Introduction to Modelling

TAG Unit 3.1.1

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Department for Transport

Transport Analysis Guidance (TAG)
1 Modelling

1.1 Introduction

1.1.1 *Summary Advice on Modelling* (TAG Unit 2.4) should be read before reading this TAG Unit. It includes a discussion of the general principles of transport modelling, the general principles of land-use modelling, and the choice of modelling approach.

1.1.2 This TAG Unit and related TAG Units provide more detailed advice on these topics and is structured as follows:

in Section 1.2, the principles of model selection are discussed at somewhat greater length; and

in Section 1.3

- references are given to selected source documents, where further details of different modelling approaches can be found,
- some information is given on the datasets available from the Department for model development,
- attention is drawn to the Department's national models which should be used in the creation of models for the studies, and
- lastly, brief note is made of software availability and the need for specialist modelling knowledge in the development of suitable models for the studies.

1.1.3 In addition, there are TAG Units which relate to this TAG Unit, as follows:

*Transport Models* (TAG Unit 3.1.2) outlines (a) the general principles of transport modelling, (b) spatially detailed transport models, and (c) spatially aggregate transport models. Outline advice on forecasting is also provided;

*Land-Use/Transport Interaction Models* (TAG Unit 3.1.3) outlines (a) the general principles of land-use modelling, and (b) the different forms of land-use/transport interaction models;

*Freight Modelling* (TAG Unit 3.1.4) provides some notes on freight modelling; and

*Data Sources* (TAG Unit 3.1.5) provides some notes on sources of travel demand and transport supply data suitable for model building.

1.2 Principles of Model Selection

General Principles

1.2.1 To recap, the choice of modelling approach will depend on a number of potentially conflicting factors:

- the nature of identified problems and their likely solutions;
- the definition and size of the study area;
- the likely number of options to be tested;
- the availability of data and existing models;
- the need to update and (re)calibrate models;
- the need to conduct new surveys;
- the timescale for model development; and
the required accuracy and robustness of results/recommendations.

1.2.2 Whether an over-arching ‘strategy’ needs to be developed before the ‘plan’ is devised may also influence the form of the models adopted.

1.2.3 For obvious reasons, the tighter the timescale and the resources, the more the availability of existing data and models will be critical in selecting a model. Even if extensive resources are available, limitations on timescale mean that the scope for new data collection will be very limited, while developing a completely new model will mean that much detail will have to be sacrificed.

1.2.4 Aside from these resource issues, the main impact of the modelling approach taken is on computation. Assuming reasonably generous resources for modelling, the more options that need to be tested, the more the model turnaround time will be an issue. Ultimately, this is a relative matter: the increase in computing power and falling hardware costs means that it may be feasible to ‘buy one’s way out’ by running the model on more than one machine at once. Nonetheless, this may cause severe logistic difficulties.

1.2.5 As well as the turnaround time per se, there are also issues of computer memory. Though once again it is possible to buy additional hardware in the form of memory, this is in principle a more severe constraint. Given that iterative procedures are involved, the performance in terms of computing effort will depend critically on whether the relevant data can be held in memory or whether extensive use needs to be made of input-output procedures.

1.2.6 The two main areas where a decision is required at an early stage are the level of spatial detail and the representation of purpose/person-type variations (segmentations) in the demand functions. A secondary decision relates to the number of modes and time periods. Unfortunately all these dimensions are cumulative (at least, multiplicative) in their impact, so that a high degree of resolution in any one dimension may result in unacceptably slow computation speeds, even when the others are substantially aggregated.

1.2.7 In assessing some of the more radical transport policies, it is likely to be necessary to model responses in rather more detail. The possible need to segment the travelling population means that, with today's computers, spatial detail may have to be foregone if unacceptably long model running times are to be avoided. In general, transport strategies may be developed using models with relatively few numbers of zones and simplified representations of transport networks, although as computers improve so modelling at greater spatial detail will be possible.

1.2.8 On the other hand, modelling transport networks for the appraisal of transport plans requires considerable spatial detail. Zone sizes need to be small, which implies large numbers of zones. Road networks need to contain all the main traffic-carrying roads, and public transport networks need to include all rail, underground, and bus services. For manageable run times to result with models of this degree of spatial complexity, with the computers currently available, some simplification of the demand modelling is unavoidable. Thus, rather than representing the different types of traveller in a disaggregated way, only a few trip purposes, broken down by car availability, are distinguished. Again, as computers improve, so it will become possible to treat more types of traveller separately.

1.2.9 The trade-off between the level of detail of the supply modelling against the level of detail of the demand modelling is shown diagrammatically in Figure 1. In a nutshell, given a large study area and today's computers, one can have either detailed demand modelling or detailed network modelling, but not both, if acceptable model run times and computing costs are to be achieved. For smaller study areas, the need to compromise will be reduced.
1.2.10 These two aspects are now discussed in more detail.

Spatial Representation

1.2.11 In general, the study areas listed in Multi-Modal Studies: Introduction to GOMMMS (TAG Unit 1.2) fall into two rather different categories: some of them are of a 'regional' character, in that they represent relatively self-contained areas with problems that could be addressed by a variety of wide-scale solutions, while others are more a 'collection' of typical highway schemes that are being grouped because of their contiguity, and hence interdependence, rather than because they have particular coherence per se. The modelling approaches to these two categories are likely to be inherently different.

1.2.12 In any case, an important principle to establish at the outset is that the definition of a study area does not, in itself, define the area which should be modelled.
The modelled area must be selected in the light of the problems to be addressed, and the impact of likely solutions.

1.2.13 A simple example should suffice. Suppose that the interest is in a particular urban area, and that the identified problem is the severe off-peak congestion in the city centre. A solution might be to remove short-term parking in the centre. If the main effect was to divert travellers (e.g. shoppers) to other competing urban centres, then it would be reasonable to include such centres within the modelled area, even though there is, perhaps, no interest in the transport impact on these centres.

1.2.14 The demand and supply processes explained in *Summary Advice on Modelling* (TAG Unit 2.4) and *Transport Models* (TAG Unit 3.1.2) need to be set in a geographical context. In general terms, the demand process relates to a system of *zones* and the movements between them, while the supply process consists typically of *links* in a network. The interaction of demand and supply also requires an interface, whereby movements between zones are assigned to paths through the network.

1.2.15 The supply process needs to ‘collect’ the different elements of demand which make use of particular links. Hence the network must be, in some way, connected to the zones, and the scales of representation need to be compatible.

1.2.16 Because zoning is essentially a form of geographical aggregation, it is not possible, except in a very approximate way, to make *geographical* distinctions within the zone. This has the important consequence that, while it is feasible to connect a zone to the network with more than one centroid connector, it is not possible, for example, to introduce a western and an eastern connector with the implication that one will be used by the western parts of the zone and the other by the eastern. The entire zone is considered to be notionally concentrated at the centroid.

1.2.17 For this reason, in particular, it is generally desirable to have both zones and network at as fine a level of detail as possible: in this way, the problem is avoided. There is reasonable guidance available as to the level of network detail required for congested assignment models: for example, the IHT’s *Guideline on Developing Urban Transport Strategies* suggests that “all roads that carry significant volumes of traffic” should be included, and, more generally that networks “should be of sufficient extent to include all realistic choices of route available to drivers”. Guidance as to zone size is harder to find, but the integrating characteristic is that noted earlier, that the entire zone is assumed to act as if concentrated at the centroid.

1.2.18 There is, of course, a limit as to how much detail needs to be represented, and in general it is unnecessary to extend this level of detail beyond the ‘area of interest’, however this may be defined. Hence, standard modelling practice is to define the area of interest, and represent anything outside it at the coarsest acceptable level. Within the modelled area, there will usually be a predisposition to a high level of detail.

1.2.19 The interface between demand and supply can lead to some problems. If the area of interest is well-defined, then it can be expected that the boundary for both systems will coincide: i.e. inside the boundary, both zones and network will be detailed, and outside they will be coarse (though it is feasible that there may be an ‘intermediate’ region or annulus around the area of interest). However, some other considerations will usually need to be taken into account.
1.2.20 Firstly, movements between the internal and external areas need to be represented at some level of detail, for two reasons. Firstly, it is necessary on the demand side for general reasons of consistency. This is essentially related to trip rate stability and destination choice: if only internal movements are defined as trips, then zones near the border will have (apparently) lower levels of trip-making. Further, the ability to model changes affecting destination choice for such zones will be inconsistent depending on whether the changes, related either to travel costs or travel opportunities, occur in relation to internal or external zones.

1.2.21 Secondly, there is an impact on the supply side (network), since clearly internal/external movements (in either direction) impact on the modelled area network. From the network point of view, there is a further complication, relating to ‘through traffic’. In other words, there are some external/external movements which will impact on the modelled area network. There are usually questions of routeing which make the definition of the relevant cells something of a problem.

1.2.22 Putting all this together, the matrix cells can be defined which, at some level of representation, need to be included in the model, using the letter A to denote internal to internal movements, B for movements between internal and external areas, and C for relevant external to external movements. Implicitly, the level of representation, both spatially and ‘behaviourally’, decreases as one moves from A to C.

