REGIONAL MODELLING SYSTEM

Transport Modelling Best Practice Review Scoping Report

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Foreword

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

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

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

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

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

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

1 Introduction

1.1 Background

The National Transport Authority's (NTA) responsibilities include strategic transport planning, integrated public transport network development, walking and cycling promotion, public transport infrastructure provision, effective management of traffic and transport demand and the regulation of public transport services. Transport modelling has a fundamental role to play in helping the NTA deliver on these responsibilities. The Modelling Services Framework was commissioned in 2012 to support the NTA in developing and enhancing its transport modelling capabilities as well as supporting the modelling, testing and appraisal of transport and land use plans.

Under the NTA Modelling Framework, SYSTRA and Jacobs Engineering Ireland along with sub-consultants Minnerva Transport Planning have been tasked with advancing the modelling capability of the NTA in line with its national transport planning remit.

1.2 Purpose of Scoping Report 3

The purpose of this scoping report is to review best practice modelling approaches to developing a typical regional model similar to the one required by the NTA for each of the regional areas as described previously in Scoping Reports 1 & 2. This review of best practice will, therefore, provide guidance to the model specification for the regional modelling system. This Scoping Report is one of four Scoping Reports which provide the basis for the specification of the development of a Regional Modelling System for Ireland, the other Scoping Reports being:

- RMS Scope 1 Greater Dublin Area Model Review;
- RMS Scope 2 Greater Dublin Area Model Review; and
- RMS Scope 4 Modelling Data Review.

The key findings and recommendations from each of the four scoping reports are combined and presented in the overall Regional Modelling System scoping report, RMS Scope 5 Scoping Report.

1.3 Scoping Report Contents

The content of Scoping Report 3 is shown below in Table 1.1.

Table 1.1 Report Contents

Chapter	Description
Chapter 2	Approach to Best Practice Review
Chapter 3	Trip Generation & Car Ownership Modelling
Chapter 4	Demand Modelling
Chapter 5	Road Network Model
Chapter 6	Public Transport Network Model
Chapter 7	Other Modes of Transport
Chapter 8	Appraisal and Other Post Assignment Utilities
Chapter 9	Summary of Best Practice Approach Recommendations

2 Approach to Best Practice Review

2.1 Introduction

As described previously in RMS Scope 1, the NTA require a regional modelling system that is capable of supporting their wide ranging remit, including land use and transport strategy development, scheme appraisal and policy testing[1].

The best practice review presented in this scoping report considers the major components of a typical transport model which will be similar to that which is required by the NTA for the regional modelling system. The modelling approaches reviewed are those designed to have wide ranging application and which have been deployed in other major urban areas which have similar transport characteristics to large Irish cities (e.g. road network congestion for parts of the day).

2.2 Sources of Best Practice

Best practice approaches to regional model development presented in this scoping report have been informed by the following sources:

- Experience acquired and lessons learnt from regional model development;
- Transport modelling guidance from the UK, EU, US and other parts of the world; and
- Relevant models in Ireland, UK, US, Australia and elsewhere.

These best practice sources cover the full range of regional model development approaches in terms of components, structure, sophistication, complexity and their application.

Table 2.1 below provides an overview of the sources that have been used to inform this note. Further details of these sources and/or electronic links to them are provided in the bibliography at the end of this note.

[1] Refer to Scoping Report 1 Sections 2.1 & 3.1 for an overview of NTA's remit and associated roles and responsibilities.

Table 2.1 Best Practice Review Sources

Country	Type	City / Region	Model / Guidance Name	Model Type
Ireland	Model	Dublin	NTA Greater Dublin Area Model	Regional Model
Ireland	Model	Dublin	RPA Greater Dublin Area Model	Public Transport Model
Ireland	Model	Cork	CASP Model	Regional Model
Ireland	Model	Ireland (Rep. of)	NRA National Model	National Roads Model
Ireland	Guidance	Ireland (Rep. of)	NRA Project Appraisal Guidelines Unit 5.0 Transport Modelling Unit 6.0 Cost Benefit Analysis	Traffic Modelling
Ireland	Guidance	Ireland (Rep. of)	National Transport Model for Ireland: Feasibility Study and Road Map for EPA/NTA/DoT)	National Model
Ireland	Guidance	Ireland (Rep. of)	**Economic and Social Research Institute (ESRI) paper entitled "Car Ownership and Mode of Transport to Work in Ireland", 2009**	National
UK	Guidance	UK	WebTAG[2]	All types
UK	Guidance	UK	**Department for Transport (DfT) National Car Ownership Model (NATCOP)[3].**	National (Car Ownership)
UK	Model	Scotland and regions of Scotland	Land Use and Transport Integration in Scotland (LATIS)	Regional / National
UK	Model	Manchester	Greater Manchester Model	Regional
UK	Models	Various UK regions	Delta Land Use Model	Regional
UK	Model	South Hampshire	Transport for South Hampshire (TfSH) Model	Regional
UK	Model	London	London Transport Study (LTS) Model	Regional
UK	Model	Sheffield	Sheffield Strategic Multi-Modal	Regional

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[2] The UK Department for Transport's Transport Analysis Guidance (TAG[2]) includes advice on transport modelling which has been considered as part of our review. However Unit 2.9 of TAG explicitly recognises that DfT's guidance does not purport to promote innovation. Innovative and state-of-the-art approaches will be considered where they further the policy goals of NTA.

Website - http://www.dft.gov.uk/webtag/

[3] http://www.dft.gov.uk/webtag/documents/expert/unit3.15.2.php, Annex A

Country	Type	City / Region	Model / Guidance Name	Model Type
			Transport Model	
UK	Model	West Midlands	Policy Response Integrated Strategy Model (PRISM)[4]	Regional
UK	Model	Nottingham	Nottingham Transport Model	Regional
US	Guidance	US	Transportation Planning Handbook 3rd Edition (2009) Institute of Transportation Engineers	Regional
US	Guidance	US	Travel Model Improvement Programme (TMIP)	All Types
US	Guidance	US	Transportation Research Board	All Types
US	Guidance	US	Department of Transport Federal Highway Administration	All Types
US	Model	New York	Best Practice for Regional Travel Demand Forecasting[5]	Regional
US	Model	Sacramento	The Sacramento Activity-Based Travel Demand Model[6]	Regional
EU	Guidance	Europe	**MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007)**	National / Regional
Australia	Model	Capital Territory	Australian Capital Territory (ACT) CSTM	Regional
Australia	Model	Sydney	**Sydney Strategic Transport Model (STM)**	Regional
Australia	Model	Brisbane	**Brisbane Strategic Transport Model (BSTM-MM)**	Regional
Australia	Model	Adelaide	**Adelaide (MASTEM)**	Regional
Australia	Model	Melbourne	**Melbourne Integrated Transport Model (MITM)**	Regional
Australia	Model	Perth	**Perth Strategic Transport Evaluation Model (STEM)**	Regional
Canada	Guidance	Victoria	**Victoria Transport Institute**	All Types
Dubai	Model	Dubai	**Dubai Activity Model (2004)**	Activity Model

[4] http://www.rand.org/pubs/technical_reports/TR280.html

[5] http://nymtc.org/project/BPM/model/bpm_userdoc.pdf

[6] http://www.mit.edu/course/11/11.951/oldstuff/albacete/Other_Documents/Europe%20Transport%20Conference/activitybased_modellin/the_sacramento_act1712.pdf

2.3 Options for a Regional Model Structure

The typical structure for a regional model of a major urban area is illustrated below in Figure 2.1. This structure has been informed by the following case studies and references:

- UK Guidance – WebTAG, in particular Unit 3.10.3;
- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007);
- Transportation Planning Handbook 3rd Edition (2009) Institute of Transportation Engineers (US);
- Victoria Transport Institute, Canada;
- Models developed in Ireland including the GDA Model and RPA Model;
- Models developed in the UK including: LATIS, Greater Manchester Model, Transport for South Hampshire Model, Sheffield Strategic Multi- Modal Transport Model; and
- General experience of the consultants modelling team in delivering models in Ireland, UK and elsewhere.

The trip generation component represents the effects of land use and socio-economic factors on travel demand. The transport demand model estimates choices that travellers make about how, when and where to travel. Demand models should be responsive to the generalised cost of travel (GC), i.e. a combination of travel time and money costs, of travel. Highway and public transport assignment processes allocate travellers to alternative routes and services.

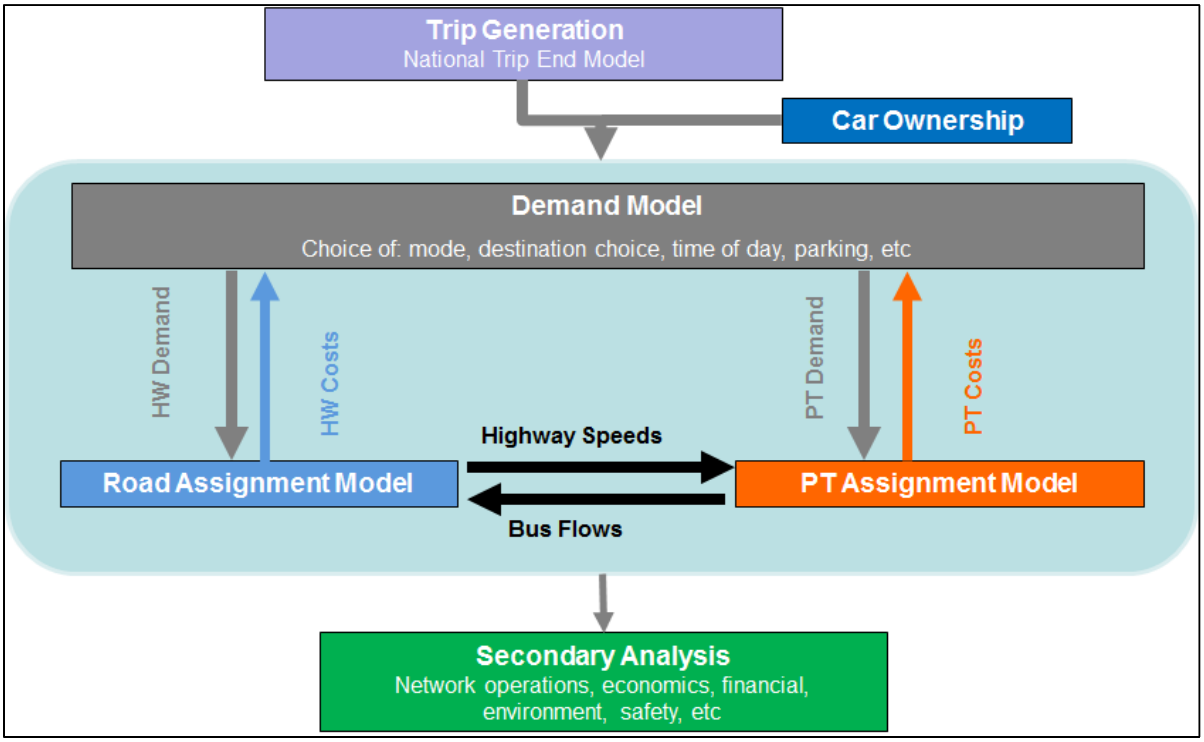

Figure 2.1 Schematic Representation of a Typical Regional Model for an Urban Area

As shown above there are six main components of a typical multi-modal regional transport model, as follows:

- **Trip Generation Model:**
  - The purpose of a trip generation model is to estimate the total quantity of transport demand generated by and attracted to each model zone. The scale of trip generation and attraction for each zone is related to the population, number of employees, school places, retail floorspace, etc. in that zone. “Trip rates” are used to determine the number of journeys generated by each resident (or household) and attracted by each job, school place, square metre of retail space, etc.
- **Car Ownership model:**
  - Whether individuals and households have access to a car has a strong bearing on travel choices. Most obviously non-car owners are unlikely to have the option of using a car. Car ownership models typically predict the proportions of households in each model zone that own 0, 1 or 2+ cars. Car ownership models should predict these proportions separately for households with different structures. Household structure is defined on the basis of the number of adults, their economic activity status and the

number of children. Other household characteristics such as household size, the need to escort children to school and other activities, and economic activity levels have been found to influence the numbers of cars owned. The car ownership model can be used to derive a measure of household competition for cars, i.e. whether a household has no cars, less than 1 car per adult or at least one care per adult. Car competition is a better explanatory variable for travel choices than household car ownership. As an illustration one would expect different mode choices to be made by members of 1 car/1 adult and 1 car/3 adult households.

- ***The Demand model*** is required to replicate the choices and behavioural responses available to transport system users. It includes the following components and features;
    - Representation of Transport Demand e.g. A range of approaches to representing how travel choices are inter-related have been employed in models. The simplest models ignore the linkages altogether, and the most complex attempt to replicate the decision processes behind scheduling activities across a full day. How demand will be represented in the model will strongly influence other aspects of model specification (including data requirements and run-times).
    - Representation of travel choices and responses of interest. These may include mode choice, time of day choice, and destination choice. It is also possible to model other choices including parking location and type (e.g. short- or long-stay, on- or off-street); vehicle occupancy/car sharing, and ticket type choice.
    - Representation of various segmentations of travel demand, for which choices and sensitivity to travel costs differ. Typical segments include journey purpose, household car competition or availability, parking availability, income and/or socio-economic group, eligibility for concessionary travel and vehicle occupancy.
    - Representation of demand for a range of modes of transport; for example car, walking and cycling, public transport (and sub-modes e.g. bus, rail), park-and-ride and taxi.
    - Representation of demand in various time periods, e.g. representing 12, 18 or 24 hour days split into time periods (e.g. A.M., inter-peak, P.M., off-peak).

    - Representation of responses to smarter travel policies, for example, measures such as Personalised and Workplace Travel Plans, and marketing sustainable modes can have a significant impact on mode and destination choice.
- **Road and public transport network assignment model:**
    - The purpose of the road network model is to determine the routes taken by vehicles between zones, to allocate traffic to these routes, to calculate the time and distances for travel between zones, and to calculate total Generalised Cost (GC) of travel between zone pairs including fares, tolls, parking charges, etc. These GC matrices are fed into the demand model as a key driver of travel choices.
    - The purpose of the public transport (PT) network model is to allocate PT users to services operating between their origin and destination zones. Costs of travel including walk, wait, in vehicle time, and fares are calculated by the PT network model for input to the demand model and economic appraisal.
    - Aspects of the PT network model which require consideration and specification include:
        - If and how to segment travel demand;
        - Which time periods to represent;
        - Design of the zone system;
        - Approach to network coding;
        - Representation of fares;
        - The routines used to allocate travellers to PT services, including whether assignments should be capacity constrained;
        - The parameters used within the assignment including GC coefficients and sensitivities; and
        - How to validate the model to ensure that it replicates observed travel conditions adequately.

In addition to the main components noted in the diagram, a regional transport model would also typically include representation of some or all of the following:

- ***Special modes*** (e.g. taxi, walking and cycling, freight, etc.);
    - Taxis;
        - In most models, little consideration is given to taxis. They may be included in the car demand matrix and treated exactly as cars. In this way the broad quantity and spatial distribution of taxis may be captured, but detail such as high volumes of taxi traffic to key attractors and transport interchanges (stations, airports, etc.) may not be represented.

  - Walking and Cycling, for which the following considerations apply;
    - Whether to include walking and cycling in the model at all;
    - Whether to represent walking and cycling as separate or a combined mode within each component of the model system;
    - How to derive matrices for walking and cycling;
    - Should walking and / or cycling matrices be assigned to the model networks; and
    - How to validate walking and cycling demand.
- ***'other aspects'*** including model interface, modelling hierarchy, software platform, links with other NTA datasets & processes etc.

The discussion on best practice approaches is structured around the above modelling components.

Each of the following chapters considers best practice approaches to the above model components under the following headings:

- Case studies / references:
  - Specific case studies and references used to inform the consideration of best practice.
- Overview of possible approaches:
  - Identified best practice approaches.
- Lessons learnt:
  - Lesson learnt from elsewhere.
- Recommended Best Practice:
  - Based on the review of best practice the recommended approach is identified.

3 Trip Generation and Car Ownership Modelling

3.1 Introduction

This chapter considers best practice approaches to trip generation and car ownership modelling.

3.2 Trip Generation Modelling

Case Studies / References

The following case studies and references have been used to inform the discussion on approaches to Trip Generation Modelling:

- WebTAG Unit 3.15.2[7] includes a summary of the UK National Trip End Model;
- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007);
- Transportation Planning Handbook 3rd Edition (2009) Institute of Transportation Engineers (US);
- David Simmonds Consultancy has developed a number of land use models in the UK and New Zealand using their DELTA system[8]; and
- SYSTRA have developed models of Bahrain and Dubai which predict the quantity of trip chains.

Overview of Possible Approaches

Trip generation models predict the total number of journeys, by all modes, made to and from each zone during an average day. There is evidence that the total number of trips is insensitive to GCs. However, if the data for the modelled area suggests that this is not the case a trip frequency response can be included as discussed in Section 4.3.

For home based travel, i.e. where one end of a trip is at home, trip generation models distinguish between:

- ***Productions:*** trip making related to the size and characteristics of the residential population in a zone; and
- ***Attractions:*** trip making related to the scale of employment, educational, retail, leisure, services, etc. within a zone.

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[7] http://www.dft.gov.uk/webtag/documents/expert/pdf/unit3.15.2.pdf

[8] http://www.davidsimmonds.com/index.php?section=33

For non-home based journeys the total number of trips travelling from (origins) or to (destinations) a zone can be calculated either as a function of population and activity variables (as used for home based travel), or a function of the estimated number of home based attractions.

In Section 4.2 we consider how the model should represent travel demand, e.g. as unlinked 1-way journeys, as productions or attractions, or as chains of linked journeys (e.g. home to school drop off to work to home). If the demand model were configured to represent chains of journeys then the Trip Generation model would need to be specified to predict the numbers of such chains.

Population and activity variables for the model base year are typically obtained from sources such as Census data, employment location data which may be collected by local or national government for economic monitoring and planning, school place records from local authority sources, data held by local authority departments responsible for land use planning and development control planning, etc.

Population and activity variables will also be required for forecast years. Sources of such data could include demographic and economic forecasting models, and data from planning authorities on proposed developments and spatial plans. An alternative approach is to develop a land use model to estimate how population, employment and other land uses will be distributed in the future. Land use models use information on base year land use distributions, rents, wages, environmental quality and transport accessibility to predict how land use distributions will evolve.

Trip rates are estimated by statistical analysis of datasets of trip making, and population and activity variables. Typically household travel diary surveys are used to estimate trip rates. This analysis should include consideration of how or if different segments of the population, types of employment, and categories of land use affect trip making. International research has indicated that factors such as age, gender, employment status, car ownership or competition and household size influence trip rates.

Trip rates may vary depending on the nature of the zone. For example a zone in the city centre may generate more or fewer trips than a zone in a suburb. The trip rate analysis can explore whether such variations exist and are significant. As travel times and public transport provision vary across the day in most urban areas, so too will travel choices. For this reason it is best practice for urban transport models to include separate representations of different time periods. Trip estimates will have to be allocated to different time periods at some stage in the modelling process, but not typically in the trip generation step because the demand model can adjust time of day splits as a function of GCs for each period. Trip generation models therefore provide estimates of travel for full days, or in some cases 16 or 18 hour periods which capture the large majority of travel.

The choice models should adjust the forecast mode split and distributions in response to changes in generalised cost and to changes in the levels of car availability. The need to include these car availability effects in turn requires an ability to predict future car ownership and to ensure that the resulting changes in car ownership and/or availability are incorporated correctly within the demand forecasting process.

Lessons Learnt

It is important that there is a high degree of consistency between the base year trip ends and time period Origin / Destination (OD) trip matrices used in the Assignment Model. Without such consistency there is a risk that forecast changes in trip ends do not get translated into plausible forecast matrices. For example if a zone in the matrix has zero trips whilst the Trip Ends are non-zero then even large growth factors from the forecast model would result in zero trips. If a matrix contained too many trips in relation to the Trip Ends then even modest Trip End growth could result in unrealistic forecast matrices. Methods to apply growth in an additive (or subtractive) manner can partly address this problem, but can result in implausible results such as negative trip ends.

The scope for discrepancies is most strongly prevalent in the development of OD trip matrices that reflect observed traffic flows on the transport network. These discrepancies are likely to be due to a combination of variability of the underlying traffic counts and the existence of specific local traffic generators which are not adequately reflected in the region-wide ‘generic’ approach to predicting road traffic. Where possible, the reasons behind significant discrepancies between ‘predicted’ and ‘observed’ traffic levels should be investigated. In particular, any ‘outlying’ traffic counts (i.e. where the match with the observed count is much worse than for other nearby/similar count sites) should be identified and investigated, to try to decide if the problem might lie with the ‘observed’ count, rather than the model predictions.

Increased segmentation of travel demand in the Trip End model, relative to the choice models, should allow for the development of more accurate models because trip rates can be determined separately for each segment. If changes in the scale and location of each segment can be developed (e.g. by spatial planners) increased segmentation would also improve forecasting of travel demand. The detailed segments need not necessarily be retained through the choice or assignment models where they add to run times but not to accuracy. For example segments with similar route choice characteristics (e.g. operating costs and values of time) can be combined in the Assignment Models.

Trip End models often assume that average all-mode daily trip rates per person (for each person type[9] and trip purpose) are constant, regardless of the transport supply. Even when this assumption has been verified by analysis of travel diary data, care is needed to ensure that any significant change in these trip rates over time (for example reductions in travel due to increasing levels of home working, video-conferencing, on-line shopping etc.) is captured. Analysis of travel diary data in London for years 2001, 2007 and 2011 showed that trip rates for employers business travel had increased over time, whilst commuting trip rates had decreased, with broadly stale trip rates if both purposes were combined. These changes may be due in part to changes in the survey specification and / or changes in actual travel behaviour. Some of these changes in trip rates may be picked up by incorporating a trip frequency response to changes in travel costs within the choice modelling, but others which reflect exogenous changes in society (such as the internet technology examples noted above) will not be picked up automatically by a trip frequency approach based solely on travel costs.

Trip frequency responses to changes in travel costs are most commonly used in models that exclude active modes, since a switch from active to motorised modes or vice versa appears as a change in trip frequency in these simplified models.

The vectors of trip productions created by Trip End modelling have merit in being straightforward to interpret and sense check. It is therefore sensible for home-based trip numbers to be at least ‘singly constrained’ at the production end. For non-home based trips, confidence is typically associated with trip attractions and modelling is singly constrained at the attraction end. Work and education trips are conventionally ‘doubly constrained’ to both trip end production and attraction vectors. This is conceptually attractive as it makes sure that all pupils arrive at school and workers at employment, but in forecast terms it can be possible that relatively remotely located employment opportunities cannot in practice attract sufficient workers that the modelling would otherwise suggest. It is therefore desirable that the demand model provides some level of flexibility in the application of trip attraction constraints. Some model implementations apply a notion of ‘soft constraints’ that encourages but does not enforce matching to trip end values.

Recommended Best Practice

- A Trip Generation model which develops estimates of total travel to and from each zone is an essential component of the transport forecasting model and must be sensitive to variables such as population, employment and other activity generators. It is best practice to estimate daily trip rates using local travel diary surveys for

[9] Trip-rates usually vary between different demand segments due to the impact that variations of car availability and/or income and/or age and/or economic status etc. have on these trip rates.

disaggregate demand segments. The definition of segments should be determined by statistical analysis of how socio-economic categories affect trip rates.

- If possible analysis of historic and recent travel surveys should be undertaken to establish whether all mode trip rates can be assumed to remain constant over time, or should be increased or decreased.
- There must be a high degree of consistency between base year trip ends and OD matrices using the network models. Without such consistency there is a risk that forecast changes in trip ends do not get translated to plausible forecast matrices.
- Checks of consistency with trip ends and land use data should be built into the matrix development steps. Means to adjust matrices to better match trip ends should be considered. Care should be taken that any matrix calibration (e.g. using matrix estimation) does not unduly disturb this consistency.
- A detailed specification of the Trip End model is required including considerations such as segmentation and how car ownership / availability forecasts are developed.

3.3 Car Ownership Modelling

Case Studies / References

The following case studies and references have been used to inform the discussion on approaches to Car Ownership Modelling:

- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007); and
- The UK NATCOP model and ESRI research for Ireland are summarised below to illustrate possible approaches.

Overview of Possible Approaches

A number of aspects of travel behaviour are influenced by whether a car is available, most notably mode choice. However, car availability has also been shown to affect the choice of destination, time of travel, trip length and trip frequency for some or all trip purposes. A number of related, but distinct concepts need to be distinguished here, including:

- Household car ownership – the number of cars or vans available for use by members of a household – usually either two bands (No Car and 1-or-More-Cars) or three bands (No-Car, 1-Car and 2-or-More Cars);
- Household Car Competition – usually defined on the basis of the ratio of the number of cars owned by the household and either the number

of adults or the number of driver-licence-holding adults in the household;

- Car-sharing – i.e. where one or more passengers travel in a vehicle owned (and driven) by a member of another household;
- Whether taxis are included in the mode choice set being considered (i.e. allowing the traveller to become ‘car available’);
- The need to distinguish between ‘car drivers’ and ‘car users’ (i.e. the latter includes both car driver and car passenger modes) and the associated need to predict the average occupancy of cars by demand segment; and
- The relationships between household car ownership (and/or household car competition) and the availability of a car for a specific trip.

A means is required to predict how car ownership and/or availability will change over time, in order to predict future travel conditions and the impacts of policies and schemes. Present day data on the proportions of a household which have access to a car can often be obtained from sources such as population censuses and travel diaries. Ideally such data should be available at a high level of spatial detail and also for each of the demand segments used in the transport model (see Section 4.14).

There are a number of ways in which car ownership or competition can be categorised. Ideally models should have information about whether a car is available for any individual journey. Some activity models (see Section 4.2) predict access to a car for an individual journey. Other modelling systems use either the number of cars owned by a household (usually categorised as 0, 1, 2+, etc.) or a measure of competition for car (e.g. at least 1 car per adult, less than one car per adult, no cars). In the UK, DfT have developed a National Car Ownership Model (NATCOP)[10]. NATCOP predicts the proportions of households owning 0, 1, 2 and 3+ cars; and categorises households by the number of cars owned relative to the number of adults (e.g. 2 adults/1 car would be a single category). NATCOP has been calibrated using data from a Family Expenditure Survey. This calibration revealed that in the UK the drivers of car ownership are:

- Household structure categories, i.e. the numbers of adults, children, employment and retirement status, etc.;
- Incomes;
- Area type with big cities typically having the lowest levels of car ownership (all other variables being equal) because jobs and amenities are relatively accessible by PT, walking or cycling; and
- Licence holding rates.

[10] http://www.dft.gov.uk/webtag/documents/expert/unit3.15.2.php, Annex A

NATCOP uses S-curve shaped logistic relationships to relate income to car ownership levels.

