.4 Transport Model Structure for Transport Demand Forecasting

A ‘without intervention’ (Do-Minimum scenario) is then developed off the Do-Nothing scenario, which includes planned or committed transport network changes within the study area, anticipated to be completed within the appraisal period. The Do Minimum scenario provides the platform which will enable the assessment of any transport interventions or policies proposed. In certain circumstances, it is accepted that the Do-Minimum may actually be a Do-Nothing scenario.

‘With intervention’ (Do-Something) scenarios are then developed in which the impact of various schemes and policies can be tested and compared against the Do-Minimum scenario. With respect to the Do-Something transport network, it will be based on the Do-Minimum network, the only difference between the Do-Minimum and Do-Something transport networks will be the presence of the intervention itself and any necessary reclassifications of downgraded roads (there may also be differences in demand between the scenarios – these considerations are addressed separately in the chapter on Variable Demand Modelling).

The inputs related to generalised cost should be adjusted in each scenario to take account of the future year assessed. The recommended growth in factors pertaining to generalised cost is given in PAG Unit 6.11: National Parameter Values Sheet. These factors must be used to update the base generalised cost assumptions in forecast years and must be the same in the Do-Minimum and Do-Something scenarios in order to allow comparability.

4.1 Assessing Modelled Traffic Projections

Applying projections to the modelled traffic, allows it to forecast what may happen if the Do-Something scheme was built, and how this compares to what would happen if it was not.

However, in advance of constructing the Do-Something model, it is recommended to forecast the impact of traffic and passenger growth within the Do Minimum horizon year models on key demand indicators to verify that the outputs from the traffic and passenger growth process are sensible.

Any adjustments applied to the Base year model as part of the calibration process should be carried forward to all future year models to ensure that the statistical errors and biases addressed in the Base year are also addressed in future years.

A comparison of Trip Length Distribution (TLD) in the Base and horizon year (Do Minimum models) represents a check that the outputs from the traffic and passenger growth process are sensible. Whilst demand responses to changes in travel conditions may bring about changes in the lengths of trips undertaken, the proportion of trips in the various time bands should be similar between the base and the horizon year, (e.g. no significant change in short trips). An example of how this assessment could be presented graphically is shown in Figure 5.1.5.