1.2.23 In the standard situation, the primary emphasis is probably on the network and the first choice of internal area will be defined in terms of that. It will then need to be considered whether the implied definition of A-type trips is consistent. Clearly, this will not be the case if the primary attraction for most zones just within the boundary is outside the boundary, or if the zones just within the boundary are the primary attraction for zones outside the boundary. Thus, there are likely to be (outward) adjustments to the first estimate of the boundary: these need to be based not only on the current levels of interaction, but on the potential level of interaction in the light of proposed policies.

1.2.24 Having defined the modelled area, and the associated system of external zones and network, the next problem to be confronted is one of scale. Hitherto, a high level of detail has been assumed. However, for at least some of the proposed multi-modal studies, the general guidelines given earlier would lead to an ‘excessive’ number of zones and links, where the term ‘excessive’ relates to issues of computer storage and run-time, and to some extent to past experience and convention.

1.2.25 Clearly this needs to be viewed in conjunction with other questions of scale, relating to the number of ‘segments’ or ‘user-classes’. However, while there may be scope for reducing the segments and user-classes, it is assumed that this has been done as far as possible, and that the problem of scale remains. In this case, some form of spatial aggregation will be required.

1.2.26 The nature of the spatial aggregation leads essentially to a choice of model. In TAG Unit 3.1.2, the distinction is made between ‘spatially detailed’ and ‘spatially aggregate’ forms of transport model. This distinction correlates conveniently with existing corpuses of research and experience, although there is, in reality, more or less a continuum between these two categories.

1.2.27 Given the importance of convergence, stressed in TAG Unit 3.1.2, there are considerable advantages in maintaining a model system which is defined on a single level of spatial detail, and the two categories of ‘spatially detailed’ and ‘spatially aggregate’ model systems respect this. It is more difficult to devise an effective strategy for establishing a converged solution when the demand and supply are operating at substantially different spatial levels.
1.2.28 Nonetheless, it may be the case that the practical requirements for aggregation are in conflict with some of the modelling aims. For example, certain kinds of environmental effects are relatively ‘global’ (e.g. CO₂ emissions), and can be adequately modelled at a more aggregate level. Others, such as noise, or particulates, are highly specific to the detailed location in which they occur, and can most sensibly be assessed at a relatively detailed spatial scale. When such conflicts arise and are seen to be important, one option is to define a hierarchical spatial system, and apply appropriate interfaces between the different spatial levels.

1.2.29 Such hierarchical systems are, in fact, quite common. For example, the London Transportation Study model has a hierarchical zoning system, with 1603 zones at the most detailed level. Most of the model, however, including the entire demand forecasting system and the highway assignment, operates at a ‘compressed’ zone system (districts) of which there are 529. The most detailed zoning system is only used for public transport assignment, to take account of the detailed location of bus stops and stations: this requires 1272 zones, since external zones are aggregated. The networks are of course compatible with the zoning systems with which they are used.

1.2.30 Such hierarchical zoning systems are part of the nature of the compromise that is required when the ideal scale of the model becomes impractical. As a matter of principle, it is probably the case that the detail is more important at the network level than at the zoning level (in terms of the demand model). Hence, a possible approach is to model demand at a coarser level, but to disaggregate the travel matrices for the supply model. This involves a further interface between demand and supply. A potentially serious problem requiring special attention is ensuring that the coarser level supply model is compatible with the fine level model.

1.2.31 An example of this approach is the work done to investigate parking control strategies in Bristol (Coombe et al., 1997). In the model developed for the work called ‘TRAM’ (Bates et al., 1997), the zoning system and the networks operated at a coarse level. At this level, TRAM enabled a number of strategies for controlling parking to be appraised. In subsequent work, the demand changes predicted by TRAM were fed down to spatially detailed road traffic and public transport assignment models so that detailed analysis of the effects of the parking strategies could be undertaken. A similar approach was adopted in the appraisal of congestion charging in London (Bates et al., 1996).

1.2.32 Note that the zone size will define the category of ‘intrazonal’ trips, and these will generally be treated differently within the modelling process (because they are not assigned to the network, if for no other reason). According to the National Travel Survey (NTS), 58% of all trips are less than 3 miles in length, though a high proportion of these are classified as ‘short walk’ trips. But even if such trips (on the NTS definition) are excluded, the proportion is 45%, and it rises to 81% at 10 miles. To give some idea of scale, if the whole of England were to be divided into equally-sized zones with an effective ‘radius’ of 3 miles, there would be approximately 1800 such zones.

1.2.33 With the exception of the spatially aggregate models in TAG Unit 3.1.2, most transport models have a number of zones in the middle hundreds and rarely, if ever in this country, exceed 1500 zones. On the basis of experience, then, it would be wise to plan for a maximum level of zoning detail compatible with around 500 zones: a clear justification would be needed for exceeding this.
Dimensions of the Demand Model

1.2.34 Mode choice and choice of time of day give rise to two dimensions of the demand model. The remaining dimensions may be termed segmentation: they relate to the modeller's interest in dividing overall travel demand into a number of independent categories, based on journey purpose and person-type.

1.2.35 As far as mode is concerned, given a multi-modal context, it can be expected as a minimum that car, public transport and non-motorised modes will need to be distinguished. Whether further distinctions need to be made will depend on the particular circumstances of the study: for example, if there is interest in cycling, it will certainly be necessary to separate cycle and walk among non-motorised modes. The choice between public transport ‘sub-modes’, where it exists, may be treated explicitly in the demand model or at the assignment level.

1.2.36 In the case of time of day, there are two pertinent questions. Firstly, is there an interest in looking at effects in different time periods (as opposed, say, to working with 24-hour averages)? Secondly, are some of the policies time-specific in their impact, such that they may well induce time-switching? If the answer to either question is “yes”, then some recognition of different time periods is required, though only when the second question is answered in the affirmative does it become obligatory to model the choice of time of day (in passing, it should be noted that this adds significantly to the overall complexity). The different performance of the morning and evening peaks means that there is usually some interest in distinguishing these two periods: this implies a minimum of three periods, allowing for the interpeak.

1.2.37 Modelling two peak periods and an average interpeak period would be standard practice. However, there are some circumstances where that would not be appropriate. For example, in the case of a very large area to be modelled, and a large number of options to test, a model which treated three periods of the day separately may take much longer to run than the 14-hour period generally available over night. In this sort of case, some compromise is necessary and modelling the day as a whole (that is, the period from the start of the morning peak period to the end of the evening peak period) might be a way forward. Note that this would not mean necessarily that congestion effects could not be represented; they could be crudely modelled by use of averaged speed/flow relationships.

1.2.38 Turning now to segmentation issues, there are strong grounds for distinguishing purpose in the demand model, since the inherent responses are different. A minimum of three purposes is required: home-based work, employers’ business, and other. A more reasonable breakdown is:

- home-based work;
- home-based employer’s business;
- home-based other;
- non-home-based employer’s business; and
- non-home-based other.

1.2.39 The home-based other category is often segmented further into, e.g., shopping and personal business, visiting friends and relations, social and recreational, or a distinction is made between ‘essential’ and ‘discretionary’ travel. Also, home-based education is sometimes split out from home-based other. The value of adopting this finer degree of segmentation in the case of a largely interurban study would need to be carefully considered. If a land-use/transport interaction model is to be used, there can sometimes be value in separating travel to work by ‘blue collar’ and ‘white collar’ workers. Advice on journey purposes can also be found in the DfT’s Design Manual for Roads and Bridges (DMRB), Volume 12.2.3.
As far as person-type is concerned, given the multi-modal context, a minimal segmentation is between persons in non-car-owning and car-owning households. Because this is only a crude measure of car availability, car-owning households may be split between those with one car and those with more than one, or, with more effort, introducing a further category based on the number of drivers relative to cars, as typified in the following scheme, used in the Dutch National Model¹ and the LTS91 Model (see Fearon, 1998):

- households with no cars;
- households with one car and one driver;
- households with one car and > 1 driver; and
- households with >1 cars.

Any further dimensions, based on the person, will generally be additional to the car ownership dimension.

Putting all this together, the total dimension of the demand model may be calculated as

\[ Z^2 \times M \times T \times P \times S \]

where \( Z \) is the number of zones, \( M \) is the number of modes, \( T \) is the number of time periods, \( P \) is the number of purposes, and \( S \) is the number of person-types. Assuming, as more or less a minimum, that \( Z = 500 \), \( M = 3 \), \( T = 3 \), \( P = 4 \) and \( S = 3 \), we obtain a total size of 27 million cells. This is before account is taken of network implications.

Although there are some opportunities for saving space, it must also be borne in mind that both demand and cost matrices are required, and that the nature of the convergence process means that some intermediate estimates need to be retained. Hence, the figure given is not the total size of the problem, but merely an indication of the scale.

Since the numbers assumed are in most cases on the low side, it will be clear that, compared with what might be considered the ideal model specification, compromises will often be necessary in at least one dimension.

**A Model Typology**

There are many ways in which models could be categorised, and what follows is not intended to be in any way exhaustive. In addition, it is deliberately restricted to the types of model which have some ‘track record’ in terms of practical application.