In 2009 Nicola Commins and Anne Nolan of the Economic and Social Research Institute (ESRI) published a paper entitled "Car Ownership and Mode of Transport to Work in Ireland"[11]. This paper reports on the calibration of a joint car ownership and mode choice model based on 2006 Place of Work Census of Anonymised Records (POWCAR) data. The ESRI approach was different to NATCOP as logit discrete choice models were developed for car ownership and mode choice. The model uses just two categories of household car ownership: no car and at least one car. ESRI found that population density, household composition, and income were important factors in car ownership; which is consistent with the NATCOP findings. Gender, Socio Economic Group and access to PT were also significant.

Lessons Learnt

Irish and UK research indicate that household structure, income and area type significantly affect car ownership. The data used for calibration in the UK allowed for licence holding to be accounted for; whilst the Irish data and approach allowed for gender, socio economic group and PT access to be accounted for. The ESRI work suggests that a car ownership forecasting model can be calibrated from the POWCAR data.

For transport demand modelling, using a measure of the household car competition often provides a better prediction of mode choice than household car ownership, since the former tends to provide a better predictor of the availability of the car(s) for specific trips. This is particularly true when predicting car driving, rather than car-use. However, predicting current and future car competition is usually more difficult than predicting household car ownership bands, since the former requires more information about current and future demographics, while the latter can usually be deduced reasonably accurately from aggregate estimate of the average number of cars per household in a given area.

Recommended Best Practice

- A method to forecast future car availability is required as it has an impact on numerous aspects of travel behaviour, including trip rates, mode choice, destination choice, trip length distributions etc.
- Competition for car is generally a better indicator of travel behaviour than household car ownership.
- A car ownership model could be calibrated using Census data.

[11] http://www.esri.ie/UserFiles/publications/20090901110946/WP310.pdf

4 Demand Modelling

4.1 Introduction

This chapter considers best practice approaches to demand modelling under the following demand modelling categories:

- Representation of Transport Demand;
- Trip Frequency;
- Mode Choice;
- Destination Choice;
- Time of Day Choice;
- Parking and Park & Ride;
- Vehicle Occupancy;
- Ticket Type Choice;
- Smarter Travel Choices;
- Generalised Cost Formulation;
- Parameters for Choice Models;
- Choice Model Forms;
- Demand Segmentation;
- Time Periods;
- Demand / Supply Convergence; and
- Calibration and Demonstration Tests.

Typical transport demand models may include the steps shown in Figure 4.1(which is informed by a review and experience of the models and guidance provided in Table 2.1from Chapter 2).[12]

[12] The travel choices illustrated in Figure 4.1 may differ by journey purpose – e.g. destination and trip frequency tend to be less important for travel to work than for shopping or other 'discretionary' trip purposes

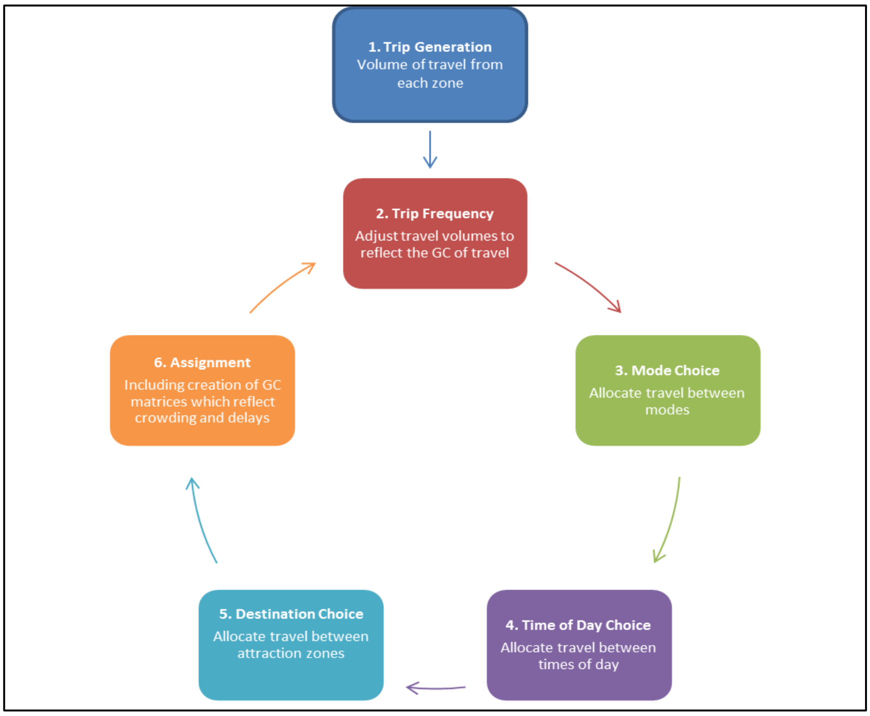

Figure 4.1 Schematic Representation of the Transport Model Cycle

The order of steps (3) to (5) differs between models depending on how sensitive each of the responses is deemed to be in the modelled area.

There are detailed choices to be made about each of the steps above:

- How should trip generation be undertaken? (Step 1, discussed in Chapter 3)
- To what extent the model considers the interactions between related journeys (e.g. the journey from home to work and the journey from work to home) and activities. Some models take a very simplistic approach where all 1-way journeys are treated in isolation; others replicate decision making processes to determine how many journeys are made, where to, how and in what order to meet an individual’s needs for a day. (Steps 1 to 5)
- Which choices and responses should be included? Some models exclude some of the steps shown above. It would be possible to model other choices including parking location and type (e.g. short- or long-stay, on- or off-street); vehicle occupancy/car sharing, and ticket type choice. (Steps 2 to 5)
- Sub-mode choice. Whether the choice of PT sub-modes (between bus, LUAS, DART, heavy rail, etc.) is dealt with as part of the PT assignment model or within the demand model. (Step 3 or Step 6).
- Choice model forms. Incremental (where choices pivot from observed data in response to cost changes) or absolute (fully

synthetic, but with calibration constants to match observations)? (Steps 2 to 5).

- Demand segmentation. Travel choices and sensitivity to GC differ depending on factors including journey purpose, car ownership or competition, parking availability, income and/or socio-economic group, eligibility for concessionary travel and vehicle occupancy. Segmenting demand also facilitates more accurate representation of the base situation, and, only if robust input data is available for future years, forecasting because the variables which influence travel volumes for each segment can be isolated. (Steps 2 to 5).
- GC formulation. How should the GCs used in the demand model be formulated? This topic includes consideration of whether to include distance based cost damping in some manner. GC is most commonly calculated as a simple linear sum of the elements of travel costs (e.g. A x time + B x money). A limitation of using a linear GC formulation within logit choice models is that a 5 minute change to a 2 hour journey is given the same importance as a 5 minute change to a 30 minute journey. (Steps 2 to 5)
- Parameters for choice models. Should these be imported or calibrated based on local data? The responsiveness of the model to changes in fuel, fare, and transport supply should be checked and calibrated regardless of the source of parameters. (Steps 2 to 5).
- Modes to include. Decisions are required on how to model other modes such as walking and cycling, (including whether to assign bicycles to the road network), park-and-ride and taxi. (Step 3 and Step 6)
- Time periods. Should the demand model represent 12, 18 or 24 hour days? What time periods should be specified? Should demand and assignment models use the same time periods? (Step 4)
- How smarter travel policies should be represented. Measures such as Personalised and Workplace Travel Plans, and marketing sustainable modes can have a significant impact on mode and destination choice. (Steps 3 and 5).
- Measurement and management of demand/supply convergence (Steps 2 to 6).

4.2 Representation of Transport Demand

Case Studies / References

The following guidance, case studies and references have been used to inform the identification of best practice approaches to the representation of Transport Demand:

- WebTAG Unit 3.10.2[13] (section 1.3) strongly recommends that the production-attraction format (rather than origin-destination) be used in demand modelling. The majority of demand models in the UK make use of either production-attraction (e.g. London Transportation Studies[14], Nottingham and Transport Model for Scotland) or simple tours formats (e.g. Greater Manchester, Sheffield, and South Hampshire). DfT's DIADEM software[15] allows for production-attraction or simple tours to be represented;
- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007);
- Transportation Planning Handbook 3rd Edition (2009) Institute of Transportation Engineers (US);
- The use of complex tours is not common in existing models of large cities. Hence such an approach would be leading edge entailing technical challenges, as well as timescale and budget risks associated with innovation. A full design exercise would be required to ensure that available data could support the approach and that the model specification was internally consistent;
- SYSTRA developed Activity Models for Dubai in 2004. A strong rationale for choosing this approach was that the population of Dubai was growing rapidly (around 8-10% p.a.) requiring extensive new development, and so current observed travel patterns were a poor guide to the future. Therefore the Dubai model was configured to develop travel patterns using wholly synthetic approaches rather than relying on spatially detailed travel surveys, which reduced the data requirements for the Activity Model approach. Also every day working practices encourage a relatively high proportion of trip chains being undertaken between work and return home. SYSTRA applied the same modelling approach to Bahrain in the mid-2000s; and
- Activity modelling is most established in the US including Sacramento, Portland, San Francisco, New York, Columbus, Dallas, Denver, Seattle, Bay Area, San Diego, Atlanta, Los Angeles and Phoenix. An overview of the activity model process is provided in a paper on the Sacramento model[16] by Bradley, Bowman and Griesenbeck.

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[13] http://www.dft.gov.uk/webtag/documents/expert/unit3.10.2.php#013

[14] http://www.transportscotland.gov.uk/analysis/LATIS/models

[15] https://www.gov.uk/government/publications/diadem-software

[16] http://www.sciencedirect.com/science/article/pii/S1755534513700277

Possible Approaches

All travel demand models make simplifying assumptions about how people choose to travel. In reality people often make interrelated decisions about a number of journeys in the same day, or even spanning several days. Individuals need to make choices about how and when they fit in all of their activities within a day or a week. For example, one could choose to visit a friend on the way home from work, or to do so after having dinner at home.

A range of approaches to representing how travel choices are inter-related have been employed in models. The simplest models ignore the linkages altogether, and the most complex attempt to replicate the decision processes behind scheduling activities across a full day. How demand will be represented in the model will strongly influence other aspects of model specification (including data requirements and run-times).

Five approaches to representing demand within the demand model may be considered. In all cases matrices would be converted to origin-destination form for assignment. The five approaches are described below in increasing order of how well they represent real travel choices.

Origin-Destination (OD). Trips are from an origin zone to a destination zone without any linkage information between the trips indicating that they are one leg of a round trip or information on whether the trip is outbound from home, returning home or an intermediate trip. Origin-Destination (O-D) matrices are used in assignment models as these models do not need to know whether the one-way trip is part of a round-trip or a more complex chain of trips. OD format matrices are typically constructed for each modelled period (e.g. AM Peak, Off-Peak, PM Peak). If an individual made a number of trips in a day the model would treat each completely separately and not take account of any dependent choices (e.g. whether a car is available for the second trip of the day).

Production-Attraction (PA). Two-way trips from a production (i.e. home) zone, to an attraction (e.g. work, school, shop, etc.) zone returning to the production zone. PA format matrices are typically constructed for the full day because each 1-way trip could happen at different times of the day.

Where the PA format is used for home-based travel, non-home-based journeys are typically represented in origin-destination format.

Simple Tour. This is the same as the PA format except that the paired from- and return-home time periods are recorded. For example many commute tours would be associated with a “from-home in the morning / return-home in the evening” time period-pair. Splitting PA matrices between time period pairs allows the model to calculate the GC of travel for the simple tour by adding the GC for the from-home leg in the outbound time period to the GC for the return-home leg for the return home period.

Complex Tour. This is similar to the simple tour format except that it allows for one or more intermediate stops to be represented within the travel pattern. Keeping these complex tours together ensures that consistent decisions (particularly mode choice) are applied to all legs of the tour (for example ensuring that those who drive a car for the first leg have a car available for the second leg and so forth). Using this format within the demand modelling will also ensure that the generalised cost of the complete multi-leg tour is used in the mode choice decision.

Activity Modelling. In conventional transport demand models the pattern of activity across a day is considered to be fixed. Activity modelling is an extension of the complex tour approach, in which the order of the various legs (and the decisions on whether or not to undertake the various activities at all on a given day) are all allowed to change in response to changes in travel costs and/or the locations of the relevant services. The approach acknowledges the fact that the travel needs of the population are determined by their need to participate in activities spread out over time and space.

Activity models take account of how decisions made for each activity affect decisions for other activities. For example a decision to drive to work, and hence to have a car available at the end of the work-day, will affect the choice of whether to ‘pop into the shops’ on the way home from work etc.

Activity models often attempt to replicate the sequence of trips undertaken by all the individuals in a household on a typical day and hence often keep track of car availability for all members of a household than the simpler models.

A typical Activity Model would include the following steps:

- Predicting long-term choices about workplace or study location (similar to a conventional distribution model);
- Car ownership or availability modelling;
- Predicting whether to travel on a typical day, and if so how many home-based tours will be made;
- Determining whether additional stops will be made as part of the main tour (e.g. to drop children at school on the way to work);
- Choosing the mode used for main tours which then strongly influences choices for other stops;
- Choosing the location for each stop based on travel costs and the attractiveness of each potential destination; and
- Choosing the time-of-day of each tour or stop.

Activity models often operate at a disaggregate level where the travel schedules of a sample of individual households are estimated and the resulting journey numbers factored up to represent to full population data.

Activity Models typically negate the need for a separate transport demand model as they must incorporate choices such as which mode(s) to use, where to travel to, what time of day to make journeys, and whether to travel at all in order to derive schedules.

Figure 4.2 illustrates how alternative approaches to representing demand in the model for somebody who travels to work in the morning, travels from work to a friend's house in the evening, and finally returns home. Each arrow on the figure represents one "unit" in the demand modelling. The demand model will calculate the GC for each unit, and predict the choices made for that unit, without consideration of any other unit.

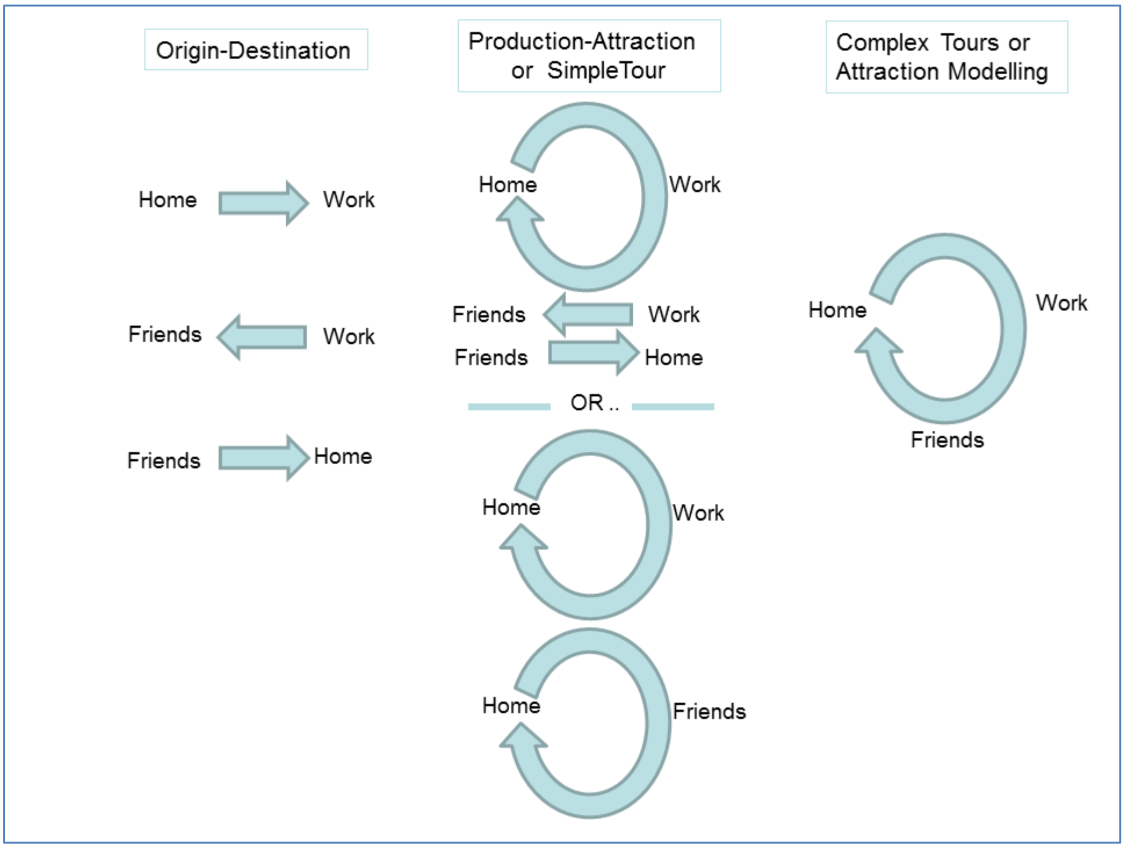

Figure 4.2 Alternative representations of a day's journeys within the demand model

Trips which involve an escort, e.g. where a parent takes a child to school or a friend gives a lift, can be represented at least approximately in each of the formats described above. In reality escort trips can entail simple 2-way "there and back" home-based tours, or be part of more complex chains of activity. The way in which escort trips are represented in each format are, in summary:

- Origin-destination: the average number of people making each trip would be established using data such as travel diaries, which may be of particular importance for estimating public transport ridership;

- Production-attraction: a decision is required on how to simplify trip chains (e.g. is a home-school-work-school-home chain treated as a home-work tour plus a home-school tour, is the school stop ignored in the model, etc.) which will determine how the average number of people making each leg is estimated;
- Simple tour: as for the production-attraction format;
- Complex tours: in principle the travel choices made for the escorted legs (e.g. whether to drive children to school) can affect choices made for other legs; and
- Activity modelling: it may be possible to replicate the complex choices that household make about structuring their activities.

Lessons Learnt

OD format is not good practice for demand modelling because:

- Demand for travel is strongly influenced by variables such as populations and job numbers which are related to productions and attraction zones, rather than origins and destinations; and
- There is no link between from- and return-home journeys and so no way of ensuring consistency in choices, e.g. the same mode being used to get to and from work, that the return-home trip happening after the from-home, or the location of the home end being fixed.

WebTAG Unit 3.10.2 lists four exceptions where the OD may be acceptable for demand modelling:

- Uniform growth rates will be applied to all model zones;
- Only a peak period will be modelled;
- Demand responses will be represented using elasticity models; and
- Original demand data is lost and there is no means to construct PA matrices.

Each of the four circumstances would result in poor quality models and in our view do not justify developing OD based demand models.

The **PA** format does allow growth forecasts to be related to changes in population and attraction variables in each zone.

A challenge with the PA ‘all-day’ format is to estimate generalised costs which are representative of travel for both legs of the journey. This can be done either by assuming that the trip choices are primarily based on the travel conditions in one modelled time period or to average the costs from two or more separate time periods to produce a set of ‘hybrid’ costs which can be used as the basis of the travel choices at the 24-hour PA level.

When the PA approach is used for demand modelling it is usually necessary to translate the PA matrices into OD form for assignment. Factors are calculated (e.g. from household travel diary surveys) to split the full-day PA matrices into from- and return-home OD trips for each time period.

This process is illustrated in Figure 4.3 below.

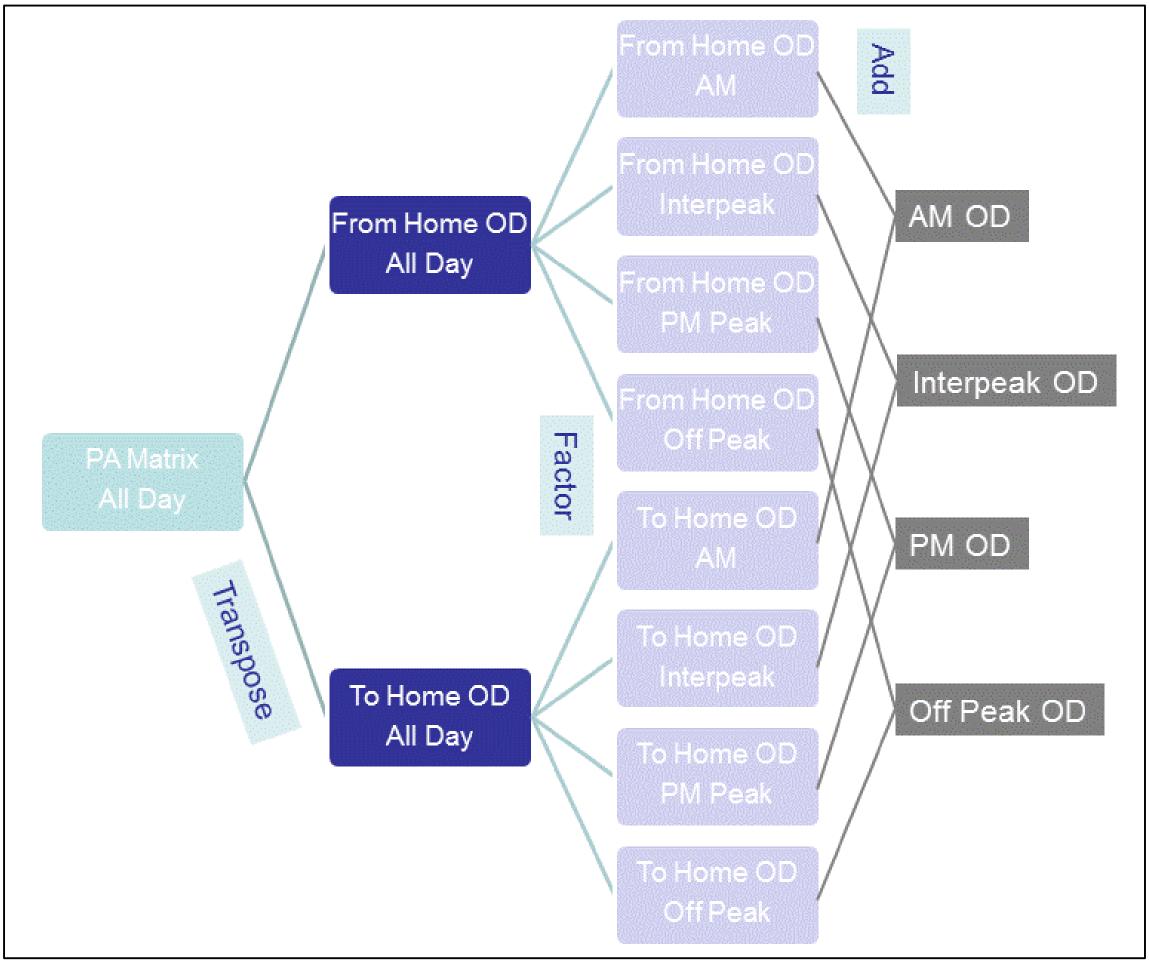

Figure 4.3 PA to OD Conversion

It is possible to undertake time of day choice modelling using the PA approach by making the factors to split All Day OD matrices to period OD matrices sensitive to cost differences between periods. However, there would not be a mechanism for ensuring consistency in time shifts between the from home and to home demand, which could result in unrealistic increases or reductions in the length of the working day, or time spent at shops or school. With **simple or complex tours** modelling the choices of out and return travel periods can be linked, to ensure that the relevant decisions can become a function of the generalised costs for the full round trip.

This is particularly important if parking capacity and/or parking location choice are being modelled in detail, since the use of a tour-based representation of the round trip makes it much easier to keep track of the duration of the various activities between the from-home and return-home trips (and hence the utilisation of the various car parks throughout the modelled day).

Similarly, if time-of-travel choices are being modelled in detail, a tour-based format of travel demand makes it easier to ensure that the duration of the activity between the from-home and return-home trips do not change in unrealistic ways (for example travelling to work later **and** coming home earlier in response to increased peak-hour congestion).

As noted above complex tour modelling is largely untested. Modelling using **complex tours** would retain the benefits of the simpler 2-way tour approach. In addition intermediate stops, such as school runs or visiting friends after work, would be treated in a consistent manner to the main journeys. It would be possible for the model to ensure consistent mode and time-of-day choices (i.e. retaining the observed order of stops). School runs are observed to result in significant local congestion ‘at the school gate’. If school runs were modelled explicitly then measures to encourage more sustainable and healthy ways of getting to school could be more accurately represented.

Complex tours would need to be categorised in the demand model. For example home-school (drop off)-work-school (pick up)-home could be one such category. For the OD, PA and simple tour forms demand would be categorised by purpose (e.g. Commute, education, shopping etc.). For the complex tour approach there will be more numerous and complicated tour categories than purposes, resulting in increased run times and data storage. There is a risk that available travel diary data may not provide statistically robust estimates for each category.

An individual’s activity patterns, both in-home and out-of-home, influence the individual’s travel patterns. In order to accurately quantify the travel needs of the population, it is useful to model the activity-travel patterns of the population (the activity-travel pattern of an individual is defined as a complete string of activities undertaken by the person over the course of a day characterised by location, time of day, and mode of travel between locations).

In principle **Activity Modelling** is sensitive to a wide range of variables including demographic changes, land use and policy measures. Activity models allow for very detailed forecasting of behaviours and are in principle a closer representation of how people decide on how to fulfil all of the activities which may require travelling throughout the modelled day.

Activity modelling is data and model run time intensive, requiring a very high sample of travel diary data across the region of interest. Activity models are made up of numerous sub-models which all require calibration to match the travel diary records.

A common disadvantage associated with activity modelling is difficulty in interpreting what household factors contribute to changes in travel behaviour in forecast years, and thus what factors are contributing to conditions on the transport network. This approach requires a comprehensive household travel diary dataset that demonstrates the proportions of the population which undertake the various combinations of the relevant ‘activities’ throughout the day.

Activity model structures are complex and would be challenging to code accurately. Forecast matrices may not reproduce observed flows on road links and public transport surveys once assigned. The benefits of this approach may be limited if a large proportion of journeys are actually just simple tours.

Recommended Best Practice

- Tours and all day modelling are recommended to enable more accurate mode choice modelling to be included, particularly in the PM Peak.
- PA modelling is the minimum standard for major urban demand models. The OD format should not be considered because it does not provide an internally consistent basis for choice modelling, or support the application of growth forecasts based on population or jobs.
- Simple tour modelling is well established and offers benefits in consistency of time of day response and in the modelling of parking capacity.
- Complex tours modelling would provide enhanced functionality over the Simple Tour approach as intermediate stops, such as school runs or visiting friends after work, can be treated in a consistent manner to the main journeys. Analysis of travel diary surveys should be undertaken to determine how many journeys and trip kilometres are related to complex tours rather than simple 2-way home based journeys.
- Whichever approach to representing demand is adopted, matrices should be developed based on recent information (TAG Unit 3.19 recommends that data should be no older than 6 years). In Ireland data is available from the national censuses which can facilitate development of travel matrices for commute and education purposes which are based on near-100% countrywide samples. Direct observation of travel patterns (e.g. based on roadside or public transport passenger interviews) is expensive and disruptive but is good practice, at least for an area related to a scheme or policy which is to be appraised. Data sources such as public transport ticket sales and mobile phone tracking can also be used in the development of matrices. Further consideration is given to the data which may be used to develop matrices in Scoping Report 4.
- Developing an activity model would be risky due to the high costs, extended timescales, and reliance on very detailed data for

calibration and forecasting. The calculation intensity of such approaches could lead to lengthy model run times.