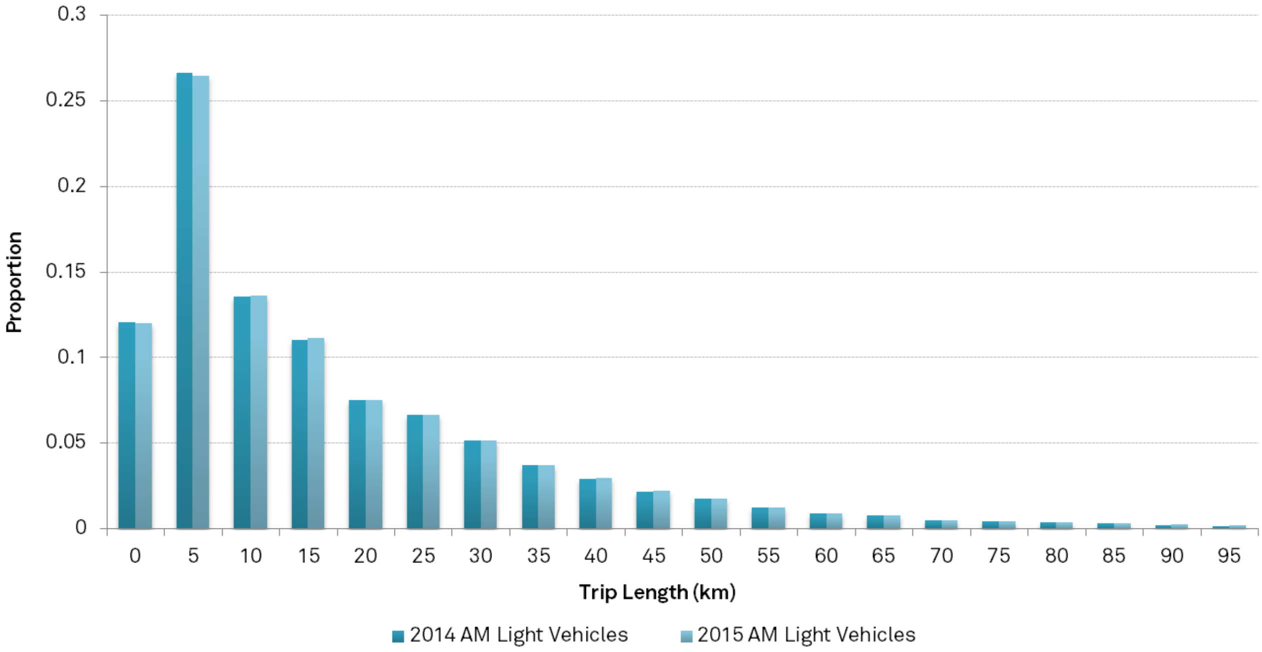

Figure 5.1.5 Sample Trip Length Distribution

An assessment of the Trip End Growth (TEG) between the Base and horizon year demand (Do Minimum models) during each time period will also determine if there are any significant changes in demand at zonal level compared to the overall growth between the two scenarios.

In order to assess the true magnitude of Trip End Growth, the GEH statistic must be applied to the Base and horizon year trip ends in order to take account of not only the difference between the Base and future year demand, but also the magnitude of the difference. A GEH statistic exceeding 10 requires investigation. An example is illustrated in Figure 5.1.6.