All the models discussed in this TAG Unit and in TAG Units 3.1.2 and 3.1.3 are essentially of the equilibrium type, though in the case of the land-use/transport interaction models described in TAG Unit 3.1.3 the term ‘equilibrium’ needs to be interpreted in a dynamic context. Thus they all distinguish supply and demand, and have a procedure for the interface between them. They all have a structure which can be more or less directly related to the ‘four-stage’ model (trip generation, trip distribution, modal choice and assignment), in some cases with an additional ‘stage’ relating to the choice of time of day.

The land-use/transport interaction models have some distinctive components, and it makes sense to discuss them separately (in TAG Unit 3.1.3). For the purely transport models, as already discussed, a key distinction is made according to the level of spatial aggregation. According to current practice, the spatially aggregate models compensate for the aggregation by including much

¹ note that the Dutch National Model also allows for whether the individual in the household holds a driving licence
more segmentation detail: conversely, the spatially detailed models keep segmentation to the minimum.

1.2.48 For small study areas, it is possible that (if not now, then in the near future) the ‘ideal’ level of detail may be feasible. In most cases, however, it will be necessary to decide on whether to sacrifice segmentation or spatial accuracy. While the two groups of models are ultimately not that different (and are beginning to come together), they have tended to be used in rather different ways, and for that reason alone, it is useful to discuss them separately.

1.2.49 The spatially detailed models, which are often loosely referred to as ‘four stage’ models (though, as noted above, nearly all models in the transport field can be viewed in this way), are briefly described in TAG Unit 3.1.2. The spatially aggregate models, which are often referred to as ‘strategic’ or ‘policy’ models, are described in TAG Unit 3.1.2.

1.2.50 Before leaving the topic of model typology, there are two other important distinctions which should be referred to. The first is the distinction between ‘aggregate’ and ‘disaggregate’ methods, and the second is the distinction between ‘incremental’ and ‘absolute’ models. Like all terminologies, these distinctions tend to carry with them a number of conventions which are more related to their practitioners than to the inherent differences in the model philosophies. Ultimately, these distinctions are less important than the questions of dimension.

1.2.51 The distinction between spatially aggregate and spatially detailed models has been discussed above. The following paragraphs discuss aggregate and disaggregate methods. It is important not to confuse these two concepts. The distinction between ‘aggregate’ and ‘disaggregate’ methods is concerned with the way in which models are specified, calibrated, and used. In principle, disaggregate methods attempt to model at the level of the individual, while aggregate methods model groups of individuals. In practice, there are severe limitations to disaggregate methods once the full spatial dimensions are introduced, so that truly disaggregate methods are most effective at the ‘trip generation’ level. The practical application of disaggregate methods to mode and destination choice is essentially at a zonal (i.e., aggregate) level, even though the models themselves are estimated at the individual level.

1.2.52 The central issues in forming an assessment of the pros and cons of disaggregate methods are as follows:

the criteria which apply to analysis (i.e. model estimation) are different from those relevant to building forecasting models (i.e. model application);

disaggregate methods are to be preferred when analysing data with a view to identifying explanatory variables (though if these are limited/pre-specified, a more aggregate analysis will achieve the same result);

in most cases, the specifications of demand models based on aggregate and disaggregate methods can be made very similar; and

disaggregate methods facilitate the retention of segmentation information through the modelling sequence (though this may not necessarily be needed or practical).

1.2.53 Given the diminishing returns in terms of explanatory power from adding further variables to a model once the key factors have been identified, plus the practical difficulties of forecasting a large number of variables, it seems likely that in most cases the preferred level of detail will be well inside the spectrum bounded by ‘fully aggregate’ and ‘fully disaggregate’.
1.2.54 The second distinction, between absolute and incremental models, has a number of ramifications. Key to the discussion is the general inability of purely ‘synthetic’ models to generate matrices of movements which are sufficiently close to ‘observed’ patterns. This has led to the use of the demand model to estimate changes which can then be applied, in various ways, to an observed matrix. In this way, the direct forecast of demand is not used as such. Such model applications have been described as ‘incremental’ or ‘marginal’.

1.2.55 In some forms, the base observed matrix is directly incorporated within the demand function as a ‘pivot’: by design, the demand model then generates the base matrix when no cost changes are forecast. However, by the introduction of appropriate ‘calibration constants’, it is possible to specify a purely ‘synthetic’ model which will also generate the base matrix: ultimately, this is a question of mathematical convenience.

1.2.56 The more important issue is the relative reliability of the ‘observed matrix’ and the model estimate. The reality is that it is prohibitively expensive to observe all the cells of the matrix, especially when account is taken of all the additional dimensions (of mode, time of day, on the one hand, and purpose and segments on the other). In addition, there are questions of temporal variability (seasonal, day-to-day, etc.). Thus, except in models that are very aggregate spatially, ‘observed’ matrices drawn from survey data are likely to contain a very high proportion of empty cells. Most forms of incremental model have the property that such cells will remain empty, in the face of policy changes. While this may be a reasonable assumption when the travel which the cell represents is truly infeasible, it is not reasonable if the cell is empty merely because of sample limitations.

1.2.57 Based on current knowledge, the best approaches seem to be as follows.

Spatially aggregate transport models generally calculate incremental changes in demand in proportion to the base demand forecast exogenously. Given the high degree of spatial aggregation at which these models work, this approach is considered satisfactory.

However, a different approach is considered more appropriate in the case of spatially detailed transport models. These will generally produce forecasts of absolute trip levels. To preserve the subtleties of the base year trip matrices, which are likely to have been derived from substantial amounts of observed data, incremental matrices of differences between the base year observed and synthesised trip matrices should be calculated and added to the synthesised forecast year trip matrices prior to assignment.

The above descriptions only outline basic approaches and a number of extensions to, and variations of, the resulting methods are used in practice.

1.3 Further Guidance on Modelling

1.3.1 Many details of the model building process have had to be omitted from this Guidance. In this section, a number of sources of further information and data are presented, as follows:

- source documents on models;
- the Department’s travel demand and transport supply datasets;
- the Department’s national car ownership and trip end models; and
- the availability of software and advice on the need for specialist modelling knowledge.
Source Documents on Models

1.3.2 This section briefly summarises the contents of the following source documents which may be of use to those developing models for the Studies:

- Volume 12 of the Design Manual for Roads and Bridges (DETR, DMRB);
- Guidelines on Developing Urban Transport Strategies (IHT, 1996);
- Strategic Transport Modelling and Strategic Multi-Modal Studies by John Fearon Consultancy for the DfT (Fearon, 1998); and

1.3.3 Traffic Appraisal Manual, DMRB Volume 12.1.1. The Traffic Appraisal Manual (TAM), setting out the recommended practice for the traffic modelling of trunk road schemes, was first published in 1981 and last reprinted in August 1991. In recent years, the Department has released new advice on modelling as separate, free standing, parts of the DMRB, withdrawing parts of the TAM as appropriate. Nevertheless, those parts of TAM which have not been withdrawn remain valid and relevant. The TAM relates specifically to trunk roads in England, although in practice the document has been used as a reference source for all forms of traffic modelling work in the UK. It has been designed so that those intending to carry out traffic modelling are provided with a logical progression through its chapters, with important cross-references to other material.

1.3.4 The Traffic Appraisal Manual gives detailed guidance on the following aspects:

- steps in carrying out a traffic study;
- definition of the study area;
- alternative model forms and their applicability;
- survey methodology and analysis;
- production and calibration of a base year trip matrix;
- assignment methods and procedures;
- assessment of errors in the base year model;
- model validation, including a discussion of national model validation and validation of local models;
- local traffic forecasting, consistency with national forecasts, and the treatment of uncertainty;
- operational appraisal of the impacts of a scheme;
- economic appraisal in relation to fixed and variable matrices;
- presentation of the results of a traffic appraisal;
- before and after monitoring of scheme implementation;
- estimating traffic flow where modes other than car are significant;
- techniques for appraisal of trunk road schemes in urban areas (but see also DMRB Volume 12.2.1, discussed below); and
- techniques for appraisal of smaller trunk road schemes.

1.3.5 Appendices to the Traffic Appraisal Manual include advice on sampling procedures, definition of statistical terms, modal choice equations, and referencing of DfT computer software.

1.3.6 Traffic Appraisal in Urban Areas, DMRB Volume 12.2.1. The purpose of this document is to review the current best practice for urban traffic appraisal techniques in the context of trunk road assessment, and to extend the general guidance set out in the Traffic Appraisal Manual (DMRB, 12.1.1) to the urban
setting and the more congested interurban situations which involve complex traffic interactions.

1.3.7 Chapter 2 provides an overview of the main issues regarding the use of urban road traffic appraisal techniques, and guidance in setting the modelling objectives. Chapter 3 reviews the types of data that are usually required for the traffic appraisal of an urban trunk road scheme, and gives guidance on how such data are to be collected and presented. Chapter 4 seeks to examine in detail the methods involved in developing a traffic model for urban trunk road appraisal, and Chapter 5 describes how the base year model can be developed to produce traffic forecasts for various future situations. Chapter 6 reviews the various forms of appraisal that are applicable to urban trunk road assessment, and highlights issues relating to traffic modelling.

1.3.8 A set of appendices are included covering the areas of: reporting on traffic surveys; local model validation reporting; report of forecasting; use of sub-time periods and time slices; speed/flow relationships; techniques for representing peak spreading; traffic growth constraint techniques; and model convergence.