4.3 Trip Frequency

Case Studies / References

- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007); and
- Trip frequency is included in models of Sheffield, Manchester and Scotland; albeit with very low sensitivity to generalised cost.

Possible Approaches

A trip frequency response would adjust the total level of trip making from each zone as a function of the GC of travel from that zone to all other zones, by all modes. A composite cost measure is typically used.

If all modes of travel including walking and cycling are included in the model then it may not be necessary to include a trip frequency response. Analysis of UK National Travel Surveys between 1988 and 1996 indicates that the total number of trips made by an average individual have been stable[17] and so are unlikely to be responsive to changes in costs of travel. The average journey distance in the UK has increased over time.

Trip frequency could be used to approximate changes in mechanised travel if walking and cycling were omitted from the model (see section 7.2).

Lessons Learnt

UK evidence, from travel diary surveys, indicates that all mode trip rates are insensitive to cost. A review of evidence from Dublin or other parts of Ireland could be undertaken. Data from travel diary surveys could be used to derive parameters for trip frequency models.

Recommended Best Practice

- A trip frequency response is unlikely to be required if walking and cycling modes are included in the mode choice stage.

4.4 Mode Choice

Case Studies / References

- WebTAG Guidance (UK);

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[17] http://www.dft.gov.uk/webtag/documents/expert/unit3.15.2.php#04

- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007);
- Transportation Planning Handbook 3rd Edition (2009) Institute of Transportation Engineers (US); and
- Most UK models include a main mode choice step implemented using a logit model. Examples include London, Scotland, Sheffield, South Hampshire, Greater Manchester, Nottingham, Derby, Leicester, Newcastle, etc. All of these models undertake sub-mode choice within the assignment step.

Standard Practices

Choice of main mode (e.g. between car, public transport, walking, cycling, and possibly park and ride) is typically undertaken using a discrete choice formulation to allocate demand between alternatives as a function of the relative cost of each alternative. The logit model is most commonly used for discrete choice in transport planning and WebTAG Unit 3.11.3 recommends that, although there exist a range of options, model development should always commence with the logit form.

Elasticity and cross-elasticity models for mode choice are rarely used for multi-modal transport models. With an elasticity model the volume of demand for option A is a function of the cost of option A and costs of alternatives are not considered. With cross-elasticity models the volume of demand for option A is a function of the cost of a single alternative option alone, but not option A itself. As stated in WebTAG unit 3.10.3, elasticity models contain certain deficiencies, including overestimation of the effects of variable demand responses on scheme benefits, and therefore are not recommended.

Sub-mode choice can be represented in the demand model to predict the use of individual sub-modes, or can be left to the assignment model. Undertaking sub-mode choice outside of the PT Assignment entails a number of steps:

- Defining the sub-modes;
- Deciding on how to categorise routes which require the use of multiple sub-modes. For example, if a route requires the use of bus and rail should it be treated as bus, rail or maybe a composite “bus-rail” mode;
- Running the PT Assignment model for each defined sub-mode to create paths and GC matrices for the sub-mode. This requires biasing the assignments in some manner to force or at least strongly encourage the use of the sub-mode;
- Deriving composite costs for PT, e.g. by taking the logsum of costs for each sub-mode;
- Using the composite PT costs as input to the main mode choice model (car vs PT);

- Applying the sub-mode choice model; and
- Assigning the sub-mode matrices to the biased paths within the PT Assignment package.

Lessons Learnt

Inclusion of mode choice is essential to test major public transport schemes and car demand management strategies. Even in the absence of transport interventions, mode choice will change over time in response to changes in congestion, fuel prices, car ownership, etc.

Elasticity and cross-elasticity models are not specified to allocate demand between alternatives or to consider the costs of all alternatives. Discrete choice models, including the logit formulation, do take account of the costs of all alternatives and distribute demand between options.

There are problems with undertaking sub-mode choice outside of the PT Assignment:

- It is not clear how sub-modes should be defined if more than one mode must be used between a given zone-pair. The model could produce different results depending on the chosen definition;
- Biasing route choice could lead to unrealistic routes and GCs for some zone-pairs for every sub-mode;
- Numerous runs of the Assignment model are needed which could be time consuming; and
- If crowding modelling was required then the biased path building, sub-mode choice and assignments would need to iterate.

Undertaking sub-mode choice outside of the PT Assignment allows for easier interrogation of the GCs that are driving the response and the sub-mode choices that the model outputs. In situations where multi-modal tickets are offered, the PT Assignment model may not be able to calculate representative fares that could be input directly to the demand model.

Recommended Best Practice

- Mode choice modelling is very well established and must be included in the Regional Modelling System if it is to be used to assess the merits of public transport investment.
- A discrete choice formulation of mode choice should be adopted.
- Undertaking sub-mode choice using the PT assignment step is the most commonly adopted approach, avoids complication and excessive run times, and offers a more realistic simulation of how travellers choose routes than a logit allocation between modes.

4.5 Destination Choice

Case Studies / References

- Most UK models include a destination choice step implemented using a logit model. Examples include London, Scotland, Sheffield, South Hampshire, Greater Manchester, Nottingham, Derby, Leicester, Newcastle, etc.;
- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007); and
- Logit, gravity and cloning approaches have all been used in the models listed above.

Possible Approaches

It is helpful to distinguish between two aspects of destination choice. Firstly, how would travel demand from a newly developed area be distributed if travel costs were as they are today? Secondly, how would the distribution of travel demand change as the GC of travel changes due to changes in congestion, public transport fares, fuel costs and so on.

There are two options for distributing demand from new development sites. Distribution patterns could be assumed to be the same as for a nearby zone or zones with similar land use. This approach is often known as “cloning”. Alternatively a logit or gravity destination choice function could be applied to distribute demand as a function of the GC of travel to each possible attraction zone.

Evidence from the UK indicates that the choice of destination in response to GC changes is, for some purposes at least, more sensitive than mode choice. This is intuitively reasonable because many people are unable or unwilling to use PT, but do have flexibility to change destination in the short-term (e.g. for supermarket trips) or longer-term (e.g. when changing job or looking for a new home).

Destination choice is most regularly represented using a logit-type, discrete choice model, which allocates demand between alternative options (in this case attraction zones) based on the cost of travel from the production zone to each attraction zone. This is similar to the methodology for implementing mode choice (as described above in Section 4.4).

For some purposes such as commuting and education, it is recommended practice[18] to “doubly-constrain” the models such that the total numbers of attractions for each zone are fixed. Doubly constraining the model means that the

[18] http://www.dft.gov.uk/webtag/documents/expert/unit3.10.3.php

total numbers of trips to each workplace or school are fixed but the locations from where employees or students travel can change as accessibility changes. This reflects the relative confidence in the measures of attraction (employment and student numbers) for commuting and education trips, as well as the relatively fixed nature of these attraction values in the short term.

The relationships between destination choice and GC, and hence trip length distributions, could differ between geographic areas. For example a city centre resident may be able to fulfil more of their needs close to home than a resident of a suburb. It is possible to estimate different destination choice parameters for different areas if supported by available data.

Lessons Learnt

Cloning approaches for distribution of trips from new developments can be useful for developments that are specialist in nature (e.g. a hospital, sports stadium, science parks, etc.) and so the cost of travel is relatively unimportant. If there are no representative zones in the vicinity then the user could derive a distribution manually, providing that assumptions were clearly stated. The distribution of demand to and from more common land use types such as housing and supermarkets are more likely to be influenced by GCs as alternative locations will be available to choose from.

Using logit models to distribute demand from more common land use types is good practice because the same model form and parameters can be used as for zones with established developments to ensure consistency.

Whichever approach is used to distribute demand from new developments, it is very important for modellers and end-users of model outputs to be able to understand the distributions. Unrealistic or unexpected distribution estimates will lead to unrealistic transport outcomes. Graphical tools such as GIS plots of distributions, as illustrated in Figure 4.4, are very useful in this regard.

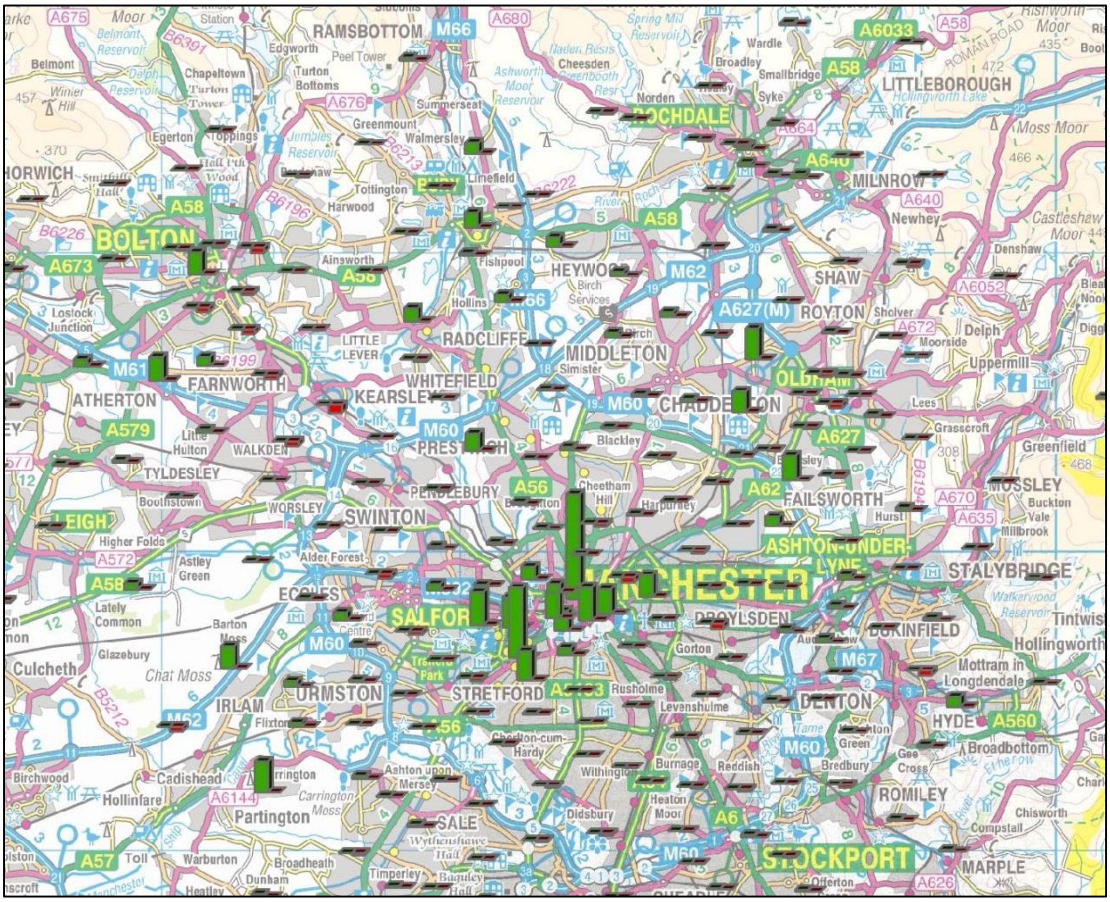

Figure 4.4 Example GIS Output

Omitting destination choice creates a risk of over-estimation of the local decongestion benefits of additional road capacity (because the modelling fails to predict the additional induced traffic travelling to the more-accessible locations) or under-estimation of the demand for a new or improved public transport service, since the overall demand will remain the same as the travel pattern which was supported by the current level of service to the relevant locations.

It is good practice to constrain the destination choice models so that the total productions from each zone cannot change in response to changes in GCs. As discussed in Section 4.3 total trip making per head of population can often be assumed to be fixed. If Irish evidence indicates that there is a sensitivity of total trip making to GC then this would be most transparently represented using a trip frequency response.

It is logical that the number of journeys attracted to each job or school place is constant and hence doubly constraining destination choice for commute and education journeys is considered good practice. If significant changes in accessibility are predicted which could affect the number of jobs or school places in a zone, then this effect would be best represented using a land use model which can take account of variables such as access to appropriately skilled workforces, rents, land/floorspace availability, planning policy, etc.

It is important that there is a high degree of consistency between the base year PA or tour (in the Demand Model), and time period OD trip matrices (in the Assignment Model). Without such consistency there is a risk that forecast changes in trip ends or distributions do not get translated into plausible forecast matrices. For example if a zone-pair in assignment matrix has zero trips whilst the equivalent cell in the demand model matrix is non-zero then even large growth factors from the forecast model would result in zero assigned trips. If the assignment matrix contained too many trips in relation to the demand model matrix then even modest growth could result in unrealistic forecast matrices (assuming that forecast demand changes are applied as factors and not incrementally).

The scope for discrepancies is most strongly prevalent in the development of OD trip matrices that reflect observed traffic flows on the transport network from road side interviews or using matrix estimation to match observed flows.

Recommended Best Practice

- Zone cloning functionality should be provided to facilitate the creation of travel patterns for greenfield developments (i.e. where the current base year travel pattern to a zone cannot provide a robust starting point for the demand model, but the base-year pattern of travel to/from some other zones can be used to provide this starting point.
- Logit destination choice approaches should be the standard approach for common land use categories.
- It is good practice to constrain the destination choice models so that the total productions from each zone cannot change in response to changes in GCs.
- Commute and education distributions should be doubly constrained. Sensitivity parameters should be calibrated using data from the GDA if possible. The statistical calibration process should include analyses of whether sensitivity parameters are significantly different for different areas.
- As part of the matrix development process, the consistency between assignment and demand model matrices should be analysed.
- Readily repeatable processes, making use of GIS plots, should be implemented to report on the output distributions to ensure the model is predicting realistic travel patterns.

4.6 Time of Day Choice

Case Studies / References

- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007);
- Macro-time of day choice is implemented in many UK models including Greater Manchester, Transport Model for Scotland and South Hampshire;
- SYSTRA's model of Sheffield has nine time periods to approximate micro-time of day choice;
- DfT's research into peak spreading has led to the development of an approach known as HADES (Heterogeneous Arrival and Departure times based on Equilibrium Scheduling theory)[19] which is incorporated into the DIADEM software with beta-test status. We are not aware of any applications of HADES;
- Transportation Planning Handbook 3rd Edition (2009) Institute of Transportation Engineers (US); and
- The lack of a time of day choice element has been highlighted by SKM[20] as a weakness in a number of Australian Regional Models including; The Sydney Strategic Transport Model (STM), Brisbane Strategic Transport Model (BSTM) and the Melbourne Integrated Transport Model (MTM).

Possible Approaches

Transport models can represent either or both of the following time of day choices:

- Macro time of day – between broad time periods such as AM peak , inter peak or PM; and
- Micro time of day/peak-spreading – when to travel within a broad time period to travel.

Micro time of day choice encompasses both active choices, e.g. choosing when to leave home to optimise the overall utility of travelling, and the passive effect of arriving later than planned because of delays.

Macro time of day choice can be implemented using a logit function in the demand model to allocate demand between time periods[21]. If demand is represented in all day PA format then the time of day choice would be applied separately to from home and return home demand as part of the PA to OD conversion as illustrated in

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[19] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/9136/diadem-user-manual-sat5.0.pdf

[20] SKM National Transport Modelling Working Group – Critical Review of Transport Modelling Tools 2009

[21] http://www.dft.gov.uk/webtag/documents/expert/unit3.10.3.php

Figure 4.3. If demand is represented as simple tours, i.e. allocated to pairs of time periods, then macro time of day choice can be applied more consistently to 2-way tours.

In recent applications such as Transport for South Hampshire, macro time period choice was implemented on the basis of tours to jointly forecast a traveller's departure time (from home) and return time (to home). The outbound and return cost changes are summed to obtain the overall cost changes for each tour. This is relevant when relative congestion between the peak, interpeak and off-peak periods changes, or where there are differential charges by time period. According to WebTAG (Unit 3.10.3c), there is less evidence available about the sensitivity of the macro-time period choice than either main mode or destination choice. In the South Hampshire demand model, the macro time period choice is positioned above the mode choice model but initially allocated logit coefficients of 1, meaning that it would operate using the same sensitivity to changes in travel cost as mode choice. During the model calibration stage, including realism tests, this lambda coefficient was reduced in sensitivity to 0.8, making time of choice sensitivity slightly lower than that of mode choice.

If complex tours were to be used then then the choice of the time period for each leg could be modelled as a function of the cost of travelling in each feasible period. These choices would exclude the option of travelling in periods earlier than that of the previous leg.

Recent studies carried out by the UK Department for Transport[22] suggests that time period choice is approximately as sensitive to changes in travel conditions as mode choice. This research also concluded, not surprisingly, that small adjustments in the time of travel are much more likely than major time period switches.

Time of day choice is an integral part of an activity modelling approach.

Active micro time of day choice can be approximated within the demand model by incorporating a larger number of time periods within the conventional logit choice structure. For example SYSTRA's model of Sheffield has 9 time periods.

Passive peak spreading can be represented using software such as SATURN where trips that cannot be completed in one time slice are passed through to a subsequent slice. This approach requires fine time slices (e.g. 15 minutes or less) to be effective.

Some research and experimentation has been carried out on alternative approaches to active micro time of day choice modelling. The UK Department for Transport commissioned research into an approach where a choice model

[22] WebTAG Unit 3.10.3 paragraph 1.11.17

allocates demand to fine time periods. The allocation seeks to optimise the sum of travel GC and the disutility of arriving earlier or later than desired. This choice model would run iteratively with a set of congested highway assignment models (e.g. SATURN) for each of the time periods. The assignment models would feed GC estimates into subsequent runs of the choice model.

In the US some innovative approaches have gone beyond the relatively simple factoring methods. These peak spreading methods address the problem that projected demand exceeds capacity in certain corridors during the peak period and failing to account for the excess demand results in a flawed assessment of travel conditions in the future. Three such approaches are:

- Link-based peak spreading;
- Trip-based peak spreading; and
- System-wide peak spreading.

Link-based peak spreading accounts for congestion at the link level and diverts trips to the shoulder hours on either side of the peak. One of the best known examples of this method was developed for Phoenix Arizona.

An alternative to the link-based peak spreading approach is a trip-based approach that spreads the number of trips for an origin-destination interchange that occur in the peak period or peak hour. Trip-based peak spreading approaches recognize the overall constraint of future highway network system capacity (by time of day) by limiting the assignment of trips to that network based on the overall capacity of the future network at selected congested links. This approach was applied in the Tri-Valley model in Contra Costa County, CA and in the Central Artery model in Boston, MA.

A system-wide peak spreading approach has been implemented by the Volpe National Transportation System Centre (VNTSC) within a modelling framework applied in evaluating Intelligent Transportation Systems (ITS). This peak spreading approach considers the system-wide excess travel demand and delay and distributes excess travel demand between the individual travel hours that comprise the peak period.

Lessons Learnt

Macro time of day choice is relatively straight forward to implement within the demand model and is beneficial where the relative GCs for travelling in different time periods are expected to change over time or in response to a scheme or strategy (e.g. user charging, differential fares or toll levels).

Micro time of day choice can be approximated within the demand model by incorporating a larger number of time periods within the conventional logit choice structure. For example SYSTRA's model of Sheffield has 9 time periods. This very greatly increases model run times and the effort required to develop assignment models. Even 9 or 10 time periods are really too coarse to model peak spreading which is often re-timing a journey by a few minutes. Having more time periods would improve the precision of the measurement of parking accumulation within a parking model, if required.

Using the PASSQ function in SATURN, trips which are not completed in one time slice are carried forward to the next as fixed link and turn flows. In this manner the congestion effect of passive peak spreading is reflected. However the problem with this approach is that the ultimate destination of the carried over demand is not retained so the areas of the network that these trips traverse in later time slices is not known.

Although we are not aware of any applications of HADES its application would lead to hugely extended run times due to the need to iterate highway assignments for numerous short (e.g. 5-20 minute long) time slices to reach convergence of travel time allocations.

Recommended Best Practice

- Macro time of day choice has become standard practice and can be readily implemented to reflect how travel timing would change over time in response to relative changes in Generalised Cost (GC) between broad time periods, e.g. constraints on growth in peak periods; and
- The benefits of modelling micro time of day choice need to be carefully assessed against the dis-benefits of increased model run times.

4.7 Parking and Park & Ride

Case Studies / References

- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007);
- Modelling of park and ride choices is included in a number of UK models including for Greater Manchester, Transport Model for Scotland, Transport for South Hampshire, Sheffield and Nottingham. In all cases the park and ride choice is integrated into the demand modelling; and
- At least two models in Ireland, the Railway Procurement Agency and Dublin Transportation Office Models, include park and ride modelling.

Possible Approaches

Modelling of park-and-ride (P&R) is important if there is significant use of existing P&R facilities, P&R sites are committed or when the model will be used to assess P&R proposals.

There is also a strong interaction between city centre parking costs and capacities and the use of peripheral P&R sites. If city centre car parks are, or become, full or expensive more P&R demand can be anticipated.

P&R occurs both at designated stations and also informally, e.g. parking on street near a suburban station.

A range of options need to be considered when scoping P&R modelling, including:

- Is the Park and Ride an integral part of the main demand modelling (i.e. within the main mode, destination, time-of-day choices etc.), or simply treated as the access leg within the route choice in the subsequent public transport network assignment;
- Does the capacity of the car park limit demand - in which case the use of P&R in a given time period will need to take account of arrivals (and departures) in previous time periods;
- Does the modelling need to take account of 'overspill' parking (i.e. where drivers using surrounding streets and/or nearby off-street car parks to access the public transport);
- Does the modelling need to consider 'informal' Park and Ride (e.g. parking at the edge of a controlled parking zone and catching a bus into the city centre);
- Does the modelling need to model the choice between alternative Park and Ride locations, or is the best 'Park and Ride' option 'hard-wired' by the user for each OD pair; and
- Is Park and Ride being considered as part of a more-general parking location decision.

If P&R is to be included in the demand model then the model scripts will need to construct generalised cost matrices for P&R by adding costs from the Road Assignment model (e.g. home to P&R site, and P&R site to home) to costs from the PT Assignment model (e.g. P&R site to work and back to the P&R site) with any (generalised) costs associated with using the site (e.g. parking charges, search time, access time from car to the public transport, perceived security etc.).

If P&R is included in the demand model then the mode choice model will be extended to have another choice. This choice could be included within the core model structure which will run iteratively to balance travel demand and costs, which would allow all of the choice models (destination, time of day, etc.) to respond to the influence of P&R on the GCs for all modes.

Alternatively the P&R choice could be a post-process after the main demand model, in which case there would be no feedback to GCs or other responses such as destination choice.

Lessons Learnt

It would be relatively easy to add P&R routes within the assignment models, but this would have drawbacks as it would not enforce consistency of choices between time periods. P&R site capacities could only be represented in an approximate fashion - this is because the assignment models have no information about the timing of the reverse-leg of a journey. For example the assignment matrix may include one trip from zone X to zone Y in the morning peak, but cannot link this to a trip from zone Y to zone X later in the day. Therefore the number of parking spaces used at any time of day cannot be accurately determined.

The post-process approach is often used when P&R is added to an existing model structure but offers few benefits in cases where a new model is being commissioned.

Calibration of P&R models can be challenging due to the interaction of choices between P&R and other modes, city centre parking capacity and costs, and site choice. If new P&R sites will be modelled in forecasting mode then the choice between P&R and other modes must have an absolute form. The absolute form means that site-constants should be used to calibrate the P&R choice to base year conditions. This leads to complications when used in conjunction with parking capacity restraint (what constant is appropriate if demand is actually controlled by the number of parking spaces?) and means that constants will be needed for any new sites.

Economic appraisal is somewhat complicated by the introduction of P&R into the model, essentially because some costs of P&R use are a function of the number of cars (e.g. parking charges and vehicle operating costs) and some costs are related to the number of passengers (e.g. travel times and PT fares). SYSTRA have developed approaches to economic appraisal for a number of UK models which address these complications.

Data on existing usage (including informal P&R) and capacity for each current site is used to validate and calibrate the P&R response. As a minimum the number of arrivals by modelled time period would be required. Data on parking charges, capacities and PT services will also be needed. Equivalent data will be required for forecast years.

Recommended Best Practice

- It is best practice to include explicit representation of park-and-ride (P&R) choice as part of the demand model in cities where this option is available or likely to be considered.
- Adding parking supply constraints to the model can increase the need for iteration of the demand model and hence run times. The benefits of improving the modelling of capacity issues should be carefully

considered, e.g. by reviewing data on the occupancy of P&R sites, and weighed up against run time implications.

4.8 Vehicle Occupancy

Case Studies / References

- Most models use fixed car occupancy rates for each modelled year. In the UK occupancies are typically calculated from local roadside interview or travel diary surveys, or else from the National Travel Survey;
- WebTAG Unit 3.5.6 includes recommended annual percentage changes to apply to the average number of car passengers to estimate forecast year occupancies. The source of these percentage changes is not stated; and
- Some models developed where HOV lanes and tolled roads are of importance have included choice between occupancy categories. Discussion of these approaches can be found in the following papers:
  - Making the State of the Art the State of the Practice: Advance Modeling Techniques for Road Pricing, Peter Vovsha, William Davidson, and Robert Donnelly. Expert Forum on Road Pricing and Travel Demand Modeling. 2004[23]; and
  - National Cooperative Highway Research Program Synthesis 364, Estimating Toll Road Demand and Revenue, 2006[24].

Possible Approaches

In most models the average number of passengers in each car is held constant for each forecast year. Data from the UK[25] indicates that average vehicle occupancy varies by journey purpose. Average vehicle occupancies can be obtained from travel diary or roadside interview surveys.

Where a number of historic surveys are available trends in average car occupancy could be established, or correlations with variables such as car ownership levels established. Such trends and correlations could then form the basis of forecast year occupancy rates.

Modelling of car sharing or occupancy could be considered as an additional logit choice level. This would be of benefit if measures to encourage car sharing

[23] http://media.tmiponline.org/clearinghouse/DOT-OST-P-001-06/DOT-OST-P-001-06.pdf

[24] http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_364.pdf

[25] http://www.dft.gov.uk/webtag/documents/expert/pdf/u3_5_6-vot-op-cost-120723.pdf

through changes in travel costs (e.g. increased fuel costs or car-pooling lanes) are to be tested. If a car occupancy response was required then the demand matrices would be segmented into occupancy categories. The assignment model could require segmentation by vehicle occupancy category as higher occupancy vehicles may be more likely to use toll roads. If High Occupancy Vehicle (HOV) lanes were to be tested then the case for segmenting the assignment matrices would be strengthened.

The current Transport Model for Scotland contains a high occupancy vehicle choice model which allows trips to move between single occupancy vehicles and multiple occupancy cars. The occupancy choice takes the form of a logit choice model using different generalised costs for single occupancy and high occupancy trips.