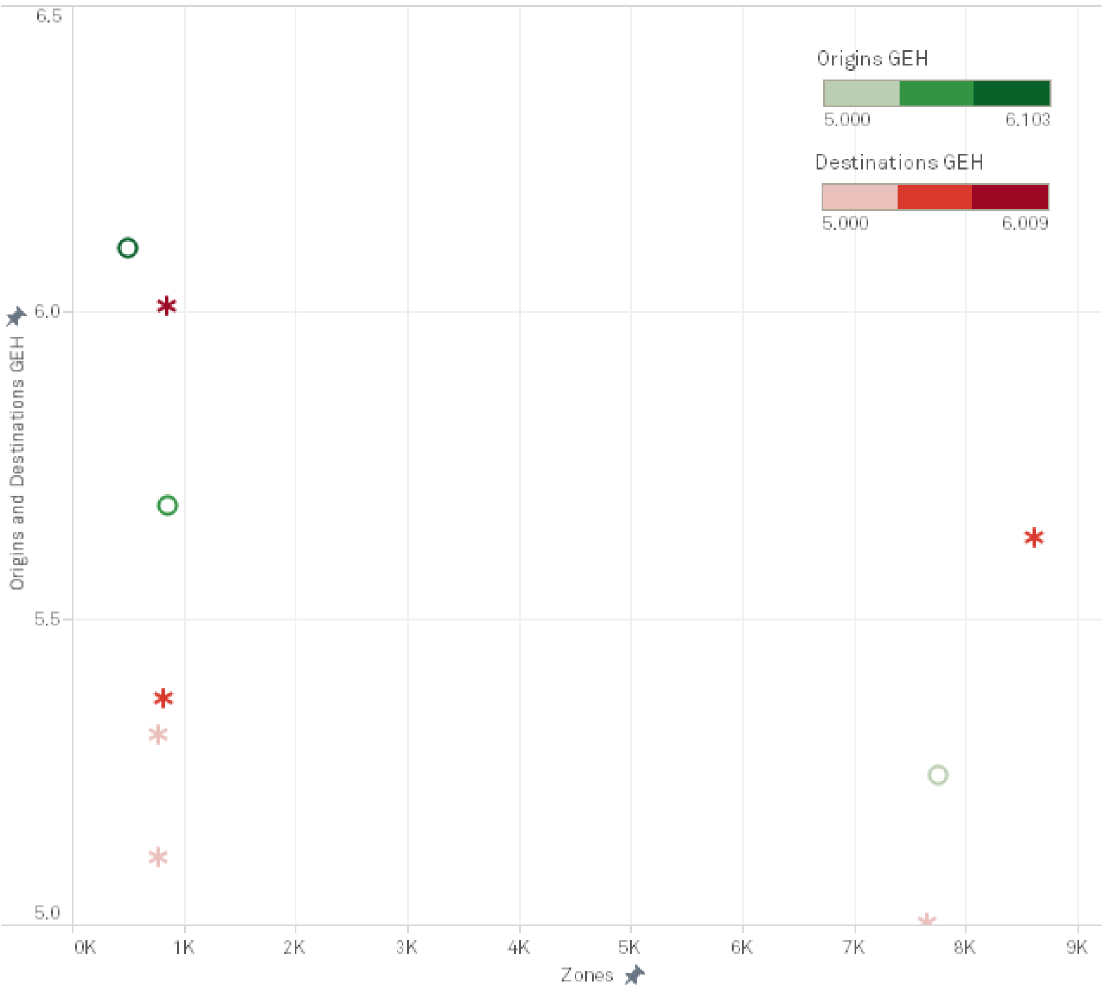

Figure 5.1.6 Trip End Growth Comparison Example

The same procedure as is recommended for Trip End Growth should also be undertaken for zone to zone growth during each time period i.e. for each origin-destination pair, an example is shown in Figure 5.1.7. Again, a GEH statistic exceeding 10 should be investigated.