1.3.9 **Guidance on Induced Traffic, DMRB Volume 12.2.2.** This document contains guidance for highway appraisal in the context of induced traffic (i.e., accepting the need to reflect variable demand procedures). It is not specific on the sources of induced traffic, though its recommended elasticities take account of the relative effects of mode choice, time of day choice and frequency.

1.3.10 The procedures recommended would be entirely applicable in cases where no explicit account of other modes is necessary. The demand models, which are of the ‘simple elasticity’ type, relate to the highway mode only, and are implicitly for all purposes combined. The document outlines more conventional modelling approaches, recommending their use for more complex schemes, but does not discuss these methods in detail.

1.3.11 The recommendations on forecasting are generally in line with the advice given earlier in this chapter, but for the highway mode only. However, relatively little guidance is given on convergence procedures.

1.3.12 **TEMPRO 4.2 Guidance Note.** This document describes the multi-modal National Trip End Model which can provide forecasts of planning data, car-ownership and the resultant growth in trip-making by different modes of transport. These datasets are made available through TEMPRO which is software designed to provide projections of growth over time for use in local and regional transport models. Availability of datasets can be checked on the TEMPRO website at [www.tempro.org.uk](http://www.tempro.org.uk).

1.3.13 **Institution of Highways and Transportation’s Guidelines for Developing Urban Transport Strategies.** Chapter 6 of this document aims to give a comprehensive review of the models for transport strategy appraisal and development in the urban context. The relevant sections have already been referred to in earlier parts of this chapter. The description of the modelling is of general relevance, but it is, by intention, confined to the urban case. For this reason, it has relatively little to offer on the choice of zoning and network detail that might be required for some studies. On the other hand, it goes into the principles of assignment in some detail.

1.3.14 While it acknowledges the importance of convergence for the supply-demand equilibrium, it is less forthcoming on how it may be achieved. In this respect, ideas, and to a lesser extent, practice, have advanced since the document was issued.

1.3.15 **Strategic Transport Modelling and Strategic Multi-Modal Studies, John Fearon Consultancy.** This Report, which was commissioned by DfT, had an objective to undertake a technical review of existing large-scale transport and
land-use/transport interaction models, so that those making the choice of modelling approach in the Studies may do so in a more informed manner.

1.3.16 In a detailed Appendix, the Report reviews eight models of a general 'strategic' nature:

- LASER (a spatially aggregate land-use/transport interaction model for London and South-East, built using the MEPLAN package);
- GMSPM (a spatially aggregate land-use/transport model for Greater Manchester, built using the START and DELTA packages);
- LTS91 (a spatially aggregate multi-modal model for London, built using the TRIPS package and bespoke software);
- NAOMI (a spatially detailed ‘variable matrix’ highway model for M25 corridor, based on SATAST, a development of the SATURN suite);
- NNMS (the Dutch National Model System);
- SSM (a spatially detailed multi-modal model for Southampton);
- KTTS (a spatially detailed multi-modal model for Kent Thames-side, built using TRIPS software); and
- PLANET (strategic rail model for London and South-East region, built using the EMME/2 package).

1.3.17 Chapter 4 of the Report provides some general guidelines as to an appropriate level of detail in the case of the largest Multi-Modal Study area, the London to South-West and South Wales study. A particular point in this long-distance context, is the definition of time period, since journeys from one end to the other may not be completed within any one ‘conventional’ time period. Chapter 5 begins by noting a number of areas of potential difficulty, given the current state of knowledge.

1.3.18 Review of Land-Use/Transport Interaction Models by David Simmonds Consultancy and Marcial Echenique and Partners. This review was prepared in response to a Brief issued by SACTRA. The Report begins by outlining the scope of land-use/transport interaction models, and the range of available models (this material is summarised in Land-Use/Transport Interaction Models TAG Unit 3.1.3). It continues with a more detailed comparison of the different models, in terms of their responses to change, their representation of economic actors’ decisions, and their representation of market systems. It then goes into a number of more detailed questions raised by SACTRA, particularly to do with the identification of economic impacts and the measurement of benefits.

1.3.19 The Annexes provide additional material on the models and packages mentioned in the present Report, and on a range of other models of significance for research and future development but of less practical relevance.

Data Sources for Model Development

1.3.20 DfT has a number of national datasets, use of which, where practical, is recommended in order to assist the process of maintaining consistency between studies:

- the TEMPRO planning data;
- Census journey-to-work trip matrices;
- rail matrices from CAPRI data;
indexes and depositories of roadside interview survey datasets; 
traffic counts; and 
the NARNAS dataset of motorways, trunk and principal roads.

Further details of these datasets are given in Data Sources TAG Unit 3.1.5.

National Models

1.3.21 DfT has produced two models - a car ownership model and a multi modal trip end model - and these should be used in the studies unless there is good reason for supposing that they are not entirely appropriate and that a better and cost-effective alternative can be identified. An earlier version of the National Trip End Model is documented in section 12.2.3 of the Design Manual for Roads and Bridges (DMRB). That document has been superseded, and is replaced by the TEMPRO guidance note which can be down loaded from the web. Development of these national models has required the preparation of an associated zoning system.

National Zoning System

1.3.22 2001 Census data on population, households and car ownership is available to a fine geographic level. In order to make use of this information, and ease the transfer of data between studies, it is recommended that studies base their zoning system on 2001 Census geography, i.e. each model zone should correspond with one or more Census areas. Census geography provides a number of nested levels - Regions are made up of counties, counties consist of a number of districts, districts are divided into wards.

1.3.23 DfT has developed “NTEM zones” as an additional level intermediate between districts and wards. Outside the metropolitan areas, where a district is entirely rural or entirely urban it is treated as a single zone. Each urban settlement with greater than around 10,000 population becomes a zone, and the remaining rural area is divided into sensible portions (e.g. to avoid “doughnut” shapes). Within the metropolitan counties, non-built-up areas are distinguished, and the main cities separately identified. Planning data projections, car ownership and trip end forecasts are published at the NTEM zone level.

1.3.24 National Car Ownership Models. The current car ownership model is based on that used in NRTF97, but has been changed to be responsive to car purchase and ownership costs and includes a company car effect.

1.3.25 The basic model, which is described in Annex C of the “TEMPRO guidance note”, provides the national car ownership forecasts used in the National Transport Model. It was developed from joint National Travel Survey and Family Expenditure Survey (FES) data, and presents household car ownership as a function of income, household categories (relating the numbers of retired persons, non-retired adults, and children), area type (5 levels of urbanisation), level of employment, ownership cost, running cost and an annual trend based on ‘licences per adult’. Saturation level by household and area type are estimated directly from the. The model produces forecasts of the number of households with 0, 1, 2, and 3+ cars.

1.3.26 National Trip End Models. NTEM is now a fully integrated part of the National Transport Model framework developed by the Department for Transport. The equations used in the NTEM model are described in Annex D of the TEMPRO guidance note. The NTEM model is now considerably more detailed spatially than the previous NTEM as well as including trips by all modes (rather than just car) and having greater segmentation of traveller types. The NTEM model starts from the basis that each one-way trip by any mode has two trip ends. The model works by relating the number of trip ends in each zone to a range of
demographic and land use factors, such as the number of households with cars in each zone, and the number of people employed in each zone.

1.3.27 Trips are categorised as either home based (HB), having one end of the trip at the place of residence; or non-home based (NHB), having neither end of the trip at home. The purpose of the trip is determined by the destination purpose of the trip; except where the destination purpose is home in which case the origin purpose is used. Fifteen purposes are recognised: Home-Based Work, Home-Based Employer’s Business, Home-Based Education, Home-Based Shopping, Home-Based Personal Business, Home-Based Recreational/Social, Home-Based Visiting friends & relatives, Home-Based Holiday/Day trip, Non-Home-Based Work, Non-Home-Based Employer’s Business, Non-Home-Based Education, Non-Home-Based Shopping, Non-Home-Based Personal Business, Non-Home-Based Recreation/Social and Non-Home-Based Holiday/Day trip. NTEM also provide tripends by six modes (Car drivers, car passengers, rail, bus, walk and cycle) and six time periods (morning peak period, inter peak period, evening peak period, other weekday periods, Saturday and Sunday).

1.3.28 The NTEM operates at a high level of disaggregation, with each combination of eleven person types and eight household size / car ownership categories – 88 combinations - having their own trip rate for each of fifteen purposes. The trip rates are derived from National Travel Survey (NTS), and are not varied as analysis of NTS data suggests that trip rates for the categories defined are stable over time.

1.3.29 The attraction ends of all trips are distributed across wards according to land-use indicator statistics. For example, for commuting trips, the statistic used is total employment. For shopping trips, it is total retail employment. For trips to visit friends and relatives at their home, it is total households.

**Software Availability and Specialist Modelling Knowledge**

1.3.30 Software for spatially detailed models is readily available from a number of providers. There are a wide range of road traffic assignment modelling packages available, and at least three public transport assignment packages that would meet the requirements for multi-modal modelling. Experience within consultancies and local authorities of the use of these models, mainly in free standing form, is quite extensive. For simple demand modelling exercises, there is also a range of proprietary software available, some of which can be tailored to a specific model’s needs.