Lessons Learnt

Car occupancy rates will be required to convert volumes of person travel, as used in the demand model, into volumes of vehicles for assignment. UK evidence indicates that average occupancies vary by journey purpose.

Predicting how car occupancies respond to GC changes is feasible as an extension of the mode choice model. Such models are most common in situations where vehicle occupancy has a strong impact of travel choices, e.g. in the cases of tolled roads and HOV lanes. Run times would increase, particularly if the assignment model included occupancy segmentation.

If model applications suggest that a car sharing / occupancy model is required then data would be needed to segment demand into occupancy categories. This could be drawn from roadside or household interview surveys. Data would also be needed to calibrate the sensitivity of occupancy to travel costs, for which a combination of the surveys and cost skims from the assignment model could be used.

Recommended Best Practice

- Average vehicle occupancies for the base year should be determined from travel diary and/or roadside interview surveys. Variations in occupancy rates by journey purpose and potentially other demand segments such as household car availability should be explored. Analysis of how occupancies have changed over time or are related to other variables which may be available for forecasting should be undertaken.
- Making car occupancy sensitive to GCs is possible as an extension of mode choice modelling, if the merits of doing so outweigh the disadvantage of increased run times and complexity.

4.9 Ticket Type Choice

Case Studies / References

- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007);
- SYSTRA are currently developing a database ticket type choice model for NTA; and
- www.fhwa.dot.gov/Planning/toolbox/sacramento_overview.htm.

Possible Approaches

SYSTRA has developed PT ticket type choice models in the context of bus and rail patronage forecasting and fare studies. These have not been implemented within a multi-modal model context but generally in a spreadsheet. Ticket type choice can be represented using a logit approach and could be implemented within the demand model structure.

Lessons Learnt

Ticket type choice modelling would be most useful if the model was to be used to test strategies for fares and payment means. The complexity of the demand model, and the calibration of the model would be increased. A means of determining the fare, and other elements of GC, for each ticket type would be needed which could necessitate amending the PT Assignment model structure.

Recommended Best Practice

- Ticket type choice could be included in the NTA's regional modelling system if the merits of doing so outweigh the disadvantage of increased run time.

4.10 Smarter Travel Choices

Case Studies / References

- SYSTRA has extensive experience of developing and applying matrix adjustments to reflect the impacts of Smarter Travel Choice interventions, in particular to assist local authorities bidding to the UK Department for Transport's Local Sustainable Transport Fund (LSTF). SYSTRA supported four LSTF bids:
  - Cheshire East Council, for the Crewe area;
  - Greater Manchester;
  - South Hampshire; and

  - Nottingham.
- The Victoria Transport Policy Institute has produced a useful report[26] detailing transport demand elasticities. The report investigates the influence that factors such as prices and service quality have on travel activity, and how these impacts can be measured using elasticity values;
- In another useful case study (Robert, 2007) discrete choice models were used to predict how people respond to various travel options and incentives, such as employers who encourage telework and car sharing. The results were then incorporated into a traffic network equilibrium model, which quantified how changes in travel behaviour affect road traffic, and traffic congestion, emissions, accidents and travel times; and
- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007).

Possible Approaches

Smarter travel marketing and policies may result in significant changes in travel choices. Demand models are configured to change travel choices in response to changes in GCs, but smarter travel measures do not always impact on GCs. SYSTRA do have experience of representing smarter travel in multi-modal transport models which could inform developments of the regional modelling system.

In broad terms there are two approaches to representing the impacts of smarter travel policies within a multi-modal model. Post demand model matrix adjustments may be made based on post-ante evaluation research. Alternatively GC adjustment matrices could be calculated which when applied to within the demand model replicates the demand changes observed in post-ante evaluation.

WebTAG, unit 3.10.6c, offers some guidance on modelling smarter choices and makes the distinction between “hard” measures and “soft” measures. Hard measures are defined as measures which directly influence the time and money components of generalised cost and soft measures being measures which change travellers’ response to differences or changes in generalised cost.

In principle, modelling of “soft” components may be approximated by modifications to one or more of; commuting trip rates, value of time for the various travel stages, mode constants or mode choice sensitivity parameters. In the case of the “hard” measures, changes may be made either to the networks from which generalised

[26] http://www.vtpi.org/elasticities.pdf

costs would be skimmed or to the generalised costs directly. In either case, the resulting changes in costs should be fed into the demand model so that the demand changes can be forecast.

Lessons Learnt

Some mechanism to represent the impacts of smarter travel would be beneficial so that such measures can be appraised and the impact of congestion and PT usage consistently appraised.

Some measures can be represented in the traditional modelling structure (e.g. road/congestion charging, road closures, public transport fares). Some cannot be modelled in the usual way.

SYSTRA undertook extensive reviews of the evaluation of smarter travel including DfT's web-based LSTF Resource Library[27] and found that the evidence on impacts was often inconsistent and needed to be translated into a consistent evidence base considering the dimensions of the matrices including:

- Which zone-pairs or trip length categories are affected;
- Differential impacts on modes;
- Differential impacts on market segments (purpose, car competition, income, etc.); and
- Impacts on travel at different times of the day.

There is currently little evidence on the long term efficacy of smarter travel choice interventions.

Recommended Best Practice

- Applying post demand model adjustments directly to the assignment matrices in order to replicate observed impacts of smarter travel policies is the most straightforward approach as it does not require calibration of adjustment factors. If evidence becomes available on how the impacts of smarter travel choices changes over time then the matrix adjustments could be modified between forecast years (e.g. reduced if the evidence shows that impacts are not sustained, or increased if evidence shows that the changed attitudes propagate).

[27] http://assets.dft.gov.uk/publications/local-sustainable-transport-fund-guidance-on-the-application-process/lstf-resource-library.pdf

4.11 Generalised Cost Formulation

Case Studies / References

- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007); and
- WebTAG Unit 3.5.6 describes approaches to estimating values of time and vehicle operating costs. Unit 3.10.2 includes discussions of cost damping. Cost damping is becoming more common in UK models, including for the Heathrow area, Sheffield and Greater Manchester.

Possible Approaches

In most transport models generalised cost (GC) is calculated as a linear sum of cost components (e.g. a x time + b x fuel cost + c x parking charge etc.). GC is conventionally expressed in units of "car in-vehicle minutes", i.e. 1 minute spent travelling in a car equals 1 GC minute. One minute spent travelling by a different mode could be viewed as being better or worse than one minute in a car. Elements of GC to be included are as follows:

- Car: time, fuel cost, non-fuel operating cost, parking charges and road user charges;
- Public transport: walk time, wait time, in vehicle time, interchange penalties, boarding penalties and fare; and
- Walk and cycle: time.

In most models GC is expressed in minutes rather than monetary units avoiding the need to define a price base year. Money costs are translated to time units using "values of time" (in €/hour) which may vary between demand segments[28]. The perceived dis-benefit of changing between or waiting for public transport services also need to be converted into time units. These parameters are often determined using statistical estimation of models to predict observed travel choices (i.e. Revealed Preference (RP) analysis). RP analysis requires data on travel choices (time of travel, mode and destination) e.g. from a travel diary survey, and estimates of each component of GC.

Values of walk and wait times and interchange penalties are usually related to the value of in vehicle time by applying weights. IHT's guidelines on Developing Urban Transport Strategies and ITS and John Bates's review of value of time savings in the UK 2003 suggest:

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[28] Further information on values of time and operating costs is provided in,www.dft.gov.ul/webtag/documents/expert/unit3.5.6.php

- Value of walk time = 1.5 – 2.0 times in-vehicle time;
- Value of wait time = 1.5 – 2.5 times in-vehicle time; and
- Interchange penalty = 5 – 10 minutes of in-vehicle time per interchange.

Where new travel choices, e.g. a new mode, are proposed Stated Preference techniques are used where interviewees are presented with hypothetical choices between options (eg bus vs tram) for which the attributes of each option (e.g. travel time, fare, and vehicle standard) are described. Model parameters can then be estimated using similar approaches to those applied to RP data.

For public transport schemes, the effects of comfort may need to be represented. Stated preference surveys have produced results whereby time spent in crowded or standing conditions incur a higher cost than time spent seated, in relative comfort. In these circumstances a “crowding factor” can be used which increases the cost of in-vehicle time when a set percentage of seats are occupied. In general, because the generalised cost method is relatively robust, the inclusion of additional elements does not present major modelling problems for demand forecasting[29].

In the UK values of time for employers business are assumed to equal staff costs (salary, National Insurance, benefits, etc.).

Car and goods vehicle operating costs should be determined based on the average fuel consumption rate (litres / km) and cost per litre. In the UK it is assumed that non-fuel car operating costs also influence behaviour of business travellers.

Logit models predict travel choices based on the absolute rather than proportional differences in GC between alternatives. In these models, two alternatives with generalised costs of 5 and 10 minutes will yield the same mode-split as two options with generalised costs of 55 and 60 minutes, since both are based on the 5-minute absolute difference between the two options. Some international research indicates that the marginal sensitivities to GC reduce with trip distance or duration. There are a number of methods[30], generally referred to as “cost damping”, to address this limitation including reducing the marginal sensitivity to generalised cost as a function of distance and using a non-linear specification of generalised cost. The general impact of cost damping is to reduce the marginal sensitivity to generalised costs for longer journeys.

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[29] http://www.dft.gov.uk/webtag/documents/expert/unit3.10.2.php#0110

[30] A concise summary is provided in www.dft.gov.uk/webtag/documents/expert/pdf/u3_10_2C-variable-demand-modelling-scope-of the-model.pdf

Lessons Learnt

There is a risk that demand model calibration, e.g. replicating observed fuel cost elasticities, may be more challenging without some form of cost damping.

From experience we have found that models without cost damping can produce larger than expected forecast changes in mean trip length. The implication of this could be that strategies and plans are developed to cater for longer distance traffic which is over-estimated.

Recommended Best Practice

- The linear sum form for calculating GC is used very widely. GC coefficients should be developed from data (RP or SP, fuel consumption and prices, incomes, etc.) specific to the local conditions of each regional modelling area, if possible.
- The model scripts should be flexible enough to allow for cost damping to be applied should calibration or demonstration testing indicate that it is required.

4.12 Parameters for Choice Models

Possible Approaches

Each response (mode, destination, etc.) in the demand model will require parameters to define the sensitivity to GCs or GC changes.

Parameters are also required to combine elements of GC, e.g. values of time, boarding or interchange penalties, etc. as discussed in Section 4.11.

These parameters could be imported from existing models, or set based on local, national or international research. Alternatively the parameters could be statistically estimated based on local evidence, using demand and cost matrices, or evidence from stated or revealed preference (SP or RP) studies.

Case Studies / References

- LATIS;
- NTA Greater Dublin Area Model;
- RPA Dublin Model; and
- MOTOS Report: Transport Modelling – Towards Operational Standards in Europe - Handbook of Transport Modelling (in Europe) learning from Best Practice (2007).

Lessons Learnt

Model calibration exercises are time-consuming and there is always a risk that the results for some variables are not plausible (e.g. of the wrong sign) or statistically significant.

Recommended Best Practice

- In principle a bespoke and locally based parameter calibration exercise is preferable so that the models accurately reflect the behaviours and preferences of travellers in Dublin.
- Existing models of Dublin and the national model could be sources of (and/or starting points for the estimation of) parameters for the regional modelling system, provided that the relevant parameters have a reasonable evidence base.
- Values and parameters from elsewhere could be used to supplement these values as required.

4.13 Choice Model Forms

Case Studies / References

- Models of Greater Manchester, Derby, South Hampshire and Sheffield use incremental logit formulations for most choices, except for park and ride; and
- Models of Nottingham and Scotland use absolute model forms necessitating the calibration of Alternative Specific Constants (ASCs) to ensure an adequate fit to observed travel patterns. ASCs must be assumed for new development zones.

Possible Approaches

Logit model forms are almost universally used for travel choice models and we would not propose a different approach. Logit models can be configured to be absolute or incremental, and in some cases it is necessary to use both in the same model (e.g. when a new mode such as park-and-ride is to be introduced).

Absolute choice models can be summarised as follows:

- Allocation of demand between choices is a function of the difference in generalised cost of the options;
- "Alternative specific constants" (ASCs), GC adjustments for each alternative, must be calculated to match observed choices;
- Results of the models can be applied as factors or increments to calibrated base year assignment matrices;
- Fills in unobserved movements, including for zones where there are large changes in land use; and
- Is the only choice for new alternatives.

Incremental choice models can be summarised as follows:

- Change in demand is calculated as a function of changes in generalised costs;
- ASCs are not required;

- They retain the complexities of observed travel behaviour – but unobserved movements have to be synthesised;
- Demand patterns for zones where there are large changes in land use must be determined outside of the incremental choice model; and
- Cannot deal with new alternatives (e.g. a new PT mode).

If the base matrices used in the Assignment and Demand models are not fully compatible, then differences (proportional or absolute) between the base year and forecast demand matrices can be applied to the base year assignment matrices.

Lessons Learnt

It is uncommon for models to be able to adopt a purely incremental approach, since there are usually likely to be schemes or policies which will generate travel demand for which no useable pattern exists in the base year model. Examples of situations where a purely incremental approach breaks down includes the provision of new public transport services in corridors where the existing public transport supply is negligible or unattractive, greenfield developments and parking and Park and Ride location choice models where the true origin/destination matrix usually needs to be synthesised for each parking location.

Purely synthetic travel demand (as predicted using ‘absolute’ choice modelling) are likely to differ significantly from ‘true’ observed local travel patterns at the local level. These differences can create problems when attempting to apply changes in the predicted levels of ‘absolute’ demand to the base-year travel demand matrices.

Recommended Best Practice

- Incremental models are recommended for main mode, destination and time of day choice (i.e. where it is reasonable to forecast the future-year Do Something demand as ‘incremental’ changes to the base year pattern);
- Parking and Park-and-Ride location choice modelling are likely to require an absolute form of choice modelling, since the relevant base year OD patterns for users of the various parking locations are unlikely to exist;
- Additional ‘absolute’ choice modelling functionality may be required If the model is to be used for testing greenfield developments or other land-use changes where the base year pattern does not provide a robust pattern from which to estimate the future demand; and
- The ‘observed’ (network assignment) and synthetic (demand model) demand matrices should be as consistent as possible, to maximise the numerical stability of whichever approach is used to convert changes in land-use or transport supply into corresponding changes in demand.

4.14 Demand Segmentation

Case Studies / References

- All of the Case Studies / References discussed throughout this report include segmentation by car availability / ownership and journey purpose;
- Models which were developed to test tolling and road user charging proposals, including a version of the Greater Manchester model, typically include segmentation by income or socio-economic group. In the Manchester case data on socio-economic level was most readily available from data being developed for a land use model; and
- No examples of 4-stage demand models with segmentation by PT fare category and parking space availability are known. Uni-modal models, e.g. the NTA ticket type choice model do require categorisation by fare category.

Possible Approaches

Demand is segmented into categories so that all travellers within the same category can be considered to behave in the same way. In practice this means that GC coefficients (e.g. value of time or fuel costs) and choice sensitivity parameters are defined for each segment.

Demand segments are also used in forecasting the impact of changes in variables such as populations, jobs, etc. Different forecasting variables could be applied to each segment.

The following factors should be considered in establishing the preferred set of demand segments:

- Data must be available to reliably segment and forecast demand, and to specify values of time and demand response sensitivities;
- The chosen segments should reflect significant variations of values of time, available travel options and sensitivity of demand responses to changes in travel costs, while still representing a ‘significant’ proportion of the overall demand – as a rule of thumb - is the distinction between any two of the demand segments likely to significantly affect any decision which the model is designed to inform;
- Data must be available to establish sensitivity parameters;
- Different levels of segmentation may be appropriate within the trip generation, demand and assignment models; and
- Model run times must be manageable.

Aspects of segmentation to consider include car ownership or competition, parking space availability, PT fare categories, journey purpose and income. A proxy of income, such as socio-economic group, could be considered depending on the available data. In addition, if 'triangular' tours are common (where two or more trip purposes are combined in a single trip (e.g. dropping children at school on way to work or shopping on way home from work), it may be desirable to identify 'Direct' from 'Indirect' versions of some of the main journey purposes, to reflect the impact of the intermediate journey purpose on mode and/or time-of-day choices.

Lessons Learnt

Segmentation on the basis of Car ownership or competition must be included to identify the level of PT and active mode captivity. Travellers with a car may also have more freedom (higher sensitivity to GC) to change destination or time of day. Car ownership is generally defined on the basis of the number of cars available to a household (e.g. 0, 1 or 2+). Car competition is a better guide to behaviour and is defined as the number of cars per adult in the household (e.g. no car, 0 to 1 cars/adult or 1+ cars/adult).

Segmentation of demand according to the availability of a free parking space at the home and/or attraction end would be most useful if a parking choice model is to be developed. Even without a parking choice model, availability of a free parking space could influence the cost of car travel to certain destinations.

Journey purpose is important because changes in the quantum and distribution of each purpose can respond to different variables. For example commute journeys can be forecast based on changes in the number of jobs. The purpose of a journey can also impact on sensitivity to GC, with business travellers generally being less sensitive to price component and more sensitive to time components than others.

Income levels have a strong impact on the willingness and ability to pay tolls. It is therefore desirable to include a measure of income in the segmentation in situations where tolls or road user charging are levied, or are to be tested.

Most models vary the level of segmentation for different processes. The greatest level of segmentation is typically at the trip generation stage, which could include variables such as gender and age if these influence trip rates. For demand responses some segments can be combined if behavioural attributes such as value of time and distributions are similar. In road assignment models, where distributions are fixed, it may only be necessary to retain segmentation between groups with significantly different values of time or vehicle operating costs. In the PT assignment it may be desirable to retain segmentation by income or PT fare category which can influence the choice of modes.

Recommended Best Practice

- Demand must be segmented by car ownership or, preferably, competition.
- At a minimum employers business trips should be separated from other segments due to differences in value of time.

- If demand is represented using PA, simple or complex tour formats then home-based and non-home-based demand should be segmented.
- It is good practice to separate commute, education, shopping and other purposes. Such segmentation means that changes in demand for each segment can be forecast using the most appropriate data such as job numbers, school places or retail floorspace.
- As there are tolled motorways in the regional modelled areas there may be a case for segmenting by a measure of income or willingness to pay.
- The required level of segmentation should be considered for each model component, e.g. trip generation, demand and assignment models.

4.15 Time Periods

Case Studies / References

- Many recent models including those for Scotland, Greater Manchester, Derby, Nottingham and South Hampshire include four time periods in the demand model;
- Some versions of the Greater Manchester model assign peak hour matrices and other assign average hours of the modelled periods. The latter approach was deemed more appropriate for work on motorway schemes because traffic profiles were relatively constant between hours within the periods; and
- The Sheffield model has nine time periods largely so that the model can keep track of car park occupancy across the day as the arrival and departure times are known with an improved level of definition.

Possible Approaches

Some demand models treat different time periods in isolation from each other, or in some cases only represent one or two time periods. It is now more common to represent demand responses across a full day, or possibly 16 or 18 hours, to improve consistency of travel choices between periods.

Most models include separate time periods in the assignment step for at least AM peak, inter peak, PM peak and off peak (after the PM peak) in order to reflect different travel conditions. This necessitates the demand model outputting matrices split into time periods using either fixed or GC responsive factors (see Section 4.6).

It is most natural for the time periods in the demand model to cover the entire modelled day. If the periods in the demand model are several hours long then the assignment models could assign matrices either for the average hour of these (long) periods, or peak hour matrices to represent the busiest times of day.

More time periods, e.g. pre-peak, peak and post-peak hours, could be modelled which would allow for a representation of peak spreading and to improve the precision to which parking accumulation can be measured.

Further consideration is given to time periods used in the assignment models in Chapters 5 and 6.

Lessons Learnt

Many aspects of the demand model should operate for a full day. For example the mode choice for home-to-work trips should be consistent with that for work-to-home trips. It may not be necessary, however, to represent the full 24 hours because the amount of travel overnight is low. Many models use 12, 16 or 18 hour days.

Including a number of time periods in the model allows for more accurate representation of travel costs and how these affect travel choices. There is a requirement to provide forecast matrices for each period included in the assignment models.

In cases where the demand model has four long time periods (e.g. 7am-10am, 10am-4pm, 4pm-7pm and 7pm-11pm) there is no clear right answer for whether to assign average hour matrices or peak hour matrices. Peak hour assignments may be more useful for some operational assessment applications as they represent a "worse case". However the GCs obtained would not be representative of the full time period. Obtaining GCs from assignments of matrices representing the average hour of the long time period are also not truly representative because of the non-linear relationship between travel demand and congestion.

Increasing the number of modelled time periods in both assignment and demand models would improve the representativeness of GCs used in the demand model and facilitate time period (macro and/or micro) and parking modelling. Data storage and run times would also increase in proportion to the number of periods.

Recommended Best Practice

- The "modelled day" should be long enough so that the majority of linked activities (e.g. to and from work trips) can be modelled consistently.
- A number of time periods should be defined in the model to represent slices of the day with broadly homogenous travel conditions.
- At a minimum it is advisable to include 4 time periods to reflect changing travel conditions across the day: AM peak, inter peak, PM peak and off-peak (rest of day). It may not be necessary to model the off peak in as much detail as the other periods if it can be assumed

that there will be minimal congestion or there is less data to support the development and validation of off peak demand matrices.

- Increasing the number of time periods to separate pre-peak, peak and post-peak hours has advantages, but would lead to increases in run times.

4.16 Demand / Supply Convergence

Case Studies / References

- The UK DfT has insisted that all recent models measure % Gap as a stopping criteria. DfT set a target of 0.2%.

Possible Approaches

The Road Assignment model will certainly include capacity restraint whereby travel times are recalculated in response to changes in assigned flows. The PT Assignment model may include a similar process to represent a perceived discomfort of travelling on crowded services. This means that the assignment and demand models should be operated iteratively, as illustrated in Figure 4.5 until the demand for travel and costs are in balance, or converged.

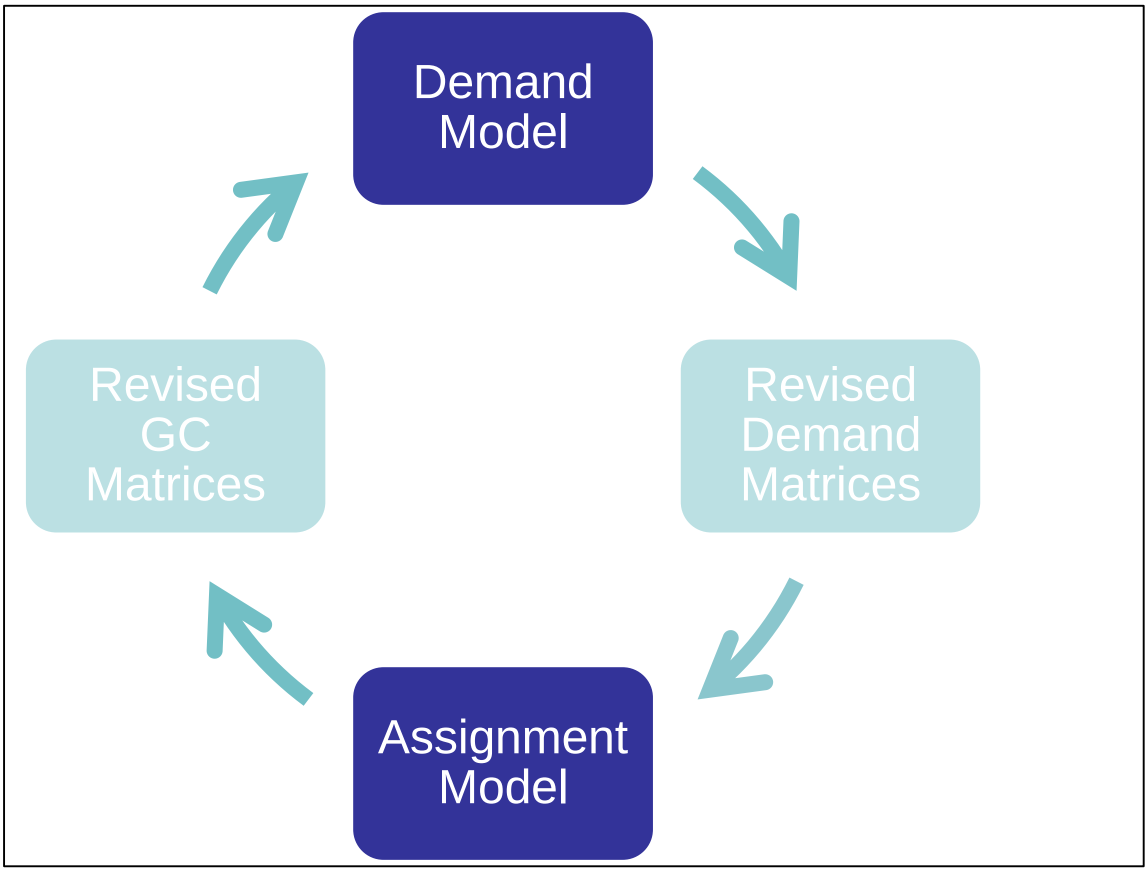

Figure 4.5 Demand / Supply Convergence

Mechanisms are required to control the convergence process which could include some form of damping changes between iterations to avoid oscillation of costs and demand. Options to control the convergence include:

- Averaging the costs output from the Assignment Models with the costs output from the previous iteration;
- Averaging the demand output from the Demand Model with the demand output from the previous iteration; and
- Method of Successive Averages (MSA) which is a way of combining costs from subsequent iterations of the Assignment Models in a way that the contribution from each new iteration is reduced, and is formulated as follows:

$$C_n' = \frac{1}{n}C_n + (1 - \frac{1}{n})C_{n-1}$$

where:

n is the loop number

C_n' is the average cost

C_n is the cost from the supply model for loop n

C_{n-1} is the cost from the supply model for loop n-1

Different approaches to converging the Assignment Models will be considered in Chapters 5 and 6, but it is useful to consider the inter-relation of assignment and demand/supply convergence here. A function, known as CASSINI, is available within SATURN to manage the convergence of SATURN in a demand modelling context. The principle of CASSINI is that SATURN assignments are converged less tightly (and so take less time) in early demand / supply loops when demand matrices are subject to significant changes between loops than for later loops when the demand matrices are more stable.

A metric for the level of convergence, and a target for this metric, is required to determine when the iterations can be stopped. The UK DfT's TAG Unit 3.10.4[31] provides advice on how to manage and measure convergence. This includes a measure of convergence known as %GAP which essentially compares the change in total demand weighted GCs between iterations (the hatched boxed in Figure 4.6) and the total demand weighted GC in the model (the larger box i.e. the combined unhatched and hatched area in Figure 4.6).