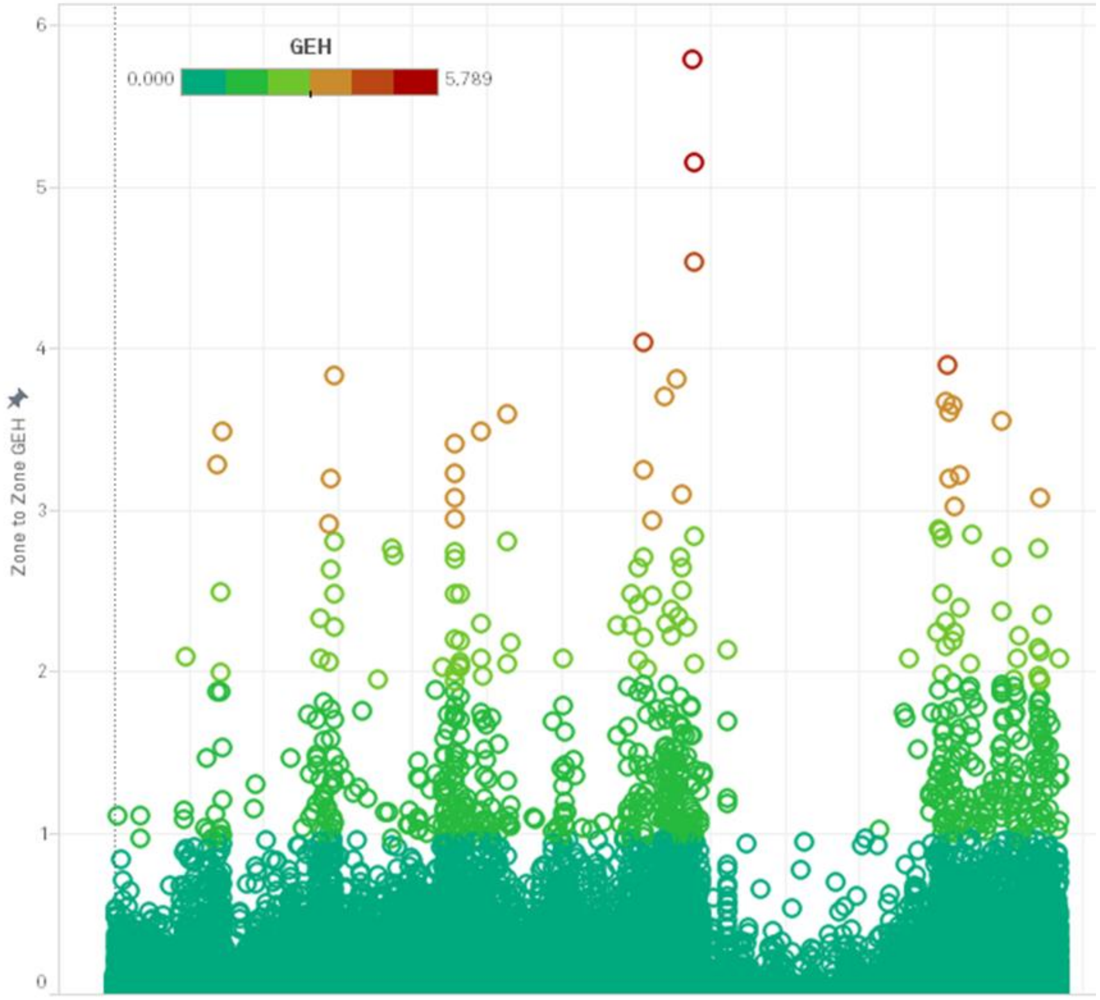

Figure 5.1.7 Zone to Zone Growth Comparison Example

5. Versions of Transport Modelling Software

Software providers very often offer new versions of their software for a variety of reasons including the introduction of enhanced features or the release of software patches to address specific issues. It is therefore important for the modeller to keep abreast of these developments and choose the most appropriate software version for the model being developed.

It is also essential that the software version does not change between the calibration of the base model and the production of a proposed model. Even with identical inputs, it is common for different software versions to produce different results. It will invalidate a previously validated model if it is used in a software version different from the one in which it was originally developed.

6. Variable Demand Modelling

6.1 Overview

The following sections provide an overview of different approaches to Variable Demand Modelling. This section should be read in conjunction with Table 5.0.3 Criteria for Scoping Variable Demand Modelling of *PAG Unit 5.0 – Transport Modelling Overview*, when scoping or considering the use of a Variable Demand Model.

6.2 Elasticity Approach

6.2.1 Definition of Elasticity

Elasticities can be used to estimate the effects of changes in transport cost variables on the demand for travel, by sourcing appropriate elasticity values which provide typical demand responses to changes in cost variables informed by research.

A stricter definition is 'The elasticity of demand, with respect to a given parameter (explanatory variable) may be seen as the percentage change in quantity demanded resulting from a one per cent change in the value of the parameter.[1]' Both the magnitude and directionality of change are important i.e. a 1% increase or decrease in a cost variable could result in either a 10% increase or 10% decrease in demand.

There are two main types of elasticity:

- **Direct Elasticity -** refers to the change in demand for one transport service or mode in terms of the change in a cost variable affecting that same service or mode. For example, the change in patronage on a rail service as a result of a change in the fare charged for that service could be estimated using the direct demand elasticity for rail with respect to fare
- **Cross Elasticity -** refers to the change in demand for one service or mode in terms of the change in a cost variable affecting a different (competing) mode or service. For example, the change in demand on an alternative mode (such as bus) resulting from passengers switching modes could be estimated using the cross elasticity of demand for bus with respect to rail fare

6.2.2 Elasticity Values

There are a number of cost variables and parameters for which elasticity values can be derived, such as fares, costs and charges, travel times, service reliability, service frequency and service quality (e.g. passenger comfort or possibility of damage to or loss of commodities).