1.3.31 Software relating to spatially aggregate models is more specialist, particularly in the case of the approach which employs area speed/flow relationships and fixed routes. Knowledge of construction techniques for such models is restricted to a relatively small number of individuals in specialist consultancies. Specialist techniques are required both for the assembly of the supply representation, and for constructing and handling the high degree of demand segmentation. A number of companies have developed specialist software which they have applied on model building exercises for which they have direct responsibility. Such modelling systems have in a number of cases been handed over for other organisations to use, but cases of model building by third parties are very rare.

1.3.32 A similar situation exists with respect to complex applications of the spatially detailed approach. Here knowledge of techniques to handle features such as time of day choice, public transport crowding and operator response, and overall demand/supply convergence, are restricted to a relatively limited number of people.

1.3.33 Software and expertise in relation to land-use modelling, whether for comprehensive land-use/transport packages or for land-use models which can be fully integrated with separate transport models, is available from only a very
small number of firms. There is some experience of using such models in university transport departments, but recent experience has shown that the main sources of land-use modelling software and associated experience are in the commercial sector.

2 Further Information

The following documents provide information that follows on directly from the key topics covered in this TAG Unit.

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3 References


4 Document Provenance

This Transport Analysis Guidance (TAG) Unit is based on Chapter 2 of *Guidance on the Methodology for Multi-Modal Studies Volume 2* (DETR, 2000).

Technical queries and comments on this TAG Unit should be referred to:

Integrated Transport Economics and Appraisal (ITEA) Division
Department for Transport
Zone 3/08 Great Minster House
76 Marsham Street
London
SW1P 4DR
[itea@dft.gsi.gov.uk](mailto:itea@dft.gsi.gov.uk)
Tel 020 7944 6176
Fax 020 7944 2198
Transport Models

TAG Unit 3.1.2

June 2005

Department for Transport

Transport Analysis Guidance (TAG)
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1 Transport Models

1.1 Introduction

1.1.1 This TAG Unit provides an introduction to transport models. It has three sections, as follows:

- general principles of transport modelling;
- an outline of spatially detailed transport models; and
- an outline of spatially aggregate models.

2 General Principles of Transport Modelling

2.1 Variable Demand Modelling

2.1.1 In the past much transport modelling, particularly on the highway side, has concentrated on what are essentially supply effects, relating to networks. In such cases, apart from allowance for general background growth, the demand for travel is assumed fixed. Since the publication of the 1994 SACTRA Report, this assumption has been considered untenable in most cases, and the presumption is that demand will be potentially affected by any proposed policy/scheme. It is, of course, in the nature of multi-modal studies that the total demand by mode should not be assumed fixed.

2.1.2 The focus on what may be termed ‘variable demand modelling’ requires an understanding of the basic principles of transport economics, and this is the main topic discussed in this section. The terms ‘supply’ and ‘demand’, which are taken from economics, are increasingly being used in the transport context, and it is useful to define them, and the related concept of an equilibrium system, at the outset.

2.1.3 In classical economics it is conventional to treat both supply and demand as functions of cost, but to ‘invert’ the normal graph by plotting cost on the vertical axis, as in Figure 2.1. The notion that travel demand T is a function of cost C (as shown in the Figure) presents no difficulties: the term ‘demand’ model implies a procedure for predicting what travel decisions people would wish to make, given the generalised cost of all alternatives. These decisions include choice of time of travel, route, mode, destination, frequency/trip suppression.
2.1.4 However, if these predicted travel decisions were actually realised, the generalised cost might not stay constant. This is where the ‘supply’ model comes in. The classical approach defines the supply curve as giving the quantity T which would be produced, given a market price C. However, it is more straightforward to conceive of the inverse relationship, whereby C is the unit cost associated with meeting a demand T. Since this is exactly what is required for the transport problem, this interpretation is adopted here. The supply model reflects how the transport system responds to a given level of demand: in particular, what would the generalised cost be if the estimated demand were ‘loaded’ on to the system? The most well-known ‘supply’ effect is the deterioration in highway speeds, as traffic volumes rise. However, there are a number of other important effects, such as the effects of congestion on bus operation, overcrowding on rail modes, and increased parking problems as demand approaches capacity.

2.1.5 Since both demand and supply curves relate volume of travel with generalised cost, the actual volume of travel must be where the two curves cross, as in Figure 2.1 - this is known as the ‘equilibrium’ point. A model with the property that the demand for travel must be consistent with the network performance and other supply effects in servicing that level of demand is referred to as an ‘equilibrium model’.

2.1.6 Although the term demand is often used as if it related to a quantity which was known in its own right, it must be emphasised that the notion of travel demand always requires an assumption about costs, whether implicitly or explicitly defined. The actual demand which is predicted to arise as a result of a strategy or plan is assumed to be the outcome of the equilibrium process referred to above.

2.1.7 Of course the level of demand will reflect the demographic composition of the population, together with other external changes (e.g. effects due to land-use, income, car ownership etc.). However, when assessing the impact of a policy, which means essentially changing the supply curve, the demand curve is held
constant. Hence, the testing of strategies can be viewed as a comparison of two (or more) equilibrium points, using a common demand curve, but with each equilibrium point associated with a different supply curve. This is demonstrated in Figure 2.2.

Figure 2.2  Appraisal in the Base Year

2.1.8 Over time, the population and land-use will vary, and this will lead to different demand curves, each related to a particular point in time. In addition, in making forecasts, there may be different views on how the future population and land-use will develop, so that different assumptions (often termed 'scenarios') may be required for the same year. The demand model therefore needs an interface with external ‘planning’ or ‘land-use’ data (in particular, forecasts of car ownership) to reflect how the scenario assumptions affect total travel demand.

2.1.9 There is, in fact, some debate about the extent to which the ‘external’ changes and the transport changes can really be separated - in particular, transport changes may give rise to land-use changes, and the demand for car ownership is likely to be in some way conditioned by the availability and cost of travel opportunities. The majority of transport models do assume independence: it is the particular characteristic of the group of models termed ‘land-use/transport interaction’ models discussed in Land-Use/Transport Interaction Models (TAG Unit 3.1.3) that they attempt to link the two elements explicitly.

2.1.10 This general modelling process may be conceptualised in the following way:

- the equilibrium demand for travel for a given scenario and a given strategy is a function of ‘external’ elements associated with the scenario and the equilibrium generalised cost arising from the strategy; and
underlying this equilibrium is a general demand function dependent on
the scenario and driven by generalised cost and a supply function
dependent on the strategy being considered.

2.1.11 There are thus two types of representation required - demand and supply - plus
a procedure to achieve equilibrium. All three components present some
difficulties, and these are further discussed in the remainder of this Section.
Central to the whole modelling process is the notion of ‘generalised cost’ which
is defined next.

2.2 Generalised Cost

2.2.1 Generalised cost is usually a linear combination of the various components of a
journey. The components of generalised costs vary by mode.

2.2.2 For car, generalised cost is usually taken to be a combination of: (a) in-vehicle
time; (b) operating costs (related to distance travelled); (c) parking ‘costs’
(which notionally include time spent searching and queuing for a space and
walking to the final destination); and (d) tolls or congestion charges. Money
costs are usually converted to time units using a value of time.

2.2.3 For goods vehicles, the components are usually similar, except that different
vehicle operating costs and values of time are used.

2.2.4 For public transport users, generalised cost is usually a combination of: (a)
walking time from the origin to a stop or station (usually weighted relative to in-
vehicle time by a factor of about two); (b) waiting time for the service (again,
usually weighted relative to in-vehicle time by a factor of about two); (c) fare; (d)
in-vehicle time; (e) penalty representing the inconvenience of changing between
services; and (f) walking time to the destination (again, usually weighted relative
to in-vehicle time by a factor of about two). Again, money costs are converted
to time units using a value of time.

2.2.5 For transport modelling purposes, the components are those perceived by
travellers, often referred to as ‘behavioural’ values. Thus, car operating costs
are usually taken as fuel costs, and car parking costs and public transport
passenger interchange penalties may contain elements to ensure that the
model better reflects actual behaviour. Goods vehicle operating costs, by
contrast, are likely to include all resource costs, including the time costs of the
driver valued at an average wage, although variations may be adopted to
reflect, in effect, drivers’ perceptions of their resource costs.

2.3 The Demand Curve

2.3.1 As noted above, the demand model predicts what travel decisions people would
wish to make, given the generalised cost of all alternatives. In principle, these
decisions can include choice of time of travel, route, mode, destination,
frequency/trip suppression, and most of these decisions require a further
definition of their dimensions. For example, choice of time of travel requires the
modeller to define whether it is desired to predict the precise departure time,
say, or merely to distinguish whether the journey is made in the peak or off-peak
period, and destination choice requires a definition of the level of spatial
representation.

2.3.2 Clearly, the more detail we require, the more complex becomes both the
specification of the demand model and the process of achieving equilibrium. It
is important, therefore, to tailor the level of detail to the requirements of the
problem. In addition, while the components of choice referred to above (i.e.
time of travel, route, mode, destination, frequency/trip suppression) are the
types of response which are most commonly modelled, it may not be necessary
to model each component separately.
2.3.3 For example, if the emphasis is on reducing peak highway travel, it may not be considered important to know whether the reduction has been brought about by trip suppression, mode switch, trip redistribution or time of day switch. Although it may still be considered more reliable to model the separate mechanisms, the fact that they are not considered necessary for the final output opens up the possibility of simplification.