[31] http://www.dft.gov.uk/webtag/documents/expert/unit3.10.4.php

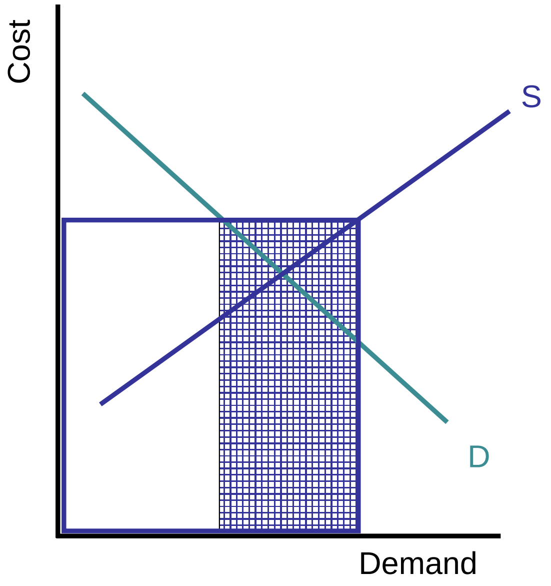

Figure 4.6 % Gap Illustration

DfT also recommend that scheme benefits as a percentage of network costs should be at least ten times greater than % Gap, e.g. if a scheme reduces overall network costs by 2% then % Gap should be 0.2% or less.

Lessons Learnt

Convergence between demand and costs is essential in modelling. If a model is poorly converged then running one more iteration could give very different results in terms of metrics such as mode share, travel times, assigned flows, emissions, etc. Travel times in congested networks can be very sensitive to small changes in flows (both in reality and in models such as SATURN) which can lead to instability in economic appraisals.

Some means to control the convergence process is generally required to avoid oscillation. Approaches such as MSA will enforce convergence as the influence of costs from each iteration is increasingly reduced. However this approach may mask imbalances between demand and supply which may either be legitimate or due to errors in model inputs.

An approach such as CASSINI could be investigated for the regional modelling system. This approach does have some drawbacks however because GCs from relatively poorly converged assignments could be unreliable and lead to unreliable demand model outcomes. If a CASSINI type approach were used then some experimentation would be required to fine tune the levels of assignment model convergence.

Road Assignments will be undertaken within each supply / demand model loop. If crowding is represented in the PT Assignment then this will also be run for each loop. Assignment model run times are likely to dominate run times for the whole model system.

DfT does not provide evidence of how stable economic appraisal results are for different values of % Gap. Achieving convergence such that benefits as a percentage of network costs are 10 times greater than % Gap may only be possible for the largest schemes in the regional model areas.

% Gap measures the convergence of the model as a whole, but could mask instability in certain areas of the model.

Recommended Best Practice

- A measure of demand / supply convergence is essential and % Gap is suitable because it takes account of both demand and cost changes. Demand and, particularly, cost changes influence economic appraisal results.
- The model system should include some method for damping cost changes between loops. However in the initial model testing phase it would be useful to experiment without damping to identify if there are any inherent discrepancies between demand or supply.
- Targets for % Gap should be developed which are appropriate for the regional modelling system and the model's intended applications.

4.17 Calibration and Demonstration Tests

Case Studies / References

Before any transport model can be used for forecasting or option testing it is vital that it is shown to produce plausible results.

- The UK DfT has insisted that the elasticity of demand with respect to fuel costs and PT fares is reported for all recent models; and
- For modelling of managed motorway schemes in Greater Manchester SYSTRA developed future year forecasts by changing model inputs one at a time so that the impact and plausibility of each change could be analysed and any remedial actions identified. This approach was adopted because it can be difficult predict how model outputs should change if a number of inputs are varied at the same time. The following changes were made one at a time:
    - Changes in values of time and vehicle operating costs;
    - Study area wide population and employment growth;
    - Individual major land use developments;
    - A representative highway scheme; and
    - A representative PT scheme.

Possible Approaches

The UK DfT offers some guidance on some methods of demonstrating plausibility, focusing on testing whether the model reproduces expected demand elasticities. WebTAG Unit 3.10.3 (section 1.6)[32] recommends that three separate tests are run where fuel, PT fare and car travel time inputs are increased by 10%. Guidance is offered on plausible elasticities for each journey purpose.

If models have an absolute form then an assessment of how closely model results match observed data is required. This could include comparing trip length distributions, sectored travel demand and validation of flows and journey times (as discussed in Section 5.9 and 6.9).

No guidance is offered on how to determine whether model forecasts are plausible. For many modelling applications a forecasting report is prepared which should include reporting on model outputs such as:

- Changes in trip making by mode between the base and future years: total and sectored;
- Changes in travel times and costs between the base and future years;
- Mode share changes; and
- Road and PT demand flows on the network.

Lessons Learnt

Understanding how responsive a model is to changes in fuel cost and fare is very useful to develop confidence in model outputs. Ideally local evidence for these elasticities should be established. This is a useful check of the outputs of the process to calibrate model parameters (discussed in section 4.12).

Understanding how the model responds to limited changes in inputs, as in the Greater Manchester case, is very helpful in capturing errors in model configuration or inputs. Including demonstration tests of development sites, highway and PT schemes allows for direct assessment of how the model performs in contexts for which it will actually be used.

Recommended Best Practice

- The fuel and PT fare elasticities implied by the model should be established. Plausible variations between demand segments should be obtained. In general it is expected that the elasticities for business trips would be lowest as sensitivity to travel costs is low. Elasticities for discretionary purposes such as leisure should be highest, and

[32] http://www.dft.gov.uk/webtag/documents/expert/unit3.10.4.php#016

elasticities for commuting and education between those for business and leisure.

- A series of incremental demonstration tests should be run to understand how the model responds to changes in each type of input.

5 Road Network Model

5.1 Introduction

The purpose of the road network model is to determine the routes taken by vehicles between zones, to allocate traffic to these routes, and to calculate the time and distances for travel between zones.

Matrices of travel demand in the base year are developed from observed data such as road side interview surveys, census travel to work information, or using synthetic approaches where the demand between zones is a function of GC and of trip ends. These matrices are adjusted to represent forecast scenarios using a demand model. In turn the road network model will calculate matrices of travel costs for input to the demand model.

Aspects of the road network model which require consideration and specification include:

- If and how to segment travel demand;
- Which time periods to represent;
- Design of the zone system;
- Approach to network coding;
- The algorithms used to calculate routes, delays and travel times;
- How convergence is monitored; and
- How to validate the model to ensure that it replicates observed travel conditions adequately.

5.2 Demand Segmentation

Case Studies / References

- TAG Unit 3.5.6 includes advice on calculation of values of time and vehicle operating costs for different vehicle types and journey purposes. These values are used almost universally in UK models; and
- TAG Unit 3.19 "Highway Assignment Modelling"[33] includes advice on segmentation of demand into "user classes" and vehicle types. This unit advises that cars on business, other cars, LGVs and HGVs should be treated as individual user classes and assigned separately; and that segmenting by income should be considered in models including tolled roads.

[33] http://www.dft.gov.uk/webtag/documents/expert/unit3.19.php

Possible Approaches

In the road network model demand may need to segmented to reflect differences in factors which affect the choice of route. These factors include vehicle operating cost rates (€/km) and values of time (€/hr).

As discussed in Section 4.14 segmentations represented in the demand could include:

- Journey purpose;
- Income or a proxy of income such as willingness to pay category or socio-economic group;
- Car availability or ownership; and
- PT fare category and availability of a parking space.

The segmentation used in the road network, PT network and demand models do not necessarily need to be identical.

Goods vehicles may not be included in the demand modelling but should be assigned in the road network model. Consideration must be given to whether to disaggregate goods vehicles by weight class, and whether light goods vehicles can be combined with cars.

Lessons Learnt

The road network assignment and public transport assignment model run times are both likely to form a significant component of overall run times of the full modelling system. These network assignment model run times will be approximately proportionate to the number of different demand segments used within the two network assignment processes.

If the demand model segments are aggregated prior to the network assignment, the overall run-times will therefore be reduced significantly, usually with little loss of model accuracy (assuming the main differences in the (perceived) costs of alternative routes are broadly maintained).

However, care is needed to ensure that any aggregations can be ‘reversed’, if the disaggregated matrices are required at a later stage (for example to support more-disaggregate appraisal of the scheme benefits.

Fuel consumption rates (and hence fuel costs per kilometre and vehicle emission rates) differ between vehicles. In principle different categories of car (e.g. based on engine size and/or fuel type) could be assigned separately. This is rarely, if ever, done in strategic multi-modal models, since the inaccuracy created by using average fuel cost rates are usually not significant enough to warrant separate assignments. Simple network-wide ‘fleet profile’ factors are then used to provide any engine-type disaggregation needed subsequently (for example for emissions-related modelling or appraisal).

Treating heavy goods vehicles as a separate category in assignment is advantageous for a number of reasons:

- To capture differences in operating costs and values of time;
- For use in air quality and maintenance analyses as heavy vehicles produce higher emissions and cause more damage to road structures;
- To allow truck bans and weight restrictions to be modelled; and
- Because toll rates often differ between vehicle classes.

There may be less difference in the vehicle operating costs and values of time for light goods vehicles and cars, than between HGV and cars. If this is the case then it may be acceptable to combine LGVs with a car user class for assignment.

People driving on employers business typically have a higher value of time than commuters or other travellers because the time spent travelling is either using up valuable working time or is being paid for by the employer or both. The ability to pass on mileage costs (which typically include both fuel and non-fuel vehicle operating costs components) to the employer results in separate treatment of these 'in-work' costs within economic appraisal, though the extent to which this difference in the perception of non-fuel costs affects driver behaviour (e.g. route choice) is debateable.

As discussed in Section 4.14 the demand model could also be segmented by car availability or ownership and PT fare category. These categories do not affect for route choice and so should carry forward to the road assignment model.

Segmentation by car park space availability is generally not required in the road network assignment model as it does not directly affect route choice, provided that the car trip has been correctly allocated to the relevant parking location zone by the parking model. The exception to this would be if the traffic assignment model also attempts to incorporate a representation of the impact which the driving round looking for an on-street space has on local traffic flows and congestion. If this is the case, then care is needed to ensure that this local search-time congestion effect is not incorrectly applied to 'off-street-space-available' trips.

Recommended Best Practice

- Goods vehicles (OGV1 & OGV2) should be represented as separate categories.
- It may be acceptable to combine light goods vehicle trips with a car user class if the values of time and vehicle operating costs are similar.
- Employers' business car trips should be a separate segment.
- The need for further segmentation by purpose should be determined once values of time and vehicle operating costs for each purpose are established.

- Segmentation by a measure of income is particularly beneficial in models which include toll roads.

5.3 Time Periods

Case Studies / References

- Most current models of urban areas include separate assignments for at least three time periods: morning peak, inter-peak and evening peak. Some models (e.g. the model used for assessing Managed Motorway options in Manchester) have single peak periods covering more than one hour, to represent networks where the peak traffic conditions remain at a consistently-high level for longer than the standard ‘peak’ hour[34];
- Other models assign peak hours (e.g. 8am to 9am and 5pm to 6pm) such as a variant of the Manchester model used for more wide-ranging applications;
- A small number of models, e.g. SYSTRA’s model of Sheffield, include separate models for pre- (e.g. 7am to 8am) and post-peak (e.g. 9am to 10am) hours in addition to peak hours. This choice was made for Sheffield to improve modelling of car park choice and to facilitate micro-time of day choice; and
- TAG Unit 3.19 recommends that at a minimum morning, average inter-peak and evening peak time periods are modelled. Peak hours (e.g. 8am to 9am) are generally preferred to arithmetic averages of longer peak periods (e.g. 7am to 10am) unless congestion (base and forecast) is minimal and/or traffic levels remain fairly constant across the extended period and/or most trips take more than one hour.

Possible Approaches

Some of the issues pertaining to choice of time periods have been discussed in the context of demand modelling (see Section 4.15).

Within the road network model separate time periods should be defined for times of day with significantly different levels of traffic or travel patterns.

Broadly speaking there are four distinct options for modelling the peak periods:

a) Representing a specific single peak hour (e.g. 08:00 -09:00), based on departure time, mid-journey time or arrival times;
b) Developing a single hour demand matrix based on the profile of link flows at key locations, either: over a specific hour (e.g. 08:00 – 09:00); or

[34] These conditions pertained in Dublin during the previous ‘boom years’ and may return again in the future

to represent the peak traffic at each location, regardless of when this peak occurs;

c) Using factors to produce a single-hour matrix which lies between the peak-hour and the arithmetic average of the 3-hour peak period – effectively smoothing out the 'peakiness' as the peak-period to peak-hour factor decreases down to 1/3;
d) Derive a generic period to hour factor based on link count data across the network to create a representative level of demand but with the characteristics of demand for the full period; and
e) Modelling more than one set of flow conditions within the peak periods.

Lessons Learnt

None of the approaches outlined above are perfect.

Option a) (single specific peak hour based on arrival, mid-point or departure times) is not guaranteed to reproduce the observed link-flow profiles, due to the mix of long and short trips and is likely to over-estimate congestion as the modelled network needs to cope with flows in excess of link or junction defined peaks everywhere at the same time – it also means that the costs in excess of 'peak hour costs' are being used to represent travel within the full 3-hour peak period in the demand model

Option b) (using differential link flows to adjust the matrix to match observed traffic flows) does not fit neatly into a demand model OD representation of the travel because it requires a complex combination of all factors that movements experience along their journey which in may differ slightly and in the case of a fixed particular hour say 0800-0900 differ significantly.

Option c) representing a 'higher than average' hour within the peak period avoids the problems associated with using the peak hour listed for a) and b) above, but might fail to identify the most-crowded/congested conditions, depending on how the 'average factors' are calculated.

Option d) use of the global generic period to peak factor would be simple and transparent while representing congestion on the network. It may however over represent delays in some areas and under- represent them in other. This limitation will be much reduced compared to the application of a simple arithmetic average hour assignment. As with all alternatives (except very finely slice assignments) delays may be larger than the shoulders of the peaks and lower than the very peak 10 or 20 minutes of the peak. This approach will however offer congestion closest to the peak hour (whenever that occurs) at all location on average.

Option e) can reflect demand distributions more accurately than the single modelled flow conditions in a) to d), which would offer improved representation of the profiles of congestion and parking utilisation and traveller responses to other temporal variations in network conditions (eg bus lane and other traffic management restrictions, variation in public transport services, time-varying congestion charging etc.). However, it will require additional model run-times, especially since the traffic assignment and public transport assignment models are both likely to represent significant proportions of the overall model run-time requirements. The coding of any temporal variation in network conditions (traffic signals, hours of operation of bus lanes, public transport service frequencies etc.) would require additional effort, as would the validation of the more-complex multi-time period model, especially on links where long and short trips come together.

Options c and d both:

- Allow for network based analysis available for environmental, network or area based link stats etc. (because hour to period expansion known); and
- Retain distribution and purpose split representative of the period under consideration.

Recommended Best Practice

- At a minimum the assignment model should be developed for three time periods. Assignment of a representative peak hour (disconnected from actual times) is preferred to either factors relating to an actual time (say 0800-0900) and to simple arithmetic averages of the peak period. Analyses of traffic count data or travel diary records can inform the specification of period to peak hour factors.
- Introducing pre- and post-peak shoulder hours would greatly increase model runs times and is most justified if parking or time of day choice is to be modelled in detail or policies which affect each of these detailed time periods are to be tested.

5.4 Zones

Case Studies / References

- TAG Unit 3.19, section 2.3 provides advice on defining zone systems; and
- Cambridge Systematics, Inc. white paper titled “A Recommended Approach to Delineating Traffic Analysis Zones in Florida”[35] provides guidance on zone delineation.

Possible Approaches

Issues in defining zones include how large zones should be in different areas of the model and how boundaries should be defined.

[35] http://www.fsutmsonline.net/images/uploads/reports/FR1_FDOT_Taz_White_Paper_Final.pdf

Lessons Learnt

TAG 3.19 suggests that in the main modelled area the maximum number of trips per hour from each zone should be between 200 to 300 to avoid loading unrealistically large amounts of traffic at a few points

It is not strictly necessary for the same zone system to be used in the demand and assignment models. Assignment zones can be subdivisions of larger demand model zones in which case forecast changes in demand for demand model zones are generally applied equally to constituent assignment model zones. This can be an advantage if demand model run times are long or data storage is a problem.

Data on population, employment, car ownership, income, etc. are required to develop base year trip matrices and also for forecasting. Such data are commonly available for administrative areas (e.g. local authorities) or census enumeration areas.

Barriers to travel, e.g. rivers and railways strongly affect where travellers can access the road network.

Defining specific zones for large car parks, or clusters of neighbouring car park, can improve the accuracy of loading of traffic to the road network.

Recommended Best Practice

- Zones should be smaller in the main area where analysis is required and proposals will be tested, and become progressively larger with distance from this area. Guidance on the number of trips per zone should be developed by considering the maximum number of zones that is desirable to achieve the required run times and the total level of trip making in each regional modelled area.
- It is beneficial for model zones to be either subdivisions or collections of administrative or census areas.
- Zone boundaries should respect barriers to travel so that trips from each zone can be accurately loaded onto the modelled network.
- Large car parks or groups of car parks should be allocated to separate zones.

5.5 Networks

Case Studies / References

- TAG Unit 3.19 is not prescriptive on which roads should be included in a model. In summary the guidance is that roads carrying significant levels of traffic should be included; and
- Models of urban areas developed by SYSTRA (including Greater Manchester, Sheffield, South Hampshire, etc.) have detailed network, including detailed junction modelling, in the main area of interest.

The level of detail is progressively reduced. In the most peripheral areas only motorways and major trunk roads are included. Guidelines on which road classes to include in each area are generally set in advance of network building.

Possible Approaches

The main issues for network coding are to decide on which roads or road classes should be included in each area of the model, and where detailed coding is required (see Section 5.6). Sources of network parameters such as junction saturation flows, gap acceptance behaviour and so on must be identified.

An approach to defining networks for forecast scenarios will be required.

Lessons Learnt

Defining classes of road to include in different areas of the model is useful to facilitate automated or semi-automated processes to construct networks from existing GIS mapping data such as that maintained by Ordnance Survey.

For peripheral areas the main purpose of the network is to ensure that traffic loads onto the right core area for analysis in the right places. In most models the level of detail is reduced by including only major roads and by excluding junction modelling. There is a need to balance demand and network supply if journey times are allowed to change with assigned flows in order to achieve realistic routing. If comprehensive count datasets are available then these can be used to assist with the selection of roads to include in each area of the model. It may be necessary to add minor roads to the network if it knows that they are heavily trafficked or to improve validation.

For some models a simple template of values for junction coding could be adopted where the characteristics of a turning movement at a particular type of junction are fixed, e.g. all left turns from minor arms at priority junctions would have the same saturation flow. Template coding speeds up model building and imposes consistency, but does not capture local issues such as turn radii or visibility. Such templates are typically simplifications of methods to determine saturation flows based on the geometry of the junction.

The UK Transport Research Laboratory (TRL) has published research reports[36] providing empirically based formulae for calculating saturation flows for junctions based on geometric measures including width, gradient, curve radii and visibility. SYSTRA has developed a spreadsheet to calculate saturation flows using the TRL research for a model of the town of Northwich (population of approximately

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[36] RR67 “The prediction of saturation flows for single road junctions controlled by traffic signals”. LR735 “The capacity of some major/minor junctions”. SR582 “The traffic capacity of major/minor junctions”. LR942 “The traffic capacity of roundabouts”.

40,000). Estimating saturation flows based on geometries would be expected to improve the representativeness of the model, but no evidence of how beneficial this is for validation of forecasting has been identified.

Recommended Best Practice

- Network detail should be greatest where most roads may be included. Detail should become progressively lower as distance from the congested urban area increases. Guidelines for which road classes to include in which area of the model should be agreed.
- In principle junction characteristics such as saturation flows should be coded based on the geometry and research such as that published by TRL.

5.6 Assignment Routines

Case Studies / References

- TAG Unit 3.19 (UK) includes recommendations for assignment routines. The most commonly used road assignment software, SATURN, incorporates all of these facilities.

Possible Approaches

Most road network assignment software provides options for the approach taken to assignment and the calculation of travel times including:

- Whether travel times and delays should be affected by traffic volumes?
- Should interactions between traffic streams, and resulting delays, be represented?
- Should flow metering, where queued traffic does not affect downstream junction performance, be modelled?
- Should blocking back, where queued traffic obstructs an upstream junction, be modelled?

Lessons Learnt

In urban areas travel times are sensitive, (often very sensitive), to traffic volumes which in turn influences route choice. Travel time savings are key component of transport economic appraisal. Junction delays caused by the interaction between traffic streams are a very major component of overall travel times. Flow metering is believed to strongly affect travel times, as queued traffic is not allowed to impact on downstream junctions. However no reporting on the scale of the impact of flow metering has been identified.

Blocking back is more readily observed in real life than flow metering and can significantly affect the time taken to exit an impacted junction. One drawback is that it can lead to instability in assignments as a small change in flow (1 or 2 pcus) on a link can induce blocking back resulting in in much increased delays.

On limited access routes such as motorways link volumes can have a significant impact on travel times.

Recommended Best Practice

- Travel times are sensitive to assigned traffic volumes. Changing travel times as flows change implies an iterative method.
- Junction modelling should be used to replicate how interactions between traffic streams at junctions affect delays. It is possible to use link speed-flow curves on limited access roads (e.g. motorways) and outside of congested urban area.
- Flow metering and blocking back facilities should be utilised if possible.

5.7 Assignment parameters

Case Studies / References

- WebTAG; and
- LATIS.

Recommended Best Practice

- Values of time and vehicle operating costs used in the road network model should be consistent with those in the demand model. If not, there is a potential that a reduced GC in the assignment model could be translated to an increased GC in the demand model (if the balance of value of time and vehicle operating costs are different in the two models). This would lead to an implausible reduction in demand as a result of increased GC (or vice versa).

Sources of values of time and vehicle operating cost parameters are discussed in Section 4.11.

5.8 Convergence

Case Studies / References

WebTAG 3.19 recommends the following minimum convergence targets, but with the caveat that tighter convergence may be required for economic appraisal. This is shown below in Table 5.1.

Table 5.1 TAG 3.19 Recommended Road Assignment Convergence

Measure of Convergence	Base Model Acceptable Values
Delta and %GAP	Less than 0.1% or at least stable with convergence fully documented and all other criteria met
Percentage of links with flow change <1%	Four consecutive iterations greater than 98%
Percentage of links with cost change <1%	Four consecutive iterations greater than 98%

SYSTRA has undertaken work for the UK Highways Agency to express convergence in the same units as benefits by calculating the implied economic appraisal results between the penultimate and final assignment iterations. As part of this work, methods were used to display economic benefits and “noise” (the implied benefits between iterations) graphically for each zone or junction, as illustrated below in Figure 5.1.

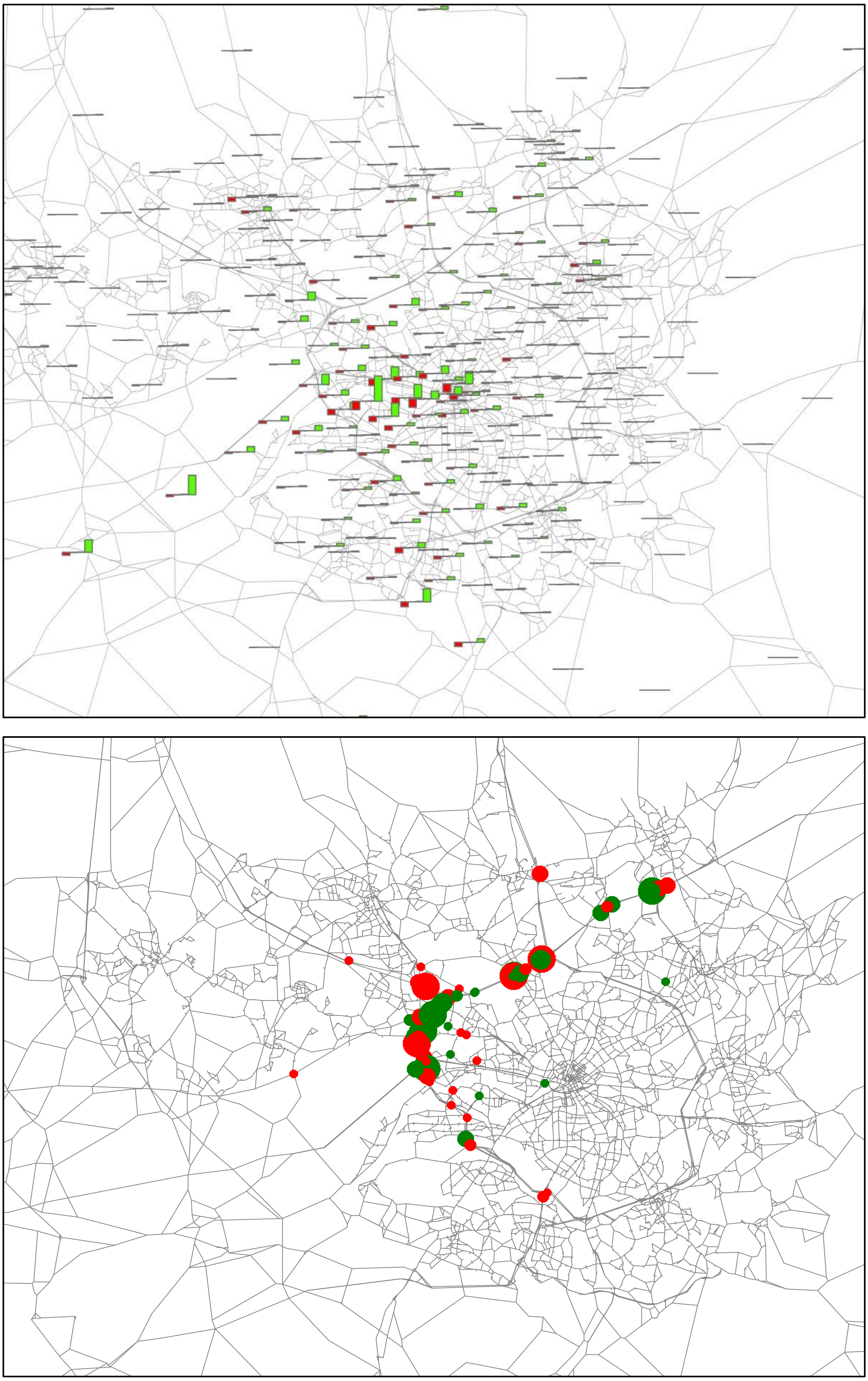

Figure 5.1 Benefit Presentation Examples

Possible Approaches

Confidence in assignment results (flows and delays) requires that they are stable between model iterations. In particular for economic appraisal, cost differences between scenarios need to be significantly greater than cost differences between iterations.

Methods of measuring convergence and convergence targets are required. The convergence measures available depend on the software being used.

The following convergence measures are most commonly used individually or in combination:

- The percentage of links where flows and / or costs change by less than a specified percentage ("%flows"); and
- A comparison between total network costs using chosen routes and the total network costs for the minimum cost routes determined from the next iteration's assignment ("delta" or "%gap").