Elasticity values for use in studies should ideally be sourced locally or derived from local data. If these are not available, research-based estimates could be used instead. Examples of appropriate values are provided here from UK TAG and Australian Transport Assessment and Planning Guidelines (ATAP):

- Elasticity of demand for car travel with respect to annual average fuel cost should lie within the range -0.25 to -0.35 (overall, across all purposes), (i.e. a 1% increase in annual average fuel cost should lead to a 0.25-0.35% decrease in car travel)[2]

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[1] Australian Transport Assessment and Planning Guidelines T1 Travel Demand Modelling
[2] UK Transport Appraisal Guidance Unit M2.1 Variable Demand Modelling

- Elasticities of car trips with respect to car journey time no greater than –0.2, (i.e. a 1% increase in car journey time should lead to a 0.2% decrease in car trips)[3]
- Elasticities of public transport trips with respect to public transport fares in the range –0.2 to -0.9 for changes over a period longer than a year, (i.e. a 1% increase in public transport fare should lead to a 0.2-0.9% decrease in in public transport trips at least one year after the implementation of the fare change)[4]
- Elasticities of bus trips with respect to bus fares for full fare paying passengers in the range –0.7 to -0.9 for changes over a period longer than 5 years, (i.e. a 1% increase in bus fare should lead to a 0.7-0.9% decrease in bus trips at least five years after the implementation of the fare change)[5]
- Short-run (within 12 months of change) elasticities of urban public transport demand with respect to total generalised costs (or generalised time) of -1.0 in peak and in the range -1.5 to -2.0 off-peak, (i.e. a 1% increase in total generalised cost should lead to a 1% decrease in urban public transport demand in the peak and a 1.5-2% decrease in the off-peak within 12 months of the change)[6]
- Long-run (7-10 years after change) elasticities of urban public transport demand with respect to total generalised costs (or generalised time) approximately twice the short-run values although varies according to size of scheme with smaller schemes showing a smaller factor, (i.e. a 1% increase in total generalised cost should lead to a 2% decrease in urban public transport demand in the peak and a 3-4% decrease in the off-peak at least 7-10 years after the increase in generalised costs)[7]
- Short-run default elasticity estimates for public transport demand with respect to fares, service levels and in-vehicle time as shown in Table 5.1.8[8]
- Long-run default elasticity estimates for public transport demand with respect to fares, service levels and in-vehicle time twice short-run values, in the case of major infrastructure initiatives. For smaller public transport schemes, long-run elasticities are typically around 5% to 20% greater than the 12-month values[9]

Table 5.1.7 Short-run Component Elasticity Estimates (ATAP)

Attribute	Best Estimate (Default) Values			Typical Ranges
	Overall	Peak	Off-peak	(All Periods)
Fares	-0.35	-0.25	-0.50	-0.2 to -0.6
Service Levels[10]	+0.40	+0.30	+0.50	+0.2 to +0.7
In-vehicle time	-0.40	-0.30	-0.50	-0.1 to -0.7

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[3] UK Transport Appraisal Guidance Unit M2.1 Variable Demand Modelling
[4] UK Transport Appraisal Guidance Unit M2.1 Variable Demand Modelling
[5] UK Transport Appraisal Guidance Unit M2.1 Variable Demand Modelling
[6] Australian Transport Assessment and Planning Guidelines T1 Travel Demand Modelling
[7] Australian Transport Assessment and Planning Guidelines T1 Travel Demand Modelling
[8] Australian Transport Assessment and Planning Guidelines T1 Travel Demand Modelling
[9] Australian Transport Assessment and Planning Guidelines T1 Travel Demand Modelling
[10] Best estimates reflect medium frequency (20-30 minutes headway). Service level elasticities may be higher than indicated in this range in evenings and weekends when frequencies are relatively low.

6.2.3 Application

An elasticity approach is typically applied to estimate demand effects of minor transport schemes with local impacts e.g. junction improvement, increase in rail service frequency serving a particular rail station.

Elasticities account for newly generated trips and shifts in demand between modes and services. They do not account for change in demand resulting from a change in trip origin or destination. Therefore, an elasticity approach should only be applied if these effects are not significant, or if these affects can be accounted for separately.