2.3.4 In the simplified diagram presented in Figure 2.1, the demand for travel $T$ was viewed as a one-dimensional quantity, dependent on another one-dimensional quantity cost, $C$. In practice, in order to represent the essential spatial component of transport, it is necessary to distinguish movements, at some level of detail, based on the area of origin and the area of destination, and, in most cases, by the mode that is used. For a consistent account, it is likely to be necessary to distinguish at least the modes car, public transport, and non-motorised or ‘slow’ (walk/cycle), and further subdivisions (e.g. between bus and rail) may be required in some cases. Other dimensions, such as time of day, may also be required.

2.3.5 Hence, it is necessary to deal with multi-dimensional arrays, or matrices, representing demand for alternative travel opportunities. In general, each of these opportunities may have its own (generalised) cost. Thus the demand model has to establish a mapping between the matrix of costs and the matrix of resulting demand. In principle, any coherent procedure for achieving such a mapping (e.g., a set of ‘rules’) could be used, but it is highly convenient to do this by means of specific mathematical forms.

2.3.6 A central concept in transport economics is the so-called ‘elasticity of demand’, which is a measure of the sensitivity of the response to changes in cost (and other variables). This can be given an exact mathematical definition, and it can be calculated for any demand model, though in most cases it is dependent on a particular point on the demand curve. For any chosen travel quantity, it represents the percentage change in demand which results from a percentage change in cost, assuming that all other costs remain at their current level (this is the economists’ familiar *ceteris paribus* condition). When the cost refers to the same travel quantity as the demand, it is termed an ‘own’ elasticity, and when it refers to a different quantity, it is termed a ‘cross-elasticity’.

2.3.7 It is possible to develop simplified demand models by making assumptions about the elasticities. Apart from the limiting case where all elasticities are zero (i.e. demand is constant, and therefore unaffected by cost changes), the simplest assumption which will yield a demand model is that all cross-elasticities are zero, and all own elasticities are constant (though not necessarily with the same value). Note that, because demand increases when costs fall, own elasticities will be negative, and, for most practical cases, cross-elasticities will be positive (or zero).

2.3.8 The assumption that cross-elasticities are zero results in a major simplification of any demand model, since it allows each travel quantity to be modelled independently. Whether it is an acceptable simplification depends, naturally enough, on whether the true cross elasticities can be expected to be small\(^1\). In most cases, there will be little empirical evidence, and it will have to be a matter of judgement. There are many cases, however, where it could not be justified. For example, the demand for travel by public transport would not be expected to be independent of the price of motoring. On the other hand, at greater levels of detail, the demand for travel by public transport between two particular zones in the peak might be assumed to be independent of the price of travel by car between two other zones in the off-peak.

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\(^1\) a possible definition of “small” might be: less than 0.05. This would mean that a 10% increase in the cost of quantity X would lead to an increase in the quantity of Y demanded of less than ½%
2.3.9 The assumption that elasticities can be treated as constant will, in general, be more reasonable (provided, of course, that the values used are appropriate). Constant elasticity models can be viewed as local approximations to a fully-specified demand function. It follows that they should produce acceptable forecasts provided the costs do not change too much from the current position. In practice, this is likely to be the case for the majority of strategies, though some of the more ‘radical’ may not fit into this category.

2.3.10 The problem with elasticity models, in this respect, is that if there are a large number of categories to be forecast, then it is usually more convenient to calculate the demand curve by means of an explicit mathematical function than to have a large table of elasticities to apply. Hence, demand models based on elasticities are best suited to ‘sketch planning’ where we are trying to forecast a small number of aggregate quantities.

2.3.11 So far the demand function has been discussed in terms of the number of ‘transport alternatives’. The most common way of dealing with this problem is by means of ‘choice models’ which predict the proportions of an overall total demand which will be allocated to each alternative. In most cases, these proportions are defined ‘conditionally’, using a specified hierarchy. Thus one model might define the proportions of a given total demand for public transport that go to different destinations, while another might define the proportion of total travel which makes use of different modes. There are well-known rules which must be followed when specifying and constructing such hierarchies of choice models (see, for example, Ortúzar and Willumsen (1994), section 7.4). A central property of choice models is that cross-elasticities are non-zero more or less by design: since in general the selection of one option can be considered to be a rejection of others, there is an inherent interdependence between the options which is explicitly recognised by choice models.

2.3.12 In addition to these dimensions of choice, however, there are other distinctions which relate essentially to the travellers. Different persons have different basic demand for travel. For example, employed persons need to get to work, retired people have more free time etc. Choices are likely to be different between those who have access to cars and those who do not, those who face different levels of pricing (e.g. children and Old Age Pensioners), those who have different levels of income etc. In addition, even for the same person, responses may be different according to the purpose for which the journey is made: this relates both to the inherent need for the journey and to institutional constraints on the timing of the journey.

2.3.13 In principle, therefore, there is a case of having separate demand functions for different categories of purpose and person-type (often referred to as ‘segments’). How far this is worthwhile depends on two key questions: the extent to which responses are different between segments, and the extent to which segments grow at different rates over time. If neither of these are significant, it is unlikely to be worth making the distinction.

2.3.14 Changes in the distribution of person-type segments between the base and forecast years will have repercussions on total demand, as will changes in zonal populations. These can be assumed not to affect the functional form of the demand curve per se, but to affect its ‘location’ or scale (see paragraph 2.12.1).

2.4 The Supply Curve

2.4.1 The purpose of the supply curve in a transport model is to reflect the way in which costs of travel vary according to usage of particular facilities e.g. a highway link or a train. As usage rises costs generally rise also, typified by the congestion that occurs as a road or turning movement approaches capacity. (Note that rising usage does not always lead to a rise in the public transport costs as experienced by users, as the response of the operator may be to
increase levels of service). The supply curve is an integral part of the assignment (route choice) stage of the transport modelling process.

2.4.2 The primary purposes of assignment models are to provide travel cost information to demand models, enable spatially detailed analyses of problems to be undertaken, and to provide information for operational, environmental, economic and financial appraisals. The relative importance of each of the above functions will vary according to the requirements of the study being undertaken. A model for transport strategy development has most need of a cost generator, whereas one being used for development of a transport plan will need a good quality operational and environmental forecasting capability.

2.4.3 Assignment models can vary considerably, according to the overall purpose and design of the transport model of which they are a part. However, a number of features are common to all:

- a computerised representation of the network (and for public transport the services that operate on the network);
- a mechanism to calculate viable routes through the network (path build);
- an origin/destination (OD) matrix of travel demand;
- a mechanism for loading OD demand onto the alternative routes available; and
- a mechanism for ensuring that supply and demand are in equilibrium at the end of the assignment model process.

2.4.4 The following paragraphs provide an overview of the types of transport supply representations that should be considered for use within a study. The key variable is the level of aggregation to which the representation of road traffic and public transport supply will be subjected. In terms of road traffic, the range available is from explicit representation of all roads and junctions with significant traffic levels, through to area-wide representation of speed/flow relationships using a single curve.

2.4.5 Aggregate approaches have benefits in terms of model run times (and hence the ability to tests a wide variety of alternative proposals) and in terms of the level of demand/supply convergence that can be achieved. However, aggregation reduces the ability of the model to reflect accurately all of the routeing opportunities that might arise from a change to the highway network, and inherently increases the margin of error associated with the estimation of travel costs.

2.4.6 Aggregate approaches are thus more suited to transport models whose purpose is to assist in the design of transport strategies, where a wide range of alternatives approaches will need to be tested and optimised. Spatially detailed representations are most applicable where the aim is the development of plans to solve individual problems.

2.4.7 The weaknesses inherent in aggregation of the supply representation can be reduced by taking a hierarchical approach to model formulation. In this configuration, the upper tier is the demand model with a spatially aggregate supply representation. The lower tier is a detailed network assignment model. The linkages need to ensure that the detailed model characteristics can be compressed to form the supply representation for the upper tier model, where travel demand forecasts are estimated. Demand forecasts from the upper tier model can in turn be disaggregated to the level of the detailed model zoning system, allowing their detailed routing implications to be tested and understood.
2.5 **Highway Supply Curves**

2.5.1 The different forms of highway supply representation that are of relevance to studies can be summarised as follows:

- area speed/flow relationships with sets of fixed route alternatives;
- link-based speed/flow relationships using ‘notional’ highway links;
- link-based speed/flow relationships using ‘real’ highway links; and
- detailed network representations with junction turning movements explicitly modelled.

2.5.2 The above list is in descending order of level of spatial aggregation, relating to both zone size and to supply. Each of these alternatives to highway supply representation is discussed below. It should be noted that the above are not discrete alternatives, and that combinations of their main features are possible in order to meet the needs of particular modelling exercises.

2.5.3 Important features of road traffic assignment models as components of multi-modal models are:

- capacity restraint (the modelling of congestion);
- multi-routeing (the spread of trips across alternative routes); and
- equilibrium - generally seen as the fulfilment of Wardrop’s First Principle which states that under equilibrium conditions no driver can reduce generalised cost by changing route.