Lessons Learnt

Measuring the percentage of links where either the flow or cost changes (%flows) are less than a specified percentage is beneficial but not sufficient to ensure stability of appraisal results. As presented above UK DfT recommend that for 98% of links the change should be 1% or less. The changes on the remaining 2% of links could be large enough to distort appraisal results.

The delta (calculated based on flows and costs for successive assignments) or %gap (which also includes cost changes made during the simulation step where the impacts of junction interactions on delays are estimated) statistics are better measures than %flows as they capture both flows and costs which are essential inputs to economic appraisal.

In some cases a model may apparently converge, as measured by %flows or %gap, for one iteration but not for subsequent iterations. For this reason the chosen convergence targets must be achieved for a number (e.g. 4) of successive iterations.

In models where costs are fixed for some links, the %gap measure and percentage of links where cost changes are less than a target level could be biased.

The %flow and %gap measures are calculated across the whole network. Even if tight convergence targets are achieved for the network as a whole, locally, potentially significant cost and flow changes between iterations may persist.

Measuring the implied economic appraisal benefits (or disbenefits) between assignment iterations provides a more direct measure of whether a model is adequately converged than the %flows or %gap measures.

Recommended Best Practice

- Costs are a key input to economic appraisal and must be captured by the convergence measure. The %gap measure (which compares the change in total demand-weighted generalised costs between one iteration and the next) reflects both flows and costs and provides a better measure of convergence than %flows.
- A target for the level of the %gap-based convergence and the number of successive iterations which achieves this target level should be specified, as part of the model documentation.
- Standard methods to present and analyse the benefits of tested interventions are required. These should include methods to display the spatial distribution of benefits to demonstrate the plausibility of the results. The same types of plots can be used to analyse the location and scale of instability in flows and costs.
- In order to determine appropriate convergence targets, sample schemes should be tested in the assignment model at various levels of convergence, and economic and environmental analyses undertaken. In this way the level of assignment convergence required to achieve stable results can be determined.

5.9 Validation

Case Studies / References

- WebTAG 3.19 (UK) provides advice on validation methodology. Recommended validation criteria as shown below and should be achieved for each time period, and for cars and total vehicles. The two count criterion should be applied separately. Table 5.2 provides examples of highway validation criteria.

Table 5.2 TAG 3.19 Recommended Highway Validation Criteria

Criteria	Description of Criteria	Acceptability Guideline
Counts 1	Individual flows within 100 veh/hour of counts for flows less than 700 veh/hour	> 85% of cases
	Individual flows within 15% of counts for flows from 700 to 2,700 veh/hour	> 85% of cases
	Individual flows within 400 veh/hour of counts for flows more than 2,700 veh/hour	> 85% of cases
Counts 2	GEH < 5 for individual flows	> 85% of cases
Journey times	Modelled times along routes should be within 15% of surveyed times (or 1 minute, if higher)	> 85% of routes

GEH is a statistic used for comparing sets of flows (e.g. modelled and observed) which captures both proportionate and absolute differences and is formulated as follows (where M and C represent modelled and counted flows):

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

Matrix estimation (ME) is a method to adjust the demand matrix so that assigned flows better match counts. TAG 3.19 advises on how to monitor the changes made to the matrix so that any undue distortion can be captured:

- Scatter plots and regression analyses of trips between zone-pairs before and after ME;
- Scatter plots and regression analyses of tripends before and after ME;
- Trip length distributions, mean trip lengths and standard deviations before and after ME; and
- Sectored matrix changes.

TAG 3.19 also gives advice on methods for obtaining traffic counts and journey time data.

Possible Approaches

Model validation is the process of checking whether assignment results adequately reproduce observed conditions. Validation can consider flows, travel times or both. Decisions on which counts and journey time routes to validate must be made. Targets for acceptable validation should be agreed in advance.

A structured approach to validation is required for efficiency and to ensure that any changes to model inputs are made for logical reasons.

Validation only considers the base year situation, and so is necessary to demonstrate the fitness for purpose of the model. Validation is not on its own sufficient because the main purpose of the model will be forecasting and so how the model responds to changes in inputs should be understood.

Lessons Learnt

Count validation is very important to provide confidence in model outputs which will be used for operational, safety and environmental analysis. Journey time validation is equally important, in particular because journey times are a key input to economic appraisal. GCs, which incorporate journey times also drive demand model responses and hence forecasts of travel patterns.

In models where Roadside Interview Surveys are used to build matrices, or counts are used to calibrate the matrix using matrix estimation (see below), then separate count data is required for validation. Counts used for validation must be different to those used for calibration to provide a fair test of how well the model predicts routes.

Validation counts and journey time routes must provide good coverage of the network. Count validation should be undertaken for individual sites and for screenlines. Where traffic levels at individual sites are low, e.g. for goods vehicles, it may be preferable to compare flows across “mini-screenlines” of neighbouring sites because the accuracy of counts at each location may not be adequate.

If the agreed validation criteria are not met then the first step should be to check the accuracy of network coding. Even if systematic checking of network coding is done during the building stage some errors may still creep through. Checks should include:

- Comparing coded link lengths with crow fly distances between the start and end nodes;
- Realism of coded free flow speeds;
- Range checks of saturation flows;
- Identifying links where the traffic count exceeds modelled capacity; and
- Worst speed validation – gross errors in capacities.

The plausibility of routes should be checked based on local knowledge as there is rarely any observed data on routes chosen. Route trees (the routes taken from a single zone to all zones) and routes for selected zone-pairs can be visually examined. Reasons for unexpected route choices should be examined.

Undertaking initial validation on a screenline or cordon basis reduces the influence of modelled route choice, which may not yet be validated, and allows for checks to be made of whether the level of demand in the matrix for aggregate movements is compatible with traffic counts. For work for the Highways Agency in Manchester, matrix estimation (ME) was applied using screenline counts, and matrix changes calculated by ME combined to sector-pair level. In this way broad-brush matrix changes were made to match the matrix to counts before full confidence in route choice was achieved.

In most UK urban models acceptable validation cannot be achieved without ME. It is common for 40% or less of links to meet the validation criteria, rather than the 85% target. ME will in general force a good match to counts which could compensate for network errors. However these network errors will affect the reliability of the model for forecasting.

Journey time observations can be obtained either by Moving Car Observer (MCO) methods or by obtaining commercially available GPS-based data. GPS data can provide a richer sample covering a period of several months or longer. However there is some evidence of bias in GPS data. Local residents making regular journeys are unlikely to switch their GPS on. GPS data providers often remove slow or fast outliers from the datasets which could affect the reported average journey times. Some GPS journey time data providers offer both mean and median results for each link. For a model of Northwich, SYSTRA reviewed both mean and median results using judgement and for some routes historic MCO data and concluded that the medians appeared more representative.

Good validation of journey times is necessary, but could mask significant localised mismatches.

Validation alone is not sufficient to demonstrate that a model is fit for purpose. If demonstration tests are run as part of the validation phase, where representative schemes are coded into the model, then the plausibility of model responses can be assessed. Such tests may highlight coding or matrix problems which can be resolved before the validation is signed off.

Recommended Best Practice

- Flows and journey times must both be validated against a comprehensive set of observed data. Validation criteria and targets should be agreed in advance.
- If (as is likely) the validation targets are not met using unadjusted matrices, then matrix estimation should be used to ensure acceptable replication of counted traffic. Network checks should be undertaken, and any necessary corrections made, before matrix estimation is used. If matrix estimation is used then changes to the matrix should be monitored. It is desirable to ensure that assignment matrix trip ends remain consistent with the demand model matrices.
- Counts used for calibration should not be used for validation. Matrices should be compared with total screenline crossing early in the validation process and broad-brush matrix adjustments considered. This can be done before routes have been validated.
- Routes for a selection of zone-pairs should be reviewed based on local knowledge.
- Vehicle / mobile device tracking based journey time data has been used extensively for validation in recent years because it can provide a larger sample than Moving Car Observer (MCO) methods. Initial analysis of the vehicle / mobile device tracking data should be undertaken to understand if there is any evident biases.
- Demonstration tests should be undertaken before the validation is considered complete.
- If possible (i.e. if the relevant historic data needed to specify the relevant inputs and validate the outputs of this test exist), a ‘backcast’ representing travel conditions a number of years prior to the model’s base year should be undertaken.

6 Public Transport Network Model

6.1 Introduction

The purpose of the public transport (PT) network model is to allocate PT users to services between their origin and destination zones. Costs of travel including walk, wait and in vehicle time, and fares are calculated by the PT network model for input to the demand model and economic appraisal.

Aspects of the PT network model which require consideration and specification include:

- If and how to segment travel demand;
- Which time periods to represent;
- Design of the zone system;
- Approach to network coding;
- Representation of fares;
- The routines used to allocate travellers to PT services, including whether assignments should be capacity constrained;
- The parameters used within the assignment including GC coefficients and sensitivities; and
- How to validate the model to ensure that it replicates observed travel conditions adequately.

6.2 Demand Segmentation

Case Studies / References

- TAG Unit 3.11.1 "Road Traffic and Public Transport Assignment Modelling"[37] recommends that demand is segmented according to the type of ticket used and familiarity with the services available;
- Many models (including Greater Manchester and Sheffield) omit purpose segmentation from the PT network model because the percentage of public transport travellers on employers business is very low;
- No models have been identified where PT assignments are segmented by car availability or ownership; and
- No models have been identified where PT assignments are segmented by fare or ticket category.

[37] http://www.dft.gov.uk/webtag/documents/expert/pdf/unit3.11.1.pdf

Possible Approaches

As with the road network model demand may need to be segmented into groups with different route choice characteristics. For PT assignment relevant characteristics could include value of time, type of fare product used and eligibility for discounted fares.

As discussed in Section 4.14 demand segmentations could include:

- Journey purpose;
- Income or a proxy of income such as willingness to pay category or socio-economic group;
- Car availability or ownership;
- PT fare category and availability of a parking space;
- The segmentation used in the road network, PT network and demand models do not necessarily need to be identical.

Lessons Learnt

PT assignment run times are likely to be a significant component of overall run-times, particularly if widespread public transport crowding effects are being modelled (i.e. requiring additional loops to achieve convergence between crowded/unattractive and uncrowded/attractive levels of service on the relevant public transport services. Care is therefore required to avoid more segmentation than necessary with the public transport assignment models, particularly if crowding modelling is required.

It is advantageous if the assignment segments are aggregations of the demand model segments so that forecast demand changes can be applied to assignment matrices. It would be possible to split demand model segments for assignment if necessary using a set of user calculated factors, although the demand forecasts could not capture differences between the behavioural traits of each “sub-segment”.

Journey purpose does not directly affect PT service choice but the differences in value of time between purposes might. If may be useful to retain journey purpose segmentation in the PT network model to reflect any value of time differences, if the proportion of PT demand with high (e.g. employers business) or low values of time is significant. Similar logic can be applied to segmentation by car availability or ownership.

Segmenting the PT assignment by ticket or fare category should in principle improve the accuracy of route choices but has rarely been implemented.

Recommended Best Practice

- The proportions of public transport demand in each car ownership or availability and purpose category, and the differences in values of time between categories should be reviewed. If there are categories which represent a high proportion of PT demand and which have values of time that are significantly different from the average, then there may be justification for segmenting the assignments.

- Segmentation by ticket or fare category is recommended in principle but the impacts of this segmentation on run times and the availability of data to segment demand reliably should be considered before a decision is made.

6.3 Time Periods

Case Studies / References

- TAG does not offer much advice on time periods for PT network modelling. Unit 3.11.2[38] “Road Traffic and Public Transport Assignment Models for Public Transport Schemes” recommends that separate periods may be required for times of day with different fare levels; and
- In most UK models the demand model and PT model assignment time periods are consistent to reflect differences in PT services and headways.

Possible Approaches

Some of the issues pertaining to choice of time periods have been discussed in the context of demand modelling (see Section 4.15).

It will be necessary to calculate PT GC matrices for each time period represented in the demand model. This generally means that there should be PT assignments for each demand model period, particularly if the PT services differ between periods.

The specification of time periods will be influenced by whether crowding is modelled (see Section 6.7). If crowding is modelled, then each time period should reflect differences in travel volumes.

Lessons Learnt

PT network model run times are generally shorter than road network model runs times and so are less of a constraint on the number of time periods.

Recommended Best Practice

- At a minimum there should be sufficient time periods to reflect the main differences in PT (frequency, journey times, fares etc.) across the day.

[38] http://www.dft.gov.uk/webtag/documents/expert/pdf/unit3.11.2.pdf

- Representation of crowding in PT assignments is recommended. Without crowding, choice of assignment period is less important as routes and GCs are likely to be similar in peak periods and peak hours.

6.4 Zones

Case Studies / References

- TAG Unit 3.11.1 includes advice on zone systems for PT models; and
- Cambridge Systematics, Inc. white paper titled “A Recommended Approach to Delineating Traffic Analysis Zones in Florida” provides guidance on zone delineation.

Possible Approaches

Many of the issues affecting the design of zone systems are discussed in section 5.4 in relation to the road network model. Zones used in the demand, road network and PT network models do not necessarily need to be identical.

Lessons Learnt

TAG Unit 3.11.1 advises that the same zone system be used in demand, road network and PT network models; with the needs of the PT network model dictating the zone system used. Many of the recommendations of Unit 3.11.1 are consistent with those for road network models:

- Zone boundaries should match census and administrative areas;
- Zones should not straddle barriers to travel; and
- Zones should have homogenous land uses.

In addition, for PT network modelling zones should reflect levels of access to PT services and group areas which are served by the same services.

For PT assignment, zones should be small enough to reflect walk catchments of services. TAG Unit 3.11.1 recommends that zones in urban areas be no more than 1km in radius. It is preferable for each zone to contain only one stop or station, although in city centres it may be reasonable to allow a choice of stops for access to a particular area or building. In areas which are not well served by PT, zones can be larger.

Recommended Best Practice

- WebTAG Unit 3.11.1 advises the use of the same zone system in the demand, road network and PT network assignments to achieve the greatest precision in assignments and demand responses.
- UK WebTAG’s Unit 3.11.1 advice of consistency with administrative boundaries, respect for barriers to travel, homogeneity of land use, and representing access to different PT services should be followed. The recommended approach for zone delineation is adapted from

Cambridge Systematics, Inc. white paper titled "A Recommended Approach to Delineating Traffic Analysis Zones in Florida"

6.5 Networks

Case Studies / References

All recent SYSTRA models use consistent node and link structures for road and PT networks. This means that bus services (coded in the PT network) can be easily transferred to the road network so that the effects on road capacity can be captured in the road assignment. Speeds, or speed changes, from the road network can be applied to the PT network to change the speeds of buses in forecast years. One drawback of this approach is that it can be quite labour intensive to determine which nodes bus services call at and which links they traverse.

Some models (e.g. the now superseded Central Leicestershire Transport Model) use stop-to-stop PT networks with a completely different structure to the road network. An advantage of this approach is that the PT services can be coded automatically from databases such as TransXchange. Unfortunately a separate coding exercise is still required to allocate buses to the road network model. With the stop-to-stop approach it is not possible to accurately reflect changes in road speeds, as predicted in the road network model, in the PT network model.

Possible Approaches

Many of the issues relating to the level of network detail are discussed in Section 5.5.

Some models use the same node and link structure for both PT and road network models. Rail, tram and walk links are added in the PT network model.

Some models use "stop-to-stop" networks with notional links between stops. The actual road links used by services between pairs of stops are not recorded.

Lessons Learnt

Using the same network structure for road and PT networks allows for the effects of congestion (as calculated in the road network model) on bus speeds to be reflected in the PT assignments. This means that the road network should include all links served by buses.

Recommended Best Practice

- The road and PT networks should have the same node and link structures, with the addition of rail, tram and walk links to the PT network.

6.6 Fares

Case Studies / References

- All recent SYSTRA models include public transport fares in the GCs used within the demand model. These fares are generally calculated within the PT assignment model;
- Options for how fares are represented in the PT assignment model will depend on the software used. Citilabs' TRIPS software as used in the current GDA model offers limited fare functionality. A single fare system must be applied to every service although fare rates can be set for each line if required. Fare system choices are:
  - Distance based, either [boarding fare] + [rate] x [distance] or defined by a series of [distance, fare] points;
  - Zonal fares, either concentric / annular or non-concentric;
  - Step down fares where the fare paid depends only on the boarding point and decreases as the service nears the end of the route (used by bus operators in Hong Kong); and
  - Stage fares where the fare paid is related to the number of stages traversed.
- TRIPS is no longer supported by Citilabs.

CUBE Voyager includes sophisticated algorithms to allocate travellers between alternative routes and sub-modes. Voyager deals with route choice as two steps. The first step (Enumeration) defines a set of reasonable routes between each zone-pair. The second step (Evaluation) applies a series of choice models to allocate demand between the reasonable routes. One weakness of Voyager is that it does not account for fares or interchange penalties in the Enumeration step. Voyager provides for the following fare systems in the Evaluation step:

- Flat fares;
- Distance based, i.e. either [boarding fare] + [rate] x [distance];
- Concentric / annular zones; and
- Non-concentric zones, either based on the number of zones traversed (e.g. if 3 zones are crossed then the fare would be €X) or on the sum of fares associated with each zone traversed (e.g. if zones x, y and z were crossed the fare would be fare(x)+ fare(y) + fare(z)).

Voyager does allow for a number of different fare structures to be used in a single assignment. Typically a fare structure will be set for each operator or mode.

Both TRIPS and Voyager allow for an approximation of through ticketing by use of a fare reduction where a transfer between lines or fare systems occurs.

Both TRIPS and Voyager could be used to model concessionary fares. This would entail undertaking separate assignments for full fare and concessionary fare using different fare tables. Flows from these assignments can be subsequently combined.

Lessons Learnt

Voyager offers improved flexibility for fare modelling compared with TRIPS and will allow for closer approximation of real fares.

Possible Approaches

Fares should ideally influence both choice of service in the PT network model and mode destination, time of day, and potentially other choices in the demand model.

Ideally all of the features of the fare system should be represented including through ticketing, discounts for multi-leg journeys, concessionary discounts, variations between operators, etc.

Recommended Best Practice

- Fares must be input to the demand model as a component of GC. Fares typically constitute a large proportion of GC and will therefore influence mode and destination choices.
- Preferably fares should ideally be an input to route identification (known as Enumeration in Voyager) stage of the PT network model, and must influence the allocation of travellers between routes (Evaluation). Choice of PT assignment software should be influenced by how closely the real regional model area fare structures can be represented.

6.7 Assignment routines

Case Studies / References

- No examples of the use of schedule based assignment have been identified; and
- Crowding is rarely modelled. Exceptions include the current GDA model, the Transport Model for Scotland, London Transportation Studies and RAILPLAN (London focussed).

Possible Approaches

Two key choices for assignment routines are whether assignments should be based on the frequency of services (e.g. four per hour) rather than the actual schedule (e.g. arrivals at 08:00, 08:10, 08:30 and 08:40); and whether the effects of crowding of route choice should be represented.

The effects of crowding are modelled by calculating a cost penalty as a function of the ratio of volume to capacity on a service as illustrated in Figure 6.1. Penalties can be applied either as a factor (e.g. multiply by 1.1) to increase in vehicle time or as an additive penalty (e.g. +5 minutes). Routes are re-estimated with the cost penalties applied, demand allocated to services, penalties are re-calculated, and so on until convergence is achieved.

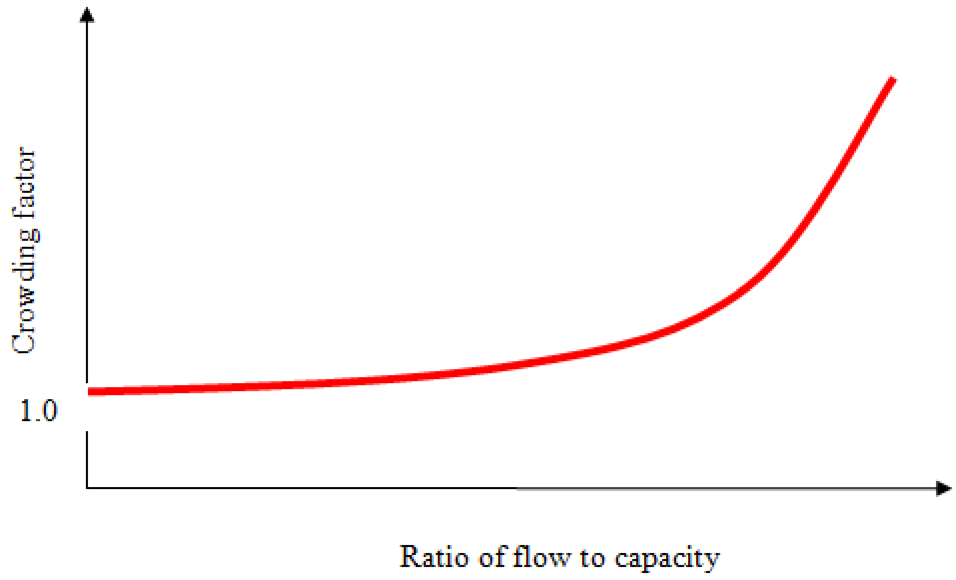

Figure 6.1 Crowding Penalty Curve

TAG Unit 3.11.2 includes advice of whether to use frequency or schedule based assignments, and the situations where crowding should be modelled.

Lessons Learnt

Frequency based approaches are weakest where services are infrequent and/or irregular (e.g. there are four services per hour but not at consistent 15 minute intervals). This is particularly true for routes where an interchange between infrequent or irregular services is required. In urban areas where services are frequent and where services may not arrive to timetable (particularly in the cases of buses and trams) frequency based approaches may be a good approximation of reality.

Schedule based approaches take account of the actual service timetables. It is thus possible in principle to account for whether a service gets one to work at the desired time. With the schedule based approach, waiting times between services should be more realistically represented. In addition schedule based approaches should be more robust when services are reliable, infrequent and irregular. TAG states that run times can be 10 times longer when schedule based assignments are used.

In principal modelling crowding is preferable in situations when many services are at or near capacity. It may not be possible to achieve an accurate representation of crowding without increasing the number of modelled time periods. In urban areas, rail and bus services arriving just in time for the start of the working day (e.g. at 8:45) can be very crowded whilst services arriving 15 minutes before or after are much less busy.

Modelling crowding implies a need to iterate the PT network model so that assigned passenger flows and perceived costs of crowding converge. This can result in a very significant increase in run times.

Recommended Best Practice

- A frequency-based (rather than a detailed journey-planning style timetable-based) approach is likely to be appropriate in the Dublin context with frequent services which will be affected by road conditions.
- Modelling crowding adds a high degree of complication and run time to a model system, and results may not be accurate unless the number of modelled periods is increased so that 15 or 30 minute periods are represented.

6.8 Assignment parameters

Case Studies / References

The following documents summarise research into model parameters:

- TAG Unit 3.5.6, "Values of Time and Operating Costs";
- TRL Report TRL593, "The demand for public transport: a practical guide"; and
- the Passenger Demand Forecasting Handbook.

Possible Approaches

The PT network models will require:

- Coefficients to convert walk time, wait time, in vehicle time, fares, and the number of boardings and / or interchanges to generalised cost (these parameters may vary by sub-mode); and
- Parameters to determine the sensitivity of route choice to differences in GCs.

Lessons Learnt

The above documents are based largely on UK research.

Recommended Best Practice

- GC coefficients and sensitivity parameters should be developed from data (RP or SP, incomes, etc.) specific to each regional model area if possible.

6.9 Validation and Demonstration Testing

Case Studies / References

- TAG Unit 3.11.2 includes guidance on validation of PT network models. TAG recommends that network coding be thoroughly checked. These checks should include comparing the number of public transport vehicles on a link with observed counts. The matrix should be validated by comparing assigned flows against counts for complete screenlines. The match of flows on screenlines should be within 15% for 95% of screenlines;
- Criteria for the validation of individual flows are that the match to counts should be within 25% except when observed flows are less than 150 passengers per hour; and
- Unit 3.11.2 recommends that the following adjustments be considered, in approximately the order shown below if necessary to improve validation:
  - Adjustments may be made to the zone centroid connector times and costs;
  - Adjustments may be made to the network detail, and any service amalgamations in the interests of simplicity may be reconsidered;
  - The in-vehicle time factors may be varied;
  - The values of walking and waiting time may be varied;
  - The interchange penalty may be varied;
  - The parameters used in the trip loading algorithms may be modified;
  - The path building and trip loading algorithms may be changed; and
  - The demand may be segmented by person (ticket) type.

Possible Approaches

Principles for validation of the PT and road network models are similar. A structured approach is required and validation targets should be defined in advance. Demonstration testing is required in order to understand how the model will respond to changes in inputs in a forecasting application.

Lessons Learnt

The validation checks recommended in TAG Unit 3.11.2 are generally appropriate. In addition:

- Bus journey times should be checked against observations rather than timetables where possible;

- If observed flows are less than 150 passengers per hour the assigned flow should also be low; and
- The plausibility of route choice should be checked for a selection of zone pairs.

Some software packages, including CUBE Voyager, include Matrix Estimation (ME) facilities to adjust matrices to better match counts. If ME is used for the PT network model then the same analyses as recommended in TAG Unit 3.19 (for the road network model) should be carried out to ensure that matrices are not unduly distorted:

- Scatter plots and regression analyses of trips between zone-pairs before and after ME;
- Scatter plots and regression analyses of trip-ends before and after ME;
- Trip length distributions, mean trip lengths and standard deviations before and after ME; and
- Sectored matrix changes.

Validation alone is not sufficient to demonstrate that a model is fit for purpose. If demonstration tests are run as part of the validation phase, where representative schemes are coded into the model, then the plausibility of model responses can be assessed. Such tests may highlight coding or matrix problems which can be resolved before the validation is signed off.

Recommended Best Practice

- Flows should be validated against a comprehensive set of observed data. Validation criteria and targets should be agreed in advance.
- If (as is likely) the validation targets are not met using unadjusted matrices then matrix estimation should be used to ensure acceptable replication of counted patronage. Network and service coding checks should be undertaken, and any necessary corrections made, before matrix estimation is used. Changes to assignment algorithms and parameters may also be considered. If matrix estimation is used then changes to the matrix should be monitored. It is desirable to ensure that assignment matrix trip ends remain consistent with the demand model matrices and land use.
- Routes for a selection of zone-pairs should be reviewed based on local knowledge.
- If possible (i.e. if the relevant historic data needed to specify the relevant inputs and validate the outputs of this test exist), a ‘backcast’ representing travel conditions a number of years prior to the model’s base year should be undertaken.

7 Other Modes of Transport

7.1 Introduction

In this chapter best practice approaches to the modelling of the following other modes are presented:

- Active modes (i.e. walking and cycling);
- Taxis;
- Freight; and
- Airport Surface Access.