An example of such an approach e.g. estimating the demand impacts of an increase in rail service frequency serving a particular rail station is:

1. Using an assignment model, derive forecast demand usage of station e.g. 5,000 passengers in AM Peak
2. Specify improvement in rail frequency serving station e.g. 2tph in AM Peak, from 2tph to 4tph
3. Applying the ATAP short-run peak service elasticity (+0.30), determine the % change in demand = % change in service (100%) * 0.3 = 30%
4. Re-calculate forecast AM Peak station demand = 5,000 + (5,000*30%) = 6,500

In this example, whilst additional passengers will be attracted to use the station, some through passengers will be discouraged from using the station as a result of increased in-vehicle time due to additional dwell time and longer run-time on approach to and on departure from the stop. The forecast reduction in passengers can be calculated as follows:

1. Using the assignment model, derive forecast demand travelling through the station e.g. 20,000 passengers in AM Peak
2. Specify increased in-vehicle time through station e.g. 1 minute, from (on average) 30 minutes to 31 minutes
3. Applying the ATAP short-run peak in-vehicle time elasticity (-0.30), determine the % change in demand = % change in in-vehicle time (3.3%) * -0.3 = -1%
4. Re-calculate forecast AM Peak through demand = 20,000 - (20,000*-1%) = 19,800

The advantage of such an approach is that it offers a simple and transparent method of estimating effects of transport schemes on demand. However, care should be taken in application to studies as the approach can significantly overestimate the effect of variable demand responses on scheme benefits. More detailed guidance on the scoping of variable demand modelling exercises using an elasticity approach is provided in *Unit 5.0 Transport Modelling Overview*, Section 3.2.

6.3 Simple Variable Demand Models

Simple Variable Demand Models estimate the effects of changes in transport cost variables on the demand for travel within a transport model using a simple matrix based calculation. By sourcing appropriate elasticity values which provide typical demand responses to changes in cost variables informed by research, changes in demand can be estimated at an origin-destination level within transport models in response to changes in cost.

A typical implementation of this approach might be undertaken as follows:

1. Using an assignment model, derive the effects of a new rail service on the route choice of trips
2. Calculate the change in travel cost at an origin-destination level between the Do-Minimum (without scheme) and Do-Something (with scheme) scenarios
3. Source an appropriate elasticity value which provides research-based evidence for the typical % change in demand for a rail service in response to a % change in travel time (in this instance the % change in demand should account for mode shift and newly generated trips only as the assignment model determines demand attracted to the new rail service from other rail and PT services)
4. Calculate the new demand at an origin-destination level by applying the elasticity to the change in travel time

In the case of an improvement of an existing PT service (e.g. an improved frequency on a rail service), a simpler implementation of this approach might be undertaken as follows:

- Source an appropriate elasticity value which provides research-based evidence for the typical % change in demand for a rail service in response to a % change in frequency (in this instance the % change in demand should account for attraction of demand from other rail and PT services as well as mode shift and newly generated trips)
- Within the assignment model, apply the elasticity value at a network level to the demand using the enhanced rail service to calculate the new demand

This method allows for differentiation by demand segment e.g. time period, mode, trip purpose if the model is segmented in such a way. For example, different elasticities can be applied for peak rail commuter trips and off-peak highway leisure trips. Further segmentation could be based on user class and car availability.

It should be noted that use of elasticities does not account for change in demand realised through change in trip origin or destination. If possible, a separate exercise could be undertaken to account for these affects.

The advantage of such an approach is that it offers a simple and transparent method whilst retaining spatial representation of demand and costs through the use of a transport model. It is likely to be suitable for local schemes with minor impacts or if used to assess major schemes, initial indications of likely demand impacts or sifting of such alternative options. More detailed guidance on the scoping of variable demand modelling exercises using a simple VDM approach is provided in *Unit 5.0 Transport Modelling Overview*, Section 3.2.