All of the methodologies described below possess these features.

2.5.4 Multiple time periods can also be an important feature of assignment models, and generally representations of peak and off-peak periods are a requirement of a demand modelling process.

2.5.5 Modelling two peak periods and an average interpeak period would be standard practice. However, there are some circumstances where that would not be appropriate. For example, in the case of a very large area to be modelled, and a large number of options to test, a model which treated three periods of the day separately may take much longer to run than the 14-hour period generally available over night. In this sort of case, some compromise is necessary and modelling the day as a whole (that is, the period from the start of the morning peak period to the end of the evening peak period) might be a way forward. Note that this would not mean necessarily that congestion effects could not be represented; they could be crudely modelled by use of averaged speed/flow relationships.

2.6 **Area Speed/Flow Relationships With Sets of Fixed Route Alternatives**

2.6.1 Area speed/flow curves with fixed routes are the most aggregate form of highway supply representation, and are best suited to studies whose purpose is to develop transport strategies rather than plans. In this methodology one or more area speed/flow curves are defined for each of the (generally large) zones in the model, as a means of representing congestion effects. The unit for flow in this context is pcu-kilometres, as the speed/flow ‘links’ do not have defined lengths.
2.6.2 For each OD pair a set of fixed routes is defined in terms of the distance travelled on each of the area speed/flow links. The route set is generally established so as to reflect distinctly different travel opportunities. Because this is the most aggregate form of supply modelling the representation of intra-zonal as well as inter-zonal movements is essential. Routes for intra-zonal movements are defined in the same way as for inter-zonal movements.

2.6.3 A variant on this methodology is to combine area speed/flow curves with representation of motorway and/or strategic highway links as separate units of capacity, an approach that is definitely required if differential pricing policies such as motorway charging are to be tested.

2.6.4 Area speed/flow curves and the associated set of alternative OD routes are most accurately and economically generated using a road traffic assignment model of the same area. Thus this form of aggregate supply modelling is best suited to the hierarchical modelling concept described above. The process of generation of the aggregate representation of supply can be fully automated and if necessary repeated for test options that involve highway infrastructure changes.

2.6.5 Speed/flow curves can be estimated by the application of upward and downward factors to the base year detailed assignment model trip matrices. For each matrix factor, speeds and flows can be accumulated for the links making up each zone, giving a series of points on a curve. Routes between OD pairs can be generated through an analysis of the routes output by the detailed assignment model.

2.6.6 The use of fixed routes within this methodology is necessitated by the fact that the supply representation does not constitute a network of ‘physically’ connected nodes and links, and thus a path building process is impractical. The trip loading process is generally an integral part of the demand model, with choice of route occurring at the bottom (most sensitive) point of the choice hierarchy. The combination of fixed routes and a high degree of spatial aggregation means that this form of representation of transport supply can achieve a high degree of convergence with a relatively low number of demand/supply iterations (see below for more on convergence).

2.7 Link-Based Speed/Flow Relationships Using ‘Notional’ Highway Links

2.7.1 In contrast to the above this approach uses conventional assignment modelling techniques in the context of an aggregated approach to supply representation. Conventional node and link network definitions combined with path building and trip loading procedures are employed. A full Wardrop equilibrium assignment can be achieved. The aggregation ensures that run times are relatively short and that a high degree of convergence is achieved.

2.7.2 A number of alternative methods for representing aggregated highway capacity within a link based model have been explored, including:

- spider links - connecting centroids of adjacent zones, with capacity set at the combined level of all of the roads that cross the zone boundary in question;
- links representing ‘amounts’ of highway capacity, such as an urban central area within an inter-urban model.

2.7.3 As with the fixed route area speed/flow approach described above, it is common practice for this form of aggregate representation of highway supply to contain a network of explicitly coded motorway and other strategic highway links. These
are coded in a manner similar to that for a conventional node/link assignment model, leaving the aggregate links to represent all other capacity.

2.7.4 The process of coding these networks is not well established, and the theoretical basis for aggregating areas of highway capacity into single links has not been clearly defined. For example, capacities of highways at the point where they cross zone boundaries may not actually encompass the limiting factor in terms of travel between two zones. Useful guidance on this type of approach is given in TRL Project Report PR/TT/092/97. This has not been formally published but can be obtained from the DfT’s ITEA Division. A complex process of trial and error calibration could well be required to get the model to perform in a satisfactory manner. The modelling of intra-zonal movements, necessary with large zones, also presents theoretical and practical difficulties for this approach.

2.7.5 The uncertainty about the theory of this approach to highway supply representation means that generation of aggregate supply representations from detailed assignment models of the study area is difficult to automate, such that the process can be repeated with confidence where major highway supply changes are to be tested. This limits the potential for use of this type of supply modelling in a hierarchical model structure.

2.8 Link-Based Speed/Flow Relationships Using ‘Real’ Highway Links

2.8.1 Assignment models in this context are typified by relatively small zones and a highway network that represents all main roads. (Note that, in this context, small zones are defined as ones in which the traffic impacts of intra-zonal trips can be assumed to be negligible.) Capacity restraint is represented by highway link-based speed/flow relationships. This type of application requires multi-route modelling and equilibrium assignment procedures. This is because of the importance of such models in the appraisal of strategies and schemes that affect the capacity of specific links in the highway network. Model convergence is measured using stability and proximity criteria (Design Manual for Roads and Bridges (DMRB), Volume 12.2.1). Aggregate outputs are available as they are for the more strategic models, but spatially more detailed outputs such as corridor flows and journey times are also available.

2.9 Detailed Network Representations With Junction Turning Movements Explicitly Modelled

2.9.1 A detailed zoning system and a network that includes all roads that carry significant volumes of traffic characterises this approach to highway supply modelling, generally known as congested road traffic assignment modelling. Multi-routeing and equilibrium assignment are essential features. Capacity restraint is affected through the explicit modelling of junctions, taking account of physical turning capacities, signal timings and the interaction of conflicting traffic movements. Link speeds are generally fixed, that is, all delays are assumed to be as a result of conflicts at junctions. Use of link-based speed/flow procedures is sometimes made in the peripheral parts of the network, to provide realistic routeing into and out of the area of junction modelling.

2.9.2 If the model tends towards the transport strategy development end of the spectrum, in some circumstances junction representation is usually a simple extension of link based speed/flow modelling procedures described in the previous section. In fully specified congested assignment models, used for development of detailed transport plans, the junction modelling procedure is used to represent the interaction between junctions. For example, where modelled queue lengths exceed the available queuing capacity, these models represent the effects that this will have on the workings of the upstream
junctions. Similarly, the effects of bottlenecks in the network in 'metering' the flow of traffic to downstream junctions are also represented.

2.9.3 Convergence is measured using stability and proximity criteria as defined in *Values of Time and Operating Costs* (TAG Unit 3.5.6) of Traffic Appraisal in Urban Areas (DMRB 12.2.1). While aggregate outputs are readily available from congested assignment models, it is the ability of these models to produce a wide variety of detailed junction performance information that distinguishes them from other types. For example, possible outputs include: flows on links by direction; main turning movements at main junctions; total delays at junctions; delays for main turning movements; and queues at junctions.

2.9.4 However, it should be noted that even with a well-converged model, the queue and delay information can display considerable instability from iteration to iteration and great care is required to avoid over-interpretation of the model output.

2.10 Representation of Public Transport Supply

2.10.1 The different forms of public transport supply representation that are of relevance to the Studies can be summarised as follows:

- aggregate approaches involving sets of fixed route alternatives (generally one option for each mode);
- link-based representations involving an aggregated representation of public transport services coded onto aggregate highway and rail network link definitions;
- link-based based representations involving an aggregated representation of public transport services coded onto networks definitions containing 'real' highway and rail links; and
- detailed service definitions coded onto networks coded as 'real' highway and rail links.

2.10.2 Again the above should not be viewed as discrete alternatives; they provide a continuum within which the needs of a particular study can be addressed.

2.10.3 The above list is in descending order of level of spatial aggregation, relating to both zone size and to supply. The fixed route approach is a direct parallel to the most aggregate form of highway modelling described earlier. The fixed routes are definitions of the path taken by passengers for each OD pair, defined in terms of distance travelled on each strategic network link, with fare and frequency measures also defined. The passenger paths are most accurately and economically generated using outputs from a detailed public transport assignment model of the study area, and therefore the approach is best suited to a hierarchical model structure. Where a radical change to public transport supply is to be tested, it is often convenient to code this into the detailed model first, and re-run the passenger path generation process.

2.10.4 Options involving simplification of the public transport supply representation to meet the requirements of an aggregate highway network, or to reduce coding effort, require skilled judgement on the part of the modelling practitioner. There is a danger that the resultant representation of public transport services will have lost some important characteristics of the public transport system, particularly those relating to interchange potential and cost. The approach to be taken to service aggregation therefore requires detailed consideration at the model design stage.
2.10.5 Disaggregate coding of all public transport services onto a network that contains all relevant highway and rail links provides the best basis for representing public transport travel costs and routeing opportunities. Such a model requires an initial high effort with respect to service coding, though the work involved here can easily be over-estimated and should be offset against the design effort and skilled modelling inputs required for a satisfactory aggregate approach. In order to obtain benefit from the detailed service representation small zones are required, and this can add significantly to model run times. However, it should be noted that public transport models that do not involve the modelling of capacity restraint (crowding) have no iterative procedures, and hence the path-build and loading take place only once.