7.2 Active Modes

Case Studies / References

- In the UK, Census Journey to Work data has been used in many models to estimate separate walking and cycling matrices. Data from travel diary surveys (including the UK National Travel Survey) has been used to provide average trip lengths for walking and cycling as a basis for calibrating gravity models to synthesis matrices. This approach has been used in models including Greater Manchester, Sheffield and South Hampshire. In these models, walking and cycling are combined within the demand model, e.g. they are treated as a single mode in the mode choice model; and
- No examples of strategic models which assign walking or cycling demand have been identified.

Possible Approaches

There is no scope for debate about whether journeys undertaken wholly by car or PT should be included in the model, as they are required to test schemes that affect both modes. There are choices to be made about whether to include walking and/or cycling in the model including:

- Whether to include walking and cycling in the model at all;
- Whether to represent walking and cycling as separate or a combined mode within each component of the model system;
- How to derive matrices for walking and cycling;
- Should walking and / or cycling matrices be assigned to the model networks; and
- How to validate walking and cycling demand.

The 2011 POWSCAR data provides recent information to develop matrices for walking and cycling to work and education. It is relatively straight-forward to estimate walking and cycling matrices for other purposes using gravity approaches calibrated to replicate journey length distributions observed using travel diary surveys.

Bicycle traffic could be assigned to the road network to contribute to traffic flows, and therefore influence the level of service for cars. Walking demand could also be assigned if the volume of pedestrians on individual links was a significant consideration in transport planning.

Lessons Learnt

A frequency response is not required in the demand model if walking and cycling are included, because international evidence has indicated that the total number of journeys, by all modes, is largely insensitive to travel costs.

Including walking and cycling matrices in the demand model would increase data storage requirements and run times. Walking and cycling matrices could be combined in the demand model which would require assumptions to be made about how to determine GCs for different journey distances, e.g. assuming that trips of more than a defined length are typically undertaken by bike rather than on foot.

Walking and cycling are often realistic alternatives to PT in particular. Many PT improvements will attract some demand from people who are currently walking or cycling, and the appraisal of any public transport schemes using the model should therefore take account of this.

It is also generally easier to calibrate to known public transport elasticities to changes in fare or service frequency if the active modes (particularly walking) are included within the demand modelling.

Generalised costs for walking and cycling may be obtained by building paths from the road network (amended to include the off-street routes, as described below) and applying typical walking and cycling speeds.

Distance profiles are expected to be very different for cycling trips, with walking trips typically averaging around 1km and cycling trips around 5km. Therefore walking and cycling matrices must be developed separately.

If bicycles were to be assigned to the network, then the validation of the cycle matrices would become more important. A passenger car unit (PCU) factor for bicycles would be required to determine how much capacity each bike takes up. If bicycles were assigned, then the network should be sufficiently detailed to include important off-street cycle routes (notably canal tow-paths, footbridges across rivers, paths across parks and large city centre squares etc.) Assignment of pedestrians would similarly require very detailed networks.

However, validation of walking and cycling matrices to support detailed analyses would require very extensive and potentially innovative surveys. Many pedestrians in the city centre, where walk volumes are highest, will be visitors to the city who may not be readily captured in the demand matrices.

Recommended Best Practice

- Walking and cycling demand should be included in the demand model in order to improve the realism of travel choices, e.g. to allow for switching of shorter walk or cycle trips to public transport or vice versa.
- Walking and cycling matrices should be derived separately because they have different travel patterns, in particular trip length.
- POWSCAR data can be used to derive walk and cycle matrices for commute. Synthetic distribution models can be calibrated for walking and cycling to match observed trip length distributions.
- The impact of cycle lanes on road capacity should be included in the traffic model, but the impact of the bicycles (or pedestrians) on road and junction capacity need not modelled.
- The model should include an ability to assign the cycling matrix to the road and cycle network, using shortest paths which, if possible, take account of some of the main attributes known to affect cyclists route choice – however, this assignment should not be expected to match individual cycle link counts, due to the difficulties associated with predicting cyclist’s routing.

7.3 Taxis

Case Studies / References

- There is an opportunity for the regional modelling system to push forward good practice with regards to modelling of taxis. SYSTRA and Jacobs knowledge of the London Transportation Studies (LTS) model could be **exploited.** LTS does include a black cab (but not minicab) matrix because of the quantity of taxi trips in some parts of London. We could also seek advice from colleagues, using their knowledge of models of cities such as Hong Kong and Singapore where private car ownership is low and hence taxi use high.

Possible Approaches

In most models little consideration is given to taxis. They may be included in the car demand matrix and treated exactly as cars. In this way the broad quantity and spatial distribution of taxis may be captured, but detail such as high volumes of taxi traffic to key attractors and transport interchanges (stations, airports, etc.) may not be represented.

There are two levels at which taxis could be modelled, the first as a simple ’pre-load’ within the traffic model (where the impact of taxis on road capacity, traffic queues and vehicle emissions are captured), or as a *bona fide* mode included within the demand model.

If there is a need to improve the representation of taxis (because of their contribution to congestion or because policies to encourage or discourage their use were to be assessed using the model), then a number of choices must be made including:

- Should taxis be treated as a separate user class within the Road Assignment model?
- Can taxis be represented within the PT Assignment model?
- Should a taxi demand matrix be developed to better reflect the base year pattern of taxi trips, and facilitate application of specific growth factors?
- Should taxi trips be included in the demand model, and if so how?
- What data should be used to forecast growth in taxi demand?

Lessons Learnt

Treating taxis as a separate user class for assignment could be useful, but only if reliable base year OD movements can be established. Reasons to consider assigning taxis separately from cars would include:

- Capturing the impact of fares on route choice – either to minimise fare (if the passenger is sufficiently knowledgeable) or to maximise fare (if the driver is unscrupulous);
- Taxis can use bus lanes and so gain a time advantage;
- It may be possible to represent “empty legs” if data suggests that these are significant; and
- The need to model taxis as a bona fide mode becomes more-important if the model is attempting to predict the travel behaviour of ‘visitors’.

PT Assignment models such as Voyager are not configured to allow a comprehensive representation of taxis, even as part of a PT journey. It may be possible to code taxi access links between key attractors and likely catchment areas.

Even if taxi trips were treated as cars within the Assignment and Demand models, there could be merit in building separate taxi matrices. This could improve the spatial detail of taxi demand, e.g. allocating more taxi demand to key transport interchange points (e.g. Dublin Airport or Heuston Station). In this way growth in taxi trips over time could be linked to different factors from those used to predict growth in general car traffic.

Taxis could be included as a separate mode in the demand model. It would be relatively straight forward to extend the mode choice model to include taxi. A calibration exercise would be needed to determine the hierarchy of the mode choice model. If much of the taxi demand was to and from key attractors such as stations or the airport it may not be appropriate to apply a destination choice model.

An overriding consideration should be to consider whether the effort, cost and additional complexity required to model taxis is in proportion to the benefits of doing so for decision makers. Whilst the number of taxi journeys and their impact on congestion is undoubtedly significant in some areas, the significance in a strategic model should be carefully considered.

Recommended Best Practice

- At a minimum the broad volume of taxi demand should be captured in the model by including them when car matrices and trip rates are calculated.
- Explicit representation of taxi in the Regional Modelling System would require development of innovative techniques.

7.4 Freight

Case Studies / References

- Most strategic models include goods vehicles in road assignment but rarely represent a travel demand response. In the UK, it is now best practice to separate light and other vehicles which have different route choice characteristics (TAG Unit 3.19, section 2.6).
- In principle, the quantity and distribution of freight traffic should be influenced to some degree by the time and money costs of travel. SYSTRA have developed models for freight that are responsive to changes in travel costs – including a freight model for Dubai. At present the Dubai freight model is not integrated into the multi-modal model structure, but the client does intend to do so. The Dubai Freight Transport Model DFTM is able to forecast freight movements by road, rail and coastal shipping. Road goods vehicle matrices for four vehicle classes are output for four time periods. The model forecasts freight for ten commodity segments based on future economic and land-use projections, and considers generation, distribution and mode choice.

Possible Approaches

A demand model which is designed to represent personal travel is not directly applicable to goods vehicles. Similar choices are made within the haulage and delivery sectors but there are obvious differences regarding the modes available, constraints on the schedule of deliveries (e.g. supermarkets may require delivery of fresh produce before opening), the role of depots for consolidating or distributing orders, etc. The modelling of goods vehicles should therefore differ to the modelling of personal travel. Developing a bespoke goods vehicle model can be an onerous task, and so the specification should be tailored depending on the importance of freight on the road network, and the intended applications of the model. Issues to consider include:

- The categories of goods vehicles to include;
- What data to use to derive origin-destination patterns?
- Should goods vehicle demand respond to changes in travel costs, and if so, how?
- The source, and spatial and temporal detail, of growth assumptions.

A sample of freight OD patterns will be available from limited roadside interview surveys, but this will not provide full geographic coverage. Relationships between land use quanta (e.g. industrial floor space) and goods vehicle trip making could potentially be established through a bespoke survey programme.

A simple approach to modelling freight demand would be to apply elasticities with respect to GC, or components of GC. A model to predict volumes of goods vehicle, allocation to modes and distribution patterns could be developed.

If a Regional Economics Model is available which may produce a matrix of Production and Consumption of goods, then this may be used as a basis for forecasting. A simpler approach would be to calibrate a relationship between goods vehicle traffic and GDP.

Lessons Learnt

There is a strong case for segmenting goods vehicles in some way because of differences in operating costs, values of time, distribution (OD and time of day) and growth rates. Issues to consider in deciding on the segmentation of vehicle types include the size of each segment (which could be estimated using count data), the data available to forecast freight traffic, and the similarity or otherwise of growth rates (which could be assessed using historic data).

Good data on how freight traffic will change over time may also be sparse. General economic activity will have a strong influence. Changes in logistics practices, increases in internet shopping, etc. will impact on freight movements and the mix of light and heavier vehicles. The level of spatial detail available for forecasting is unlikely to match the model zoning system.

Own cost elasticity models for goods vehicles would give a broad-brush assessment of how changes in costs affect demand. A limitation is that elasticity models cannot represent spatial or temporal redistribution. The demand for an option will not change if the cost for this option does not change, even if the costs for competing options do change. For example if peak hour congestion increased an elasticity model could not re-allocate demand to the off peak period.

Developing a model for Dublin, for example, which is similar to that for Dubai would require bespoke research and data collection.

Recommended Best Practice

- Goods vehicles demand must be included in the assignment models.
- Goods vehicles (OGV1 & OGV2) should be represented separately from light goods vehicles.
- The latter may be combined with in-work cars, if necessary.
- Development of a bespoke freight demand model would be possible but time and resource intensive.
- Elasticity models are poor proxies for travel choices as they cannot represent choice between alternatives.

7.5 Airport Surface Access

Case Studies / References

- Most general purpose strategic models of urban areas include separate zones for airports and apply the airport operator or government growth aviation passenger forecasts to access demand. The models of Greater Manchester and South Hampshire follow this approach. In the Greater Manchester model, airport demand is treated as a separate demand segment for which destination choice is unavailable.
- Other models, in particular those which are developed specifically for airport planning, include bespoke mode choice models which take account of the characteristics of air travellers, as summarised above. An example of this is the London Airports Strategic Access Model.
- No strategic urban transport models have been identified which incorporate a mechanism to predict the choice of airport.

Possible Approaches

It is possible to treat the airport zone in the same way as other zones, perhaps with a special approach to predicting future growth in the level of demand to/from this zone.

However, there are a number of features of travel to/from an airport which require more-sophisticated consideration if the model is to be used to design or appraise changes in infrastructure or policy associated with the surface access to the airport. These differences include the higher-than-average proportion of visitors (with limited knowledge of transport choices), the impact of luggage on mode choice, the non-standard segmentation of the travel demand, differences in the value of time and perceived reliability (by direction of travel), non-standard time of day profiles, non-standard car availability (including the impact of taxis, car hire, the costs of short and long-stay car-parking etc.). Decisions to be made in relation to modelling surface access to Dublin Airport include:

- What data to use to derive origin-destination patterns?

- Should air passenger trips be treated as a separate purpose?
- Should air passengers traffic be included in the demand model, and if so should the demand model be amended for this group?
- What data will be used to forecast air passengers and employees over time?
- Should the choice of airport (e.g. between Cork, Dublin, Shannon and Belfast) be modelled within the regional modelling system and be treated as an exogenous variable?

Many international airports undertake surveys of their passengers to understand their patterns of travel to or from the airport, the modes they use, and what time of day they travel. In addition, their reasons for air travel are often recorded in such surveys.

There are good reasons to treat airport passengers differently to other trip makers in the demand model. Re-distribution to non-airport zones should be avoided. Factors which influence air passengers' choice of access/egress mode are somewhat different to those influencing other trip makers and include taking account of kiss-and-fly, group size, the cost of access/egress compared to air fares, etc. There are established processes for bespoke airport mode choice modelling.

National governments and / or bodies in charge of managing Airports often require forecasts of aviation demand for planning and policy purposes. If such data are available then these could be used as a basis for forecasting airport access demand.

Lessons Learnt

Restricting surface transport choices available to air passengers aids the realism of forecasts. In particular air passengers should not be allowed to change destination to a non-airport zone.

Forecast changes in air passenger numbers can be reasonably used to forecast changes on the volumes of passengers accessing the airport. Care should be taken to exclude transfer passengers from such forecasts. The number of airport employees may not change in the same proportion as the number of air passengers.

Choice of airport will be determined by many factors which cannot be represented in a surface travel model, e.g. which destinations are served, flight prices, flight schedules, the quality of the airport experience, etc. Developing a model of airport choice would be a very significant task.

Recommended Best Practice

- If available from airport surveys, data on the landside origin or destination of travel to the airport should be used. Similarly, the

Airport Authority may hold data on the home location or employees, and the POWSCAR data also provides this information.

- Airport related travel should be excluded from destination choice. Consideration could be given to refining the mode choice model for air passenger surface access if the volumes were significant or the model is to be used to test measures which would affect such choices.
- Forecasts of air passenger travel should be obtained as a basis for forecasting surface access.

8 Appraisal and Other Post-Assignment Utilities

8.1 Introduction

Model outputs will be used in analyses of the impacts of transport, and transport related interventions, on issues which affect the population's wellbeing, quality of life and wealth. Facilities are required to efficiently and consistently calculate indicators of such issues. The following impacts can be informed by model outputs (travel costs, demands and flows):

- Social economic and financial appraisal;
- Road safety and accidents;
- Environmental impacts: noise, local air quality and carbon; and
- Fitness benefits of more use of active travel modes.

Options for post model utilities to calculate indicators of these impacts are discussed in this chapter.

8.2 Economic and Financial Appraisal

Case Studies / References

- Detailed guidance on the appraisal of the above impacts is provided in TAG Units 3.5.X.
- National Roads Authority (NRA) Project Appraisal Guidelines (PAG), Unit 6.0 Cost Benefit Analysis[39].
- The Department of Transport, Tourism and Sport (DTTAS) Guidelines on a Common Appraisal Framework for Transport Projects and Programmes[40].

Possible Approaches

Economic appraisal could consider issues such as[41]:

- Travel time and cost benefits to users of transport networks;
- Impacts on transport provides from changes in costs or revenues (e.g. fares and parking charges);
- Impact on public sector tax and duty yields;
- Reliability benefits; and

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[39] http://www.nra.ie/policy-publications/project-appraisal-guideli/

[40] http://www.transport.ie/upload/general/11801-DOT_COMMON_APPRAISAL_FRAMEWORK1-0.PDF

[41] Drawn from TAG Unit 3.5 and the Knowledgebase on Sustainable Urban Land use and Transport (Konsult) project (www.konsult.leeds.ac.uk) which was developed with the support of the European Commission, the UK Department for Transport, the Engineering and Physical Sciences Research Council and the Rees Jeffreys Road Fund.

- Wider impacts on jobs, incomes and business efficiency.

Capital costs are not related directly to model outputs such as travel times and demand and so are not considered here.

Lessons Learnt

User benefits can be calculated using either cost and demand matrices, or aggregate network statistics such as vehicle hours and kilometres. When a variable demand model is used (which is assumed to be the case for the regional modelling system) a matrix based approach is necessary. For example a new road may induce traffic which could result in more vehicle hours even if the average travel time for each driver reduced. A matrix based approach to calculate the change in consumer surplus is required. The NRA's PAG and the UK TAG recommend using the "rule of half" approach for this calculation where:

- **Benefits** = 0.5 x [$\text{Demand}_{\text{Do Minimum}}$ + $\text{Demand}_{\text{Do Something}}$] x [$\text{Cost}_{\text{Do Minimum}}$ – $\text{Cost}_{\text{Do Something}}$]

Benefits must be calculated for the duration of the agreed appraisal period. (The NRA's PAG recommends a 30-year appraisal period for road schemes while the UK DfT recommends a 60 year appraisal period for most transport schemes). This leads to a requirement for the application of discount rates for future years to convert to Present Value. Typically transport models are run for 2 or 3 future years. Benefits for years which are not modelled are calculated by interpolation or extrapolation. Appropriate vehicle operating costs and values of time must be applied for each appraisal year. These calculations are in principle straight forward and could be implemented in a bespoke database or software system. A spreadsheet approach would be unwieldy due to the size of the datasets which are related to the square of the number of zones, number of years and number of demand segments. DfT's TUBA software could potentially be used but should be reviewed to ensure that it can represent the Irish context, such as tax and duty regimes. The NRA have developed guidance for using TUBA for road scheme appraisal.

A simple utility to output demand and cost matrices in a format that can be read by TUBA or a bespoke alternative will be required. Most transport modelling suites provide facilities to do this.

Analysts can find it challenging to interpret appraisal outputs. For example is €200m of benefits over 30 years a plausible result? Economic appraisals can also be strongly influenced by instability in assignments or assignments for the without-scheme and with-scheme scenarios converging to different solutions, leading to apparently significant benefits and disbenefits in locations which in reality are unlikely to be within the sphere of influence of the scheme being tested.

For these reasons the utility developed to undertake economic appraisals must provide facilities to analyse the results by zone, sector, demand segment, year, time period and so on. It is very useful to be able to analyse benefits per user to understand if the scale of benefits is plausible. Such outputs can also be used to explain appraisal results to non-modellers. One way of analysing the impacts of instability in model results is to calculate the "economic benefits" implied by two consecutive loops of the demand model for the same scenario.

Impacts on transport providers could include changes in fare revenues, bus operating costs, parking revenue, tolls, etc. These could be calculated from aggregate network statistics as all that is required is an understanding of how total costs or revenues change. Matrix based calculations can also be used, and may be most convenient as it is easy to extend the utility for calculating user benefits to derive transport provider impacts. Changes in public sector tax or duty yields can be calculated in a similar manner.

TAG Unit 3.5.7[42] recommends an approach to calculating benefits of road travel time reliability. In brief, the approach estimates the standard deviation of travel time as a function of average speed (as calculated in the road network model) and applies a willingness to pay for reliability factor. The calculations use the same inputs as transport user benefits and can be implemented using TUBA (or a similar utility) and by making simple arithmetic transformations using standard matrix manipulation facilities within the modelling software.

Wider economic impacts include a range of factors which are of great importance to policy makers, business and the general public including:

- Agglomeration – efficiencies created by ease of interaction between businesses;
- Economic productivity; and
- Labour market changes.

Agglomeration is generally the largest of these impacts. It is calculated as a function of the percentage change in "effective density" for a zone. Effective density is a measure of how efficiently workers can access a zone, and can be calculated using generalised cost matrices and zonal employment data. Because the calculation uses percentage change in effective density it can result in implausible benefits in cases where the GC of travel between neighbouring zones changes by a small amount (in minutes) but by a large percentage. This can happen when delays at a single junction change significantly. It has also been found that small changes in GCs from an area where a scheme is located to areas with high levels of employment (e.g. improving access to a motorway in the north of England which can be used to travel towards London) can produce implausibly large benefits. DfT's WITA software can be used to calculate wider economic impacts using the same inputs as TUBA, but does not provide effective means to

[42] http://www.dft.gov.uk/webtag/documents/expert/unit3.5.7.php

interrogate results in detail. For this reason bespoke database or software approaches may be preferred.

Recommended Best Practice

- A utility to calculate and analyse user benefits based on model demand and cost matrices is required. TUBA should be reviewed to determine if it is suitable. It is most convenient to use the same utility to calculate transport provider and public sector impacts.
- Reliability benefits can be very significant. An approach based on Unit TAG 3.5.7 can be applied. If so research into appropriate parameters, in particular the willingness to pay for reliability, in Ireland will be required.
- Wider economic impacts are of great interest to policy makers. Consideration should be given to implementing an approach similar to that set out in TAG Unit 3.5.14[43], NRA PAG Unit 6.8 and DTTAS Guidelines on a Common Appraisal Framework for Transport Projects and Programmes.

8.3 Road Safety

Case Studies / References

The UK DfT has developed a computer programme called COBA to estimate the number, and severity of accidents. Monetary valuations of the actual costs of accidents and willingness to pay to prevent accidents are also applied. TAG Unit 3.4.1[44] documents the COBA approach. In summary the approach to calculating road safety benefits is:

- Define accident rates (per vehicle km for each type of accident) which vary by type, age and standard of road;
- Define the values of accidents including the actual costs of repairing damage and police time, etc. and the price that the public is prepared to pay to prevent accidents (elicited using stated preference techniques);
- Extract flows from the model; and
- Use COBA to apply accident rates and values to flows to calculate the number and value of accidents.

Unit 3.4.1 includes data on how accident rates are predicted to decline over time.

[43] TAG unit 3.5.14 provides guidance on the appraisal of wider economic impacts http://www.dft.gov.uk/webtag/documents/expert/unit3.5.14.php

[44] http://www.dft.gov.uk/webtag/documents/expert/pdf/u3_4_1-accidents-120817.pdf

To use COBA, the modelled road network must be converted to a specific format and flows extracted. A SATURN facility known as SATCOBA facilitates this process. A road type must be allocated to each link in the network.

It is possible to amend accident rates in COBA to reflect local data. Care must be taken to ensure that there is a statistically significant sample of accidents. It is generally better to use accident rates from a wider area so that a representative sample is obtained.

As with economic appraisal it is necessary to interpolate and/or extrapolate accident numbers and valuations and apply discount rates in order to calculate the total present value of benefits over an appraisal period. DfT recommend that the willingness to pay to prevent accidents and costs of accidents are increased at the same rate as values of time based on GDP per capita.

A specific version of the COBA software has been developed by Transport Research Laboratory (TRL) for use on road schemes in the Republic of Ireland[45]. Guidance on the use of COBA software in the Irish context is included in the NRA PAG.

Possible Approaches

Road traffic accidents are understandably a focus of the public and policy makers. Link or turn flows extracted from the model can be used to calculate the number of accidents, by severity category (e.g. minor, serious injury, fatality) in future years, and how interventions will change accident occurrence.

Lessons Learnt

The COBA approach is well established and robust. It would be appropriate to derive accident rates (per vehicle kilometre) for each severity class, and willingness to pay to prevent accidents, from Irish data.

Recommended Best Practice

- COBA should be used in the Irish context using accident rates and valuations derived based on Irish data.

8.4 Environmental

Case Studies / References

- Environmental Protection Agency (EPA) Guidelines on the information to be contained in Environmental Impact Statements[46];

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[45] A report prepared by the TRL documenting the development of the Irish COBA is included as PAG Unit 6.3: TRL COBA Report

[46] http://www.epa.ie/pubs/advice/ea/guidelines/EPA_Guidelines_EIS_2002.pdf

- EPA Advice notes on current practices in the preparation of Environmental Impact Statements[47];
- Detailed guidance on the appraisal of environmental impacts is provided in TAG Units 3.3.X;
- Continued exposure to excessive levels of noise can cause stress and displeasure. An estimate of traffic induced noise at a given distance from a road centre line can be calculated for each model link as a function of flows, the proportion of heavy goods vehicles, speed and distance. DfT's "Calculation of Road Traffic Noise" (CRTN)[48] provides approaches and parameters for these calculations;
- In the UK, data are available on the co-ordinates of postcode centroids and the number of residential addresses for each post code. These data can be used to calculate the distance between each postcode and each link. Average household size data can be used to estimate populations in each distance band. The number of people exposed to varying levels of noise can therefore be estimated;
- Different people find different levels of noise annoying. Tables of the proportion of the population annoyed by increasing levels of road noise are provided in TAG Unit 3.3.2[49];
- In the UK, willingness to pay to avoid noise (£ per dB change, which depends on the do minimum noise level) has been estimated from an analysis of noise levels and house prices. This allows for a monetary value to be placed on exposure to noise. DfT provides a spreadsheet to implement the calculation of noise valuation over a 60-year appraisal period;
- The approach to calculating the number of people annoyed by noise and the values of changes in noise levels described above does not take full account of factors such as barriers or the sound absorbent characteristics of the landscape and buildings. CRTN provides advice on how to take account of such factors;
- TAG Unit 3.3.3[50] describes an approach to calculating the exposure to pollutants which affect local air quality (NOx, CO, PM10 and volatile organic compounds) which is relatively straight forward to implement using road network model outputs. In outline, the approaches to calculating concentrations and exposure are as follows:

[47] http://www.epa.ie/pubs/advice/ea/guidelines/EPA_advice_on_EIS_2003.pdf

[48] http://www.noiseni.co.uk/calculation_of_road_traffic_noise.pdf

[49] http://www.dft.gov.uk/webtag/documents/expert/unit3.3.2.php

[50] www.dft.gov.uk/webtag/documents/expert/unit3.3.3.php

- Calculate emissions of NOx, CO and PM10 for each link as a function of link flows, percentage of heavy vehicles and speeds (DfT provide a spreadsheet for this purpose[51]);
- Sum emissions for each zone; and
- Calculate the population exposed to an improvement or worsening of air quality as a result of an intervention.

The DTTAS 'Guidelines on a Common Appraisal Framework for Transport Projects and Programmes' outlines monetary values to be applied to specific road transport emissions in Ireland.

The approach to calculating exposure to pollutants described above does not take account of local conditions such as wind direction, topography, etc.

Greenhouse gas (GHG) emissions are also calculated based on traffic flows, proportions of heavy vehicles, speeds and emissions rates. GHG emissions can either be calculated from matrix or link inputs. TUBA calculates GHG emissions on a matrix basis and applies monetary values per tonne of carbon. TUBA also interpolates and extrapolates from modelled years and applies discount rates to calculate the Present Value of GHG emissions. DfT's emissions spreadsheet performs GHG emissions on a link basis but does not calculate the Present Value.

DfT provide spreadsheets to calculate the link based environmental impacts with inputs extracted from road network models. SYSTRA's ENEVAL software applies the same approaches in a GIS environment which facilitates map based presentation of environmental impacts. There is less need for spatial analyses of GHG emissions as the impacts are global rather than local.

Possible Approaches

TAG Unit 3.3.1 and Konsult recommend that the following environmental impacts of transport are considered by decision makers:

- Noise;
- Local air quality; and
- Greenhouse gases.