6.4 Full Variable Demand Models

Full variable demand models forecast the effects of changes in transport costs on transport demand on each origin-destination movement within strategic transport models. This section provides guidance on the structure and components of such models. More detailed guidance on the scoping of variable demand modelling exercises using a full VDM approach is provided in *Unit 5.0 Transport Modelling Overview*, Section 3.2.

6.4.1 Demand

Matrix Form

Most variable demand models use trip-based matrices. However, it is possible to also model 'tours' which are defined *'as any round trip, starting and finishing at home, and may contain stops at several different destinations'*[11]

Trip ends can be defined by:

- Production (the location where the decision to travel is made) and Attraction (the reason for travel) – these form P/A matrices
- Origin (beginning of trip) and Destination (end of trip) – these form O/D matrices

Given their greater refinement by trip purpose, P/A matrices are more suited to taking account of non-standard growth. Where the model is simple enough or used for a specific purpose such that a simple overall growth rate can be applied, the use of O-D matrices may be satisfactory.

Segmentation

The DfT in the UK states that 'Segmentation is the division of travel, traveller and transport attributes into different categories so that all travellers in the same category can be treated in the same way.[12]'

DfT also advises that 'Ultimately the segmentation adopted in the modelling process must depend on the nature of the study area, the objectives of the study, the data available, the outputs required and the intended model structure.[13]' Table 5.1.8 suggests the minimum levels of segmentation for demand modelling.

Table 5.1.8 Minimum Segmentations for a Multi Stage Demand Model[14]

Attribute	Segmentation
Household type and traveller type	Two categories: travellers categorised into car-available/no-car-available or by household car ownership into car-owning/non-car-owning. Models that only need to deal with road traffic will include only those travellers who have a car available. If a local trip generation model is being developed, a more detailed segmentation into household structure, employed members, etc is very desirable, but this finer level of segmentation need not be carried through to the subsequent stages.
Value of time	Variation of VOT across the population is important but can usually be addressed sufficiently through the trip purpose split. However, for schemes specifically involving charging, some additional segmentation by willingness-to-pay or income may be required. In this case 3 separate income ranges – high, medium and low (with different VOT) with demand distributed evenly across the groups - will be adequate. Where there is a large range of trip distance, it is desirable to allow VOT to vary with trip distance.
Trip purpose	3 categories: Commuting/Work/Non-work: these categories are likely to have different elasticities and different distributions in both time and space, and substantially different values of time.
Modes	2 categories: Car/public transport. It is usually necessary to have a base of trips that can transfer to and from car.
Road vehicle types	2 categories: Car/other, where the "other" may include freight and bus/coach as a fixed-flow matrix for assignment.

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[11] UK Transport Appraisal Guidance Unit M2.1 Variable Demand Modelling
[12] UK Transport Appraisal Guidance Unit M2.1 Variable Demand Modelling
[13] UK Transport Appraisal Guidance Unit M2.1 Variable Demand Modelling
[14] UK Transport Appraisal Guidance Unit M2.1 Variable Demand Modelling

Whilst it may be useful to adopt an elaborate segmentation of demand at the trip generation stage, there is less requirement to carry this forward to subsequent stages of the modelling process. As a minimum, segmentation is recommended:

- by trip purpose i.e. commuting, work, non-work. This is also important where scheme appraisal is being undertaken, as values of time (contained in Table 3 of *PAG Unit 6.11 – National Parameters Values Sheet*) are considered different for these purposes
- where mode choice is modelled, where a distinction between travellers with and without availability of a car should be made

6.4.2 Division Into Time Periods

In order to capture variation in travel conditions across the day, it is conventional practice to divide the day into different periods for modelling purposes. It needs to be determined how best to define each time period so that travel conditions are sufficiently constant to provide a realistic mean cost within each time period.

The time divisions applied within the demand model should be consistent with the associated assignment models. In theory, different demand responses can be modelled over different time periods. It is common practise for UK regional models to estimate trip frequency, mode choice and distribution over a 24 hour time period. In these cases, procedures need to be adopted to convert such 24 hour trip patterns to be compatible with the shorter time-scales generally required for assignment modelling (a peak hour or an average inter-peak period, for instance).