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[51] www.dft.gov.uk/ha/standards/guidance/air-quality.htm

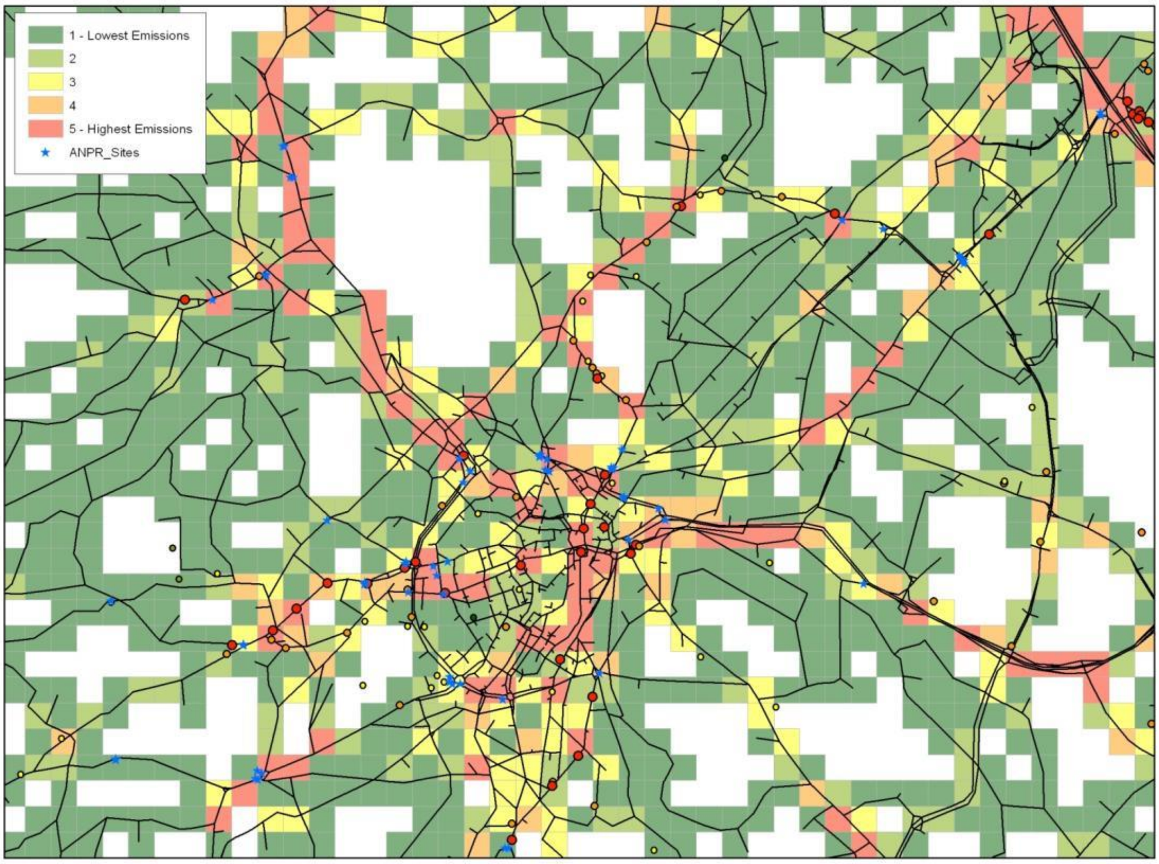

Figure 8.1 ENEVAL Output Example

Lessons Learnt

Simplified approaches to calculating road traffic noise can be automated quite readily. In order to take full account of how landscape and buildings affect noise levels a more detailed approach would be required.

It is relatively straightforward to implement a simplified approach to estimating exposure to pollutants. Specialist software has been developed to calculate exposure, taking account of factors such as wind direction and topography. Such software generally uses different network definitions than the road network model, e.g. links may be shaped rather than straight and the link and node structure may differ. From experience it can be time consuming to define the equivalence between the environmental and transport model networks.

Environmental calculations would be more accurate if estimates of acceleration, cruise speed and deceleration were available. Such information could be obtained from micro-simulation models but not marco-scopic models such as SATURN.

GHG emissions rates are related to speed in a non-linear manner. With a matrix based approach to GHG calculation (as with TUBA) an average speed is calculated between the origin and destination zones. GHG calculations which take account of the speed on individual link speeds will be more accurate than a matrix based approach (as used in TUBA).

Recommended Best Practice

- Simplified approaches to calculating noise and exposure to pollutants could be implemented to allow for quick assessments of air quality impacts. Use of specialist software could be considered for more definitive assessments to inform final decisions and statutory processes.
- A link-based approach to calculating GHG emissions is more accurate than the matrix based approach implemented in TUBA.
- Parameters which reflect the emissions and noise characteristics and rates of the Irish fleet should be established.

8.5 Physical Fitness

Case Studies / References

If walk and cycle demand and costs (walk times and or distances) are included in the transport model then the number of people walking or cycling for more than 30 minutes can be estimated.

The World Health Organisation (WHO) Health and Economic Assessment Tool (HEAT) methodology[52,53] calculates the changes in mortality arising from a predicted change in walking or cycling. The relationship between activity levels and mortality have been established through nine international studies for walking and one (Copenhagen) for cycling. HEAT requires data on the duration or distance walked or cycled and the numbers of people doing so. The economic value of life (as discussed in the context of traffic accidents in Section 8.3) can be applied to monetise the benefits or reduced mortality. The HEAT website includes an interactive tool for the mortality calculations.

Possible Approaches

Policy makers are often interested in how transport policy can affect health and physical fitness. This concern is driven by factors such as the aging population, increasing levels of obesity and high health care costs. “Smarter Travel” approaches have been developed in part to address these health objectives.

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52 http://www.heatwalkingcycling.org

53 http://www.euro.who.int/en/health-topics/environment-and-health/Transport-and-health/activities/guidance-and-tools/health-economic-assessment-tool-heat-for-cycling-and-walking

The UK DfT propose two methods to assess the impacts transport on physical fitness:

- Estimating the number of people who walk or cycle for more than 30 minutes (in total) a day as described in TAG Unit 3.3.12[54]; and
- The World Health Organisation (WHO) Health and Economic Assessment Tool (HEAT) for walking and cycling (documented in TAG Unit 3.14.1[55] and www.heatwalkingcycling.org).

Lessons Learnt

Both of the approaches are straightforward to implement. The advantage of the HEAT approach is that it provides numeric estimates of impacts on mortality rates and the monetary value of these impacts.

The web-based HEAT tool is easy to use but only provides for calculations based on a single set of before and after travel times or distances. This single set could be representative of an entire study area or a single zone-pair. If the HEAT approach was to be adopted, there would be advantages in creating a spreadsheet (or similar) tool which could process numerous data points (e.g. every zone pair) and allowing for inputs, calculations and outputs to be stored for future checking and analyses.

HEAT does not provide estimates of how improved fitness improves quality of life through reduced illness or enhanced physical capability (e.g. better sporting performance, ability to play with one's children, running for a bus, etc.).

Recommended Best Practice

- The model's appraisal modules should include an ability to capture the health-related benefits of the resulting increase in walking and cycling, using the methodology set out in the World Health Organisation's Health Economic Assessment Tools (HEAT) for walking and cycling.
- The model documentation should provide guidance on the use of these HEAT-based appraisal tools.

[54] www.dft.gov.uk/webtag/documents/expert/pdf/unit3.3.12.pdf

[55] www.dft.gov.uk/webtag/documents/expert/pdf/unit3.3.12.pdf

9 Summary of Best Practice Approach Recommendations

9.1 Summary of Recommendations

The following are a summary of the best practice recommendations for the development of a regional transport model:

9.1.1 Trip End Model

- A Trip Generation model which develops estimates of total travel to and from each zone is an essential component of the transport forecasting model and must be sensitive to variables such as population, employment and other activity generators. It is best practice to estimate daily trip rates using local travel diary surveys for disaggregate demand segments. The definition of segments should be determined by statistical analysis of how socio-economic categories affect trip rates.
- If possible analysis of historic and recent travel surveys should be undertaken to establish whether all mode trip rates can be assumed to remain constant over time, or should be increased or decreased.
- There must be a high degree of consistency between base year trip ends and OD matrices using the network models. Without such consistency there is a risk that forecast changes in trip ends do not get translated to plausible forecast matrices.
- Checks of consistency with trip ends and land use data should be built into the matrix development steps. Means to adjust matrices to better match trip ends should be considered. Care should be taken that any matrix calibration (e.g. using matrix estimation) does not unduly disturb this consistency.
- A detailed specification of the Trip End model is required including considerations such as segmentation and how car ownership / availability forecasts are developed.

9.1.2 Car Ownership Model

- A method to forecast future car availability is required as it has an impact on numerous aspects of travel behaviour, including trip rates, mode choice, destination choice, trip length distributions etc.
- Competition for car is generally a better indicator of travel behaviour than household car ownership.
- A car ownership model could be calibrated using Census data.

9.1.3 Demand Model

Representation of Travel Demand

- Tours and all day modelling are recommended to enable more accurate mode choice modelling to be included, particularly in the PM Peak.
- PA modelling is the minimum standard for major urban demand models. The OD format should not be considered because it does not provide an internally consistent basis for choice modelling, or support the application of growth forecasts based on population or jobs.
- Simple tour modelling is well established and offers benefits in consistency of time of day response and in the modelling of parking capacity.
- Complex tours modelling would provide enhanced functionality over the Simple Tour approach as intermediate stops, such as school runs or visiting friends after work, can be treated in a consistent manner to the main journeys. Analysis of travel diary surveys should be undertaken to determine how many journeys and trip kilometres are related to complex tours rather than simple 2-way home based journeys.
- Whichever approach to representing demand is adopted, matrices should be developed based on recent information (TAG Unit 3.19 recommends that data should be no older than 6 years). In Ireland data is available from the national censuses which can facilitate development of travel matrices for commute and education purposes which are based on near-100% countrywide samples. Direct observation of travel patterns (e.g. based on roadside or public transport passenger interviews) is expensive and disruptive but is good practice, at least for an area related to a scheme or policy which is to be appraised. Data sources such as public transport ticket sales and mobile phone tracking can also be used in the development of matrices. Further consideration is given to the data which may be used to develop matrices in Scoping Report 4.
- Developing an activity model would be risky due to the high costs, extended timescales, and reliance on very detailed data for calibration and forecasting. The calculation intensity of such approaches could lead to lengthy model run times.

Trip Frequency

- A trip frequency response is unlikely to be required if walking and cycling modes are included in the mode choice stage.

Mode Choice

- Mode choice modelling is very well established and must be included in the Regional Modelling System if it is to be used to assess the merits of public transport investment.
- A discrete choice formulation of mode choice should be adopted.
- Undertaking sub-mode choice using the PT assignment step is the most commonly adopted approach, avoids complication and excessive run times, and offers a more realistic simulation of how travellers choose routes than a logit allocation between modes.

Destination Choice

- Zone cloning functionality should be provided to facilitate the creation of travel patterns for greenfield developments (i.e. where the current base year travel pattern to a zone cannot provide a robust starting point for the demand model, but the base-year pattern of travel to/from some other zones can be used to provide this starting point.
- Logit destination choice approaches should be the standard approach for common land use categories.
- It is good practice to constrain the destination choice models so that the total productions from each zone cannot change in response to changes in GCs.
- Commute and education distributions should be doubly constrained. Sensitivity parameters should be calibrated using data from the GDA if possible. The statistical calibration process should include analyses of whether sensitivity parameters are significantly different for different areas.
- As part of the matrix development process, the consistency between assignment and demand model matrices should be analysed.
- Readily repeatable processes, making use of GIS plots, should be implemented to report on the output distributions to ensure the model is predicting realistic travel patterns.

Time of Day Choice

- Macro time of day choice has become standard practice and can be readily implemented to reflect how travel timing would change over time in response to relative changes in Generalised Cost (GC) between broad time periods, e.g. constraints on growth in peak periods.
- The benefits of modelling micro time of day choice need to be carefully assessed against the dis-benefits of increased model run times.

Parking & Park and Ride

- It is best practice to include explicit representation of park-and-ride (P&R) choice as part of the demand model in cities where this option is available or likely to be considered.
- Adding parking supply constraints to the model can increase the need for iteration of the demand model and hence run times. The benefits of improving the modelling of capacity issues should be carefully considered, e.g. by reviewing data on the occupancy of P&R sites, and weighed up against run time implications.

Vehicle Occupancy

- Average vehicle occupancies for the base year should be determined from travel diary and/or roadside interview surveys. Variations in occupancy rates by journey purpose and potentially other demand segments such as household car availability should be explored. Analysis of how occupancies have changed over time or are related to other variables which may be available for forecasting should be undertaken.
- Making car occupancy sensitive to GCs is possible as an extension of mode choice modelling, if the merits of doing so outweigh the disadvantage of increased run times and complexity.

Ticket Type Choice (Public Transport)

- Ticket type choice could be included in the NTA's regional modelling system if the merits of doing so outweigh the disadvantage of increased run time.

Smarter Travel Choices

- Applying post demand model adjustments directly to the assignment matrices in order to replicate observed impacts of smarter travel policies is the most straightforward approach as it does not require calibration of adjustment factors. If evidence becomes available on how the impacts of smarter travel choices changes over time then the matrix adjustments could be modified between forecast years (e.g. reduced if the evidence shows that impacts are not sustained, or increased if evidence shows that the changed attitudes propagate).

Generalised Cost Formulation

- The linear sum form for calculating GC is used very widely. GC coefficients should be developed from data (RP or SP, fuel consumption and prices, incomes, etc.) specific to the local conditions of each regional modelling area, if possible.
- The model scripts should be flexible enough to allow for cost damping to be applied should calibration or demonstration testing indicate that it is required.

Parameters for Choice Models

- In principle a bespoke and locally based parameter calibration exercise is preferable so that the models accurately reflect the behaviours and preferences of travellers in Dublin.
- Existing models of Dublin and the national model could be sources of (and/or starting points for the estimation of) parameters for the regional modelling system, provided that the relevant parameters have a reasonable evidence base.
- Values and parameters from elsewhere could be used to supplement these values as required.

Choice Model Forms

- Incremental models are recommended for main mode, destination and time of day choice (i.e. where it is reasonable to forecast the future-year Do Something demand as 'incremental' changes to the base year pattern).
- Parking and Park-and-Ride location choice modelling are likely to require an absolute form of choice modelling, since the relevant base year OD patterns for users of the various parking locations are unlikely to exist.
- Additional 'absolute' choice modelling functionality may be required If the model is to be used for testing greenfield developments or other land-use changes where the base year pattern does not provide a robust pattern from which to estimate the future demand.
- The 'observed' (network assignment) and synthetic (demand model) demand matrices should be as consistent as possible, to maximise the numerical stability of whichever approach is used to convert changes in land-use or transport supply into corresponding changes in demand.

Demand Segmentation

- Demand must be segmented by car ownership or, preferably, competition.
- At a minimum employers business trips should be separated from other segments due to differences in value of time.
- If demand is represented using PA, simple or complex tour formats then home-based and non-home-based demand should be segmented.
- It is good practice to separate commute, education, shopping and other purposes. Such segmentation means that changes in demand for each segment can be forecast using the most appropriate data such as job numbers, school places or retail floorspace.
- As there are tolled motorways in the regional modelled areas there may be a case for segmenting by a measure of income or willingness to pay.

- The required level of segmentation should be considered for each model component, e.g. trip generation, demand and assignment models.

Time Periods

- The “modelled day” should be long enough so that the majority of linked activities (e.g. to and from work trips) can be modelled consistently.
- A number of time periods should be defined in the model to represent slices of the day with broadly homogenous travel conditions.
- At a minimum it is advisable to include 4 time periods to reflect changing travel conditions across the day: AM peak, inter peak, PM peak and off-peak (rest of day). It may not be necessary to model the off peak in as much detail as the other periods if it can be assumed that there will be minimal congestion or there is less data to support the development and validation of off peak demand matrices.
- Increasing the number of time periods to separate pre-peak, peak and post-peak hours has advantages, but would lead to increases in run times.

Demand / Supply Convergence

- A measure of demand / supply convergence is essential and % Gap is suitable because it takes account of both demand and cost changes. Demand and, particularly, cost changes influence economic appraisal results.
- The model system should include some method for damping cost changes between loops. However in the initial model testing phase it would be useful to experiment without damping to identify if there are any inherent discrepancies between demand or supply.
- Targets for % Gap should be developed which are appropriate for the regional modelling system and the model’s intended applications.

Calibration / Demonstration Tests

- The fuel and PT fare elasticities implied by the model should be established. Plausible variations between demand segments should be obtained. In general it is expected that the elasticities for business trips would be lowest as sensitivity to travel costs is low. Elasticities for discretionary purposes such as leisure should be highest, and elasticities for commuting and education between those for business and leisure.
- A series of incremental demonstration tests should be run to understand how the model responds to changes in each type of input.

9.1.4 Road Network Model

Demand Segmentation

- Goods vehicles (OGV1 & OGV2) should be represented as separate categories.
- It may be acceptable to combine light goods vehicle trips with a car user class if the values of time and vehicle operating costs are similar.
- Employers' business car trips should be a separate segment.
- The need for further segmentation by purpose should be determined once values of time and vehicle operating costs for each purpose are established.
- Segmentation by a measure of income is particularly beneficial in models which include toll roads.

Time Periods

- At a minimum the assignment model should be developed for three time periods. Assignment of a representative peak hour (disconnected from actual times) is preferred to either factors relating to an actual time (say 0800-0900) and to simple arithmetic averages of the peak period. Analyses of traffic count data or travel diary records can inform the specification of period to peak hour factors.
- Introducing pre- and post-peak shoulder hours would greatly increase model runs times and is most justified if parking or time of day choice is to be modelled in detail or policies which affect each of these detailed time periods are to be tested.

Zones

- Zones should be smaller in main area where analysis is required and proposals will be tested, and become progressively larger with distance from this area. Guidance on number of trips per zone should be developed by considering the maximum number of zones that is desirable to achieve the required run times and the total level of trip making in each regional modelled area.
- It is beneficial for model zones to be either subdivisions or collections of administrative or census areas.
- Zone boundaries should respect barriers to travel so that trips from each zone can be accurately loaded to the modelled network.
- Large car parks or groups of car parks should be allocated to separate zones.

Networks

- Network detail should be greatest where most roads may be included. Detail should become progressively lower as distance from the congested urban area increases. Guidelines for which road classes to include in which area of the model should be agreed.

- In principle junction characteristics such as saturation flow should be coded based on the geometry and research such as that published by TRL.

Assignment Routines

- Travel times are sensitive to assigned traffic volumes. Changing travel times as flows change implies an iterative method.
- Junction modelling should be used to replicate how interactions between traffic streams at junctions affect delays. Possible use of link speed-flow on limited access roads (e.g. motorways) and outside of congested urban area.
- Flow metering and blocking back facilities should be utilised if possible.

Assignment Parameters

- Values of time and vehicle operating costs used in the road network model should be consistent with those in the demand model. If not, there is a potential that a reduced GC in the assignment model could be translated to an increased GC in the demand model (if the balance of value of time and vehicle operating costs are different in the two models). This would lead to an implausible reduction in demand as a result of increased GC (or vice versa).

Convergence

- Costs are a key input to economic appraisal and must be captured by the convergence measure. The %gap measure (which compares the change in total demand-weighted generalised costs between one iteration and the next) reflects both flows and costs and provides a better measure of convergence than %flows.
- A target for the level of the %gap-based convergence and the number of successive iterations which achieves this target level should be specified, as part of the model documentation.
- Standard methods to present and analyse the benefits of tested interventions are required. These should include methods to display the spatial distribution of benefits to demonstrate the plausibility of the results. The same types of plots can be used to analyse the location and scale of instability in flows and costs.
- In order to determine appropriate convergence targets sample schemes should be tested in the assignment model at various levels of convergence and economic and environmental analyses undertaken. In this way the level of assignment convergence required to achieve stable results can be determined.

Validation

- Flows and journey times must both be validated against a comprehensive set of observed data. Validation criteria and targets should be agreed in advance.
- If (as is likely) the validation targets are not met using unadjusted matrices then matrix estimation should be used to ensure acceptable replication of counted traffic. Network checks should be undertaken, and any necessary corrections made, before matrix estimation is used. If matrix estimation is used then changes to the matrix should be monitored. It is desirable to ensure that assignment matrix trip ends remain consistent with the demand model matrices.
- Counts used for calibration should not be used for validation.
- Matrices should be compared with total screenline crossing early in the validation process and broad-brush matrix adjustments considered. This can be done before routes have been validated.
- Routes for a selection of zone-pairs should be reviewed based on local knowledge.
- Vehicle / mobile device tracking based journey time data has been used extensively for validation in recent years because it can provide a larger sample than Moving Car Observer (MCO) methods. Initial analysis of the vehicle / mobile device tracking data should be undertaken to understand if there is any evident biases.
- Demonstration tests should be undertaken before the validation is considered complete.
- If possible (i.e. if the relevant historic data needed to specify the relevant inputs and validate the outputs of this test exist), a ‘backcast’ representing travel conditions a number of years prior to the model’s base year should be undertaken.

9.1.5 Public Transport Network Model

Demand Segmentation

- The proportions of public transport demand in each car ownership or availability and purpose category, and the differences in values of time between categories should be reviewed. If there are categories which represent a high proportion of PT demand and which have values of time that are significantly different from the average then there may be justification for segmenting the assignments.
- Segmentation by ticket or fare category is recommended in principle but the impacts of this segmentation on run times and the availability of data to segment demand reliably should be considered before a decision is made.

Time Periods

- At a minimum there should be sufficient time periods to reflect the main differences in PT (frequency, journey times, fares etc.) across the day.
- Representation of crowding in PT assignments is recommended. Without crowding choice of assignment period is less important as routes and GCs are likely to be similar in peak periods and peak hours.

Zones

- WebTAG Unit 3.11.1 advises the use of the same zone system in the demand, road network and PT network assignments to achieve the greatest precision in assignments and demand responses.
- UK WebTAG's Unit 3.11.1 advice of consistency with administrative boundaries, respect for barriers to travel, homogeneity of land use, and representing access to different PT services should be followed. The recommended approach for zone delineation is adapted from Cambridge Systematics, Inc. white paper titled "A Recommended Approach to Delineating Traffic Analysis Zones in Florida"

Networks

- The road and PT networks should have the same node and link structures, with the addition of rail, tram and walk links to the PT network.

Assignment Routines

- A frequency-based (rather than a detailed journey-planning style timetable-based) approach is likely to be appropriate in the Dublin context with frequent services which will be affected by road conditions.
- Modelling crowding adds a high degree of complication and run time to a model system, and results may not be accurate unless the number of modelled periods is increased so that 15 or 30 minute periods are represented.

Assignment Parameters

- GC coefficients and sensitivity parameters should be developed from data (RP or SP, incomes, etc.) specific to each regional model area if possible.

Validation and Demonstration Testing

- Flows should be validated against a comprehensive set of observed data. Validation criteria and targets should be agreed in advance.
- If (as is likely) the validation targets are not met using unadjusted matrices then matrix estimation should be used to ensure acceptable replication of counted patronage. Network and service coding checks

should be undertaken, and any necessary corrections made, before matrix estimation is used. Changes to assignment algorithms and parameters may also be considered. If matrix estimation is used then changes to the matrix should be monitored. It is desirable to ensure that assignment matrix trip ends remain consistent with the demand model matrices and land use.
- Routes for a selection of zone-pairs should be reviewed based on local knowledge.
- If possible (i.e. if the relevant historic data needed to specify the relevant inputs and validate the outputs of this test exist), a 'backcast' representing travel conditions a number of years prior to the model's base year should be undertaken.

9.1.6 Other Modes of Transport

Active Modes

- Walking and cycling demand should be included in the demand model in order to improve the realism of travel choices, e.g. to allow for switching of shorter walk or cycle trips to public transport or vice versa.
- Walking and cycling matrices should be derived separately because they have different travel patterns, in particular trip length.
- POWSCAR data can be used to derive walk and cycle matrices for commute. Synthetic distribution models can be calibrated for walking and cycling to match observed trip length distributions.
- The impact of cycle lanes on road capacity should be included in the traffic model, but the impact of the bicycles (or pedestrians) on road and junction capacity need not modelled;
- The model should include an ability to assign the cycling matrix to the road and cycle network, using shortest paths which, if possible, take account of some of the main attributes known to affect cyclists route choice – however, this assignment should not be expected to match individual cycle link counts, due to the difficulties associated with predicting cyclist's routing.

Taxis

- At a minimum the broad volume of taxi demand should be captured in the model by including them when car matrices and trip rates are calculated.
- Explicit representation of taxi in the Regional modelling System would require development of innovative techniques.

Freight

- Goods vehicles demand must be included in the assignment models.
- Goods vehicles (OGV1 & OGV2) should be represented separately from light goods vehicles.
- The latter may be combined with in-work cars, if necessary
- Development of a bespoke freight demand model would be possible but time and resource intensive.
- Elasticity models are poor proxies for travel choices as they cannot represent choice between alternatives.

Airport Surface Access

- If available from airport surveys, data on the landside origin or destination of travel to the airport should be used obtained. Similarly the Airport may hold data on the home location or employees, and the POWCAR data does provide such information.
- Airport related travel should be excluded from destination choice. Consideration could be given to refining the mode choice model for air passenger surface access if the volumes were significant or the model is to be used to test measures which would affect such choices.
- Forecasts of air passenger travel should be obtained as a basis for forecasting surface access.

9.1.7 Appraisal & Other Post Model Utilities

Economic & Financial Appraisal

- A utility to calculate and analyse user benefits based on model demand and cost matrices is required. TUBA should be reviewed to determine if it is suitable. It is most convenient to use the same utility to calculate transport provider and public sector impacts.
- Reliability benefits can be very significant. An approach based on Unit TAG 3.5.7 can be applied. If so research into appropriate parameters, in particular the willingness to pay for reliability, in Ireland will be required.
- Wider economic impacts are of great interest to policy makers. Consideration should be given to implementing an approach similar to that set out in TAG Unit 3.5.14.

Road Safety

- COBA should be used in the Irish context using accident rates and valuations derived based on Irish data.

Environmental

- Simplified approaches to calculating noise and exposure to pollutants could be implemented to allow for quick assessments of air quality impacts. Use of specialist software could be considered for more definitive assessments to inform final decisions and statutory processes.

- A link-based approach to calculating GHG emissions is more accurate than the matrix based approach implemented in TUBA.
- Parameters which reflect the emissions and noise characteristics and rates of the Irish fleet should be established.

Physical Fitness

- The model's appraisal modules should include an ability to capture the health-related benefits of the resulting increase in walking and cycling, using the methodology set out in the World Health Organisation's Health Economic Assessment Tools (HEAT) for walking and cycling[56,57].
- The model documentation should provide guidance on the use of these HEAT-based appraisal tools.

[56] http://www.heatwalkingcycling.org

[57] http://www.euro.who.int/en/health-topics/environment-and-health/Transport-and-health/activities/guidance-and-tools/health-economic-assessment-tool-heat-for-cycling-and-walking

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