6.4.3 Model Form

The form of the demand model can be split into three categories (the latter two methods retain all the detail of observed base data, but generally face difficulties where too many (or key) cells in the observed matrices are empty because of the limited amount of surveying possible):

- **Absolute Models** - in which modelled base year and forecast trip patterns are produced independently of each other using common model parameters and the base year is calibrated using observed data
- **Absolute Models (applied incrementally) -** that use absolute model estimates to apply changes to an observed base matrix
- **Pivot-point Models** - that use cost changes to estimate the changes in the number of trips from an observed base matrix

Due to the more time-consuming nature of developing absolute models, incremental and pivot point models are preferable from an efficiency perspective. On the other hand, there may be some instances where an absolute model would be preferable from a methodological perspective, in particular where there are large changes in land use between the base and forecast years, which will significantly change the distributions of origins and destinations. Alternatively, where there are just a few zones where significant changes in land-use occur, an absolute approach could be applied to those movements whilst maintaining an incremental or pivot-point approach overall.

Choice Responses

Any model of the demand for travel relies on a mathematical mechanism that reflects how demand will change in response to a change in generalised cost. A single logit model may be applied to the entire range of choices available using a multinomial logit model. However, that would implicitly assume that the sensitivities of those choices were all the same which is unlikely to be the case. Therefore, most variable demand models use some form of “hierarchical logit” formulation in which at each level a limited number of choices are considered. For example, a variable demand model might:

- first estimate the number of trips from any given origin (trip frequency - usually as an elasticity formulation)
- then estimate how many trips will choose each available mode (mode split)
- then estimate when trips will choose to travel (time period choice)
- then estimate how these trips choose amongst the available destinations (trip distribution)

The sequence in which these choices are applied is important to the overall outcome as the predicted travel pattern will be affected by it. The sequence must be determined by the relative sensitivity of each choice to the generalised cost of travel, so that the greater the sensitivity of each choice the lower it is placed within the hierarchy.

Within any of the hierarchical levels, it may be desirable to model a secondary choice. It may be preferable to split mode choice into a “high-level” two-way choice between car and public transport, with a “lower level” split into the different public transport modes. This is often referred to as nested logit. Other secondary choices which might be considered are micro time period choice and parking choice.

Calculation of Costs

At each level in the hierarchy, composite costs are calculated. Where an absolute choice model is used, the following logsum formulation is appropriate:

$$G_{comp}^{y-1} = -\frac{1}{\lambda_y} ln\left(\sum_x exp(-\lambda_y G_x^y)\right)$$

Where:

G_{comp}^{y-1} is the composite cost or disutility summed over the choices x in stage y

G_x^y is the disutility or generalised cost of choice x given choice y

(for example, the stage y may refer to 'destination choice', while x varies over the destination zones)

λ_y is the choice sensitivity parameter for choice stage y.

Where the demand model is incremental or pivot-point, the mathematical form of the logit function requires that the logsum be weighted by the choice shares in the logarithmic summation. The formulation to be used is then:

$$\Delta G_{comp}^{y-1} = -\frac{1}{\lambda_y} ln\left(\sum_x \frac{T_x^y}{T_{tot}^y} exp(-\lambda_y \Delta G_x^y)\right)$$

Where:

T_x^y is the number of trips choosing x at stage y

T_{tot}^y is the total number of trips available at stage y.

There is strong empirical evidence that the sensitivity of demand responses to changes in generalised cost reduces with increasing trip length, an affect known as cost damping. Damping generalised cost by a function of distance may be achieved using the following formulation:

$$G' = (d/k)^{-\alpha}.(t + c/VOT)$$

where

t, c	are the trip time and monetary cost[9], respectively
VOT	is the value of time
$(t + c/VOT)$	is generalised cost
G'	is the damped generalised cost
d	is the trip length[10]

α and k are parameters that need to be provided or calibrated

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