2.10.6 Important features that need to be considered when designing public transport assignment models as components of multi-mode models are:

- sub-modal choice;
- multi-routeing;
- capacity restraint (crowding effects); and
- operator response to patronage change.

2.10.7 Sub-mode choice can be carried out as part of the route choice process within the assignment model, or as part of the overall demand model hierarchy. In the above examples the fixed route approach would involve sub-mode choice as a demand model stage. For the other approaches a decision would need to be made as part of the overall model design. In some studies there may be a need to explicitly model the different modes used on different legs of a multi-modal trip. The capabilities of the alternative approaches to this will need to be carefully assessed.

2.10.8 Multi-routeing is important where there are a number of viable alternative passenger paths through a network - e.g. parallel rail routes or bus rail competition (where sub-mode choice is a feature of the assignment model). Multi-routeing is also important where zonal aggregation means that the walk element of the start and end of trips is poorly represented, and hence allocation of all trips to a single route opportunity would significantly affect loadings on alternative routes.

2.10.9 It is general practice in the UK for public transport models to ignore the potential impacts of crowding upon route choice and perceived costs, though a notable exception occurs in models of London. Where this significant simplification is unacceptable, the assignment process needs to form part of an iterative process under which wait times and/or perceived journey times are recalculated between runs of the assignment model, with the iterations carrying on until a converged position is achieved. However, as is the case with the LTS model of London, the resulting model run times can become very large. However, where crowding exists, or could occur as a result of some strategies or plans, it may be important to represent it in the model to ensure that decisions are robust.

2.10.10 Related to the crowding issue is the potential for public transport operators to respond to rising or falling patronage levels. This effect can be included as a fare or frequency response or some combination of the two. The relationship between patronage and service levels is complex and currently not fully understood. It is reasonable to assume that bus operators in a competitive market will respond so as to maintain the equilibrium between operating costs and revenues that can be assumed to exist in the base situation. However, factors such as real wage changes and technology developments could influence applicability of this assumption. For the rail mode, which is subject to much greater regulation and long lead times for vehicle purchase and infrastructure development, the operator response is likely to be slower and less certain.
2.10.11 Taking account of operator response allows the potential for stemming the long term ‘spiral of decline’ in patronage and service to be investigated, alongside the potential for establishment of ‘virtuous circles’. Models in which this feature is included have demonstrated that the impact is significant. However, including this feature in the model complicates the software and can greatly increase model run times. A simpler approach is to reflect operator response by adjusting input service levels as part of option development. Where operator response is included, care is required to ensure that the model does not generate a ‘hidden’ investment scenario, especially where this might result in increases in grants or subsidy payments.

2.11 Seeking Equilibrium Between Demand and Supply

2.11.1 As noted earlier, at equilibrium the demand for travel must be consistent with the network performance and other supply effects in servicing that level of demand. In other words, if the estimate of demand is loaded on to the supply, the resulting costs should exactly generate the estimate of demand which is loaded. (Note that this equilibrium is different from assignment equilibrium, discussed earlier in this TAG Unit.)

2.11.2 The importance of the need to find the points of equilibrium with some accuracy must be emphasised. The demand/supply diagrams shown in Figures 2.1 and 2.2 have been drawn with false origins for the sake of clarity. However, the diagram drawn as in Figure 2.3 is likely to be a better representation of reality. The benefits are actually, in essence, a very small quantity derived as the difference between two large quantities which have a certain degree of error associated with them. In order to derive the benefits accurately, it is essential that the equilibrium points are found accurately for both the do-minimum and do-something cases. Failure to recognise this fact and adopt modelling procedures which enable equilibrium to be found with accuracy could easily result in erroneous decisions being taken.
2.11.3 In practice, with the exception of the very simplest models, there are no direct ways of calculating the equilibrium solution, and it is necessary to set up iterative procedures. Although a well-conceived iterative system should converge to a unique solution, the nature of the method is likely to produce only approximate equilibria, both because of inherent computational inaccuracy (e.g. rounding) and the desire to limit computing time.

2.11.4 In addition, it is very often the case that the iterative system is not well conceived: at best, this can mean that it takes a very long time to converge, at worst, that convergence is not obtained at all.

2.11.5 In order to address this issue, it is necessary to develop criteria for satisfactory model convergence. For a detailed model, the total number of demand estimates may be very large, and while it would be possible to test each element for stability, the natural desire for compromise means that criteria may be defined at relatively aggregate levels. However, while the procedure may appear to converge according to these criteria, in reality stability is not being achieved at more detailed levels.

2.11.6 If the aim of the model is merely to give broad levels of magnitude, a high degree of convergence may not be important (provided, of course, that the iterative process has not simply ‘got stuck’). However, for detailed comparison of options, it is essential that the accuracy of convergence is substantially greater than the difference between the options. In other words, the chance of erroneously concluding that option A is preferred to option B because of inadequate convergence must be minimised. This is particularly important.
when there is a tendency for successive iterations to oscillate around the true solution, as is very often the case.

2.11.7 The simplest form of iterative procedure is known as the ‘cobweb’: at any stage in the iterative sequence, this simply takes the ‘current’ demand, ‘loads’ it on to the supply, calculates the resulting costs, inputs these to the demand model to get a new ‘current’ demand, etc., as illustrated in Figure 2.4. It is well-known that such procedures have no general guarantee of convergence, and in those cases where they should converge, convergence is very slow. This is because, at each iteration, all previous estimates are discarded. In principle, some averaging procedure which makes use of previous estimates is always to be preferred.

![Figure 2.4 The Cobweb Method of Seeking Equilibrium](image)

2.11.8 Unfortunately, the detailed design of appropriate convergence procedures is highly technical. The preferred theoretical approach is along the following lines.
Establish that a unique solution (equilibrium point) exists. For most transport problems this is likely to be the case, though it may be difficult to prove.

Design a ‘search’ procedure (‘algorithm’) which consistently improves the estimate of the solution with each iteration. This is a specialist topic. The most straightforward procedure in common use is the so-called ‘Method of Successive Averages’ (MSA): see, for example, Ortúzar and Willumsen (1994). However, although this is generally guaranteed to converge, the rate of progress may be extremely slow.

2.11.9 On theoretical grounds, the preferred approach is to set up some kind of ‘objective function’ which is then minimised, yielding a result which coincides with the equilibrium solution. For a very limited range of demand and supply functions, this can be done using commercially available software. Such an approach provides much greater control, in terms of allowing appropriate convergence statistics to be designed, while at the same time offering substantial advantages in terms of computational efficiency. Unfortunately, specifying the appropriate objective function for an arbitrarily defined modelling system is a highly complex task, though there is at present great interest in developing the approach.

2.11.10 The best general advice that can be given is to investigate the sensitivity of the conclusions to the number of iterations. For example, assuming that options A and B have been independently judged to have ‘converged’, how does the comparison of A and B alter under the following numbers of additional iterations?

<table>
<thead>
<tr>
<th>Option B</th>
<th>Current converged</th>
<th>+1 iteration</th>
<th>+2 iterations</th>
<th>+3 iterations</th>
<th>+10 iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current converged</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 1 iteration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 2 iterations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 5 iterations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+10 iterations</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

2.11.11 The output can also be subjected to a statistical analysis, with a view to estimating the error range of the current estimate in the light of subsequent iterations.

2.11.12 If the conclusions are generally unaffected by increasing the number of iterations for either option, or (which is effectively the same) the difference between the options is significant after taking account the error obtaining for each, then they can be considered secure. If this is not the case, further attention will be required to the level of convergence. While in the simplest case, this may merely mean increasing the number of iterations, in more serious cases it may require a reassessment of the iterative procedure.

2.11.13 A practical problem in carrying out such analysis is that the software may not have the facility to start off at a previous ‘intermediate’ estimate. If the iterative process is terminated after N iterations, and then has to be restarted at zero in order to obtain an estimate for N+1 iterations, the kind of sensitivity analysis envisaged here will be prohibitive. A ‘warm start’ procedure is thus essential, and software should be designed or chosen with this explicitly in mind.
2.12 **Principles of Forecasting**

2.12.1 So far, the focus has been on the specification of the demand curve at a particular point in time, and the problem of estimating equilibrium with different assumptions about supply. However, as already noted, the demand curve will shift over time, reflecting exogenous factors such as demographic and land-use changes. There are also some technical issues relating to other changes, such as the value of time. These matters will now be discussed.

2.12.2 As will be described in subsequent sections, a basic procedure underlying the vast majority of practical transport models is a ‘trip generation’ stage, which relates the general volume of travel (separately, in most cases, for a number of distinct journey purposes) to person-type characteristics. Regardless of how these relationships are derived, they tend to be applied at the zonal level: in this way they are sensitive to the (forecast) numbers of persons of different types in the zone.

2.12.3 The data requirements are discussed explicitly in *Data Sources* (TAG Unit 3.1.5) but the general range may be noted here. As a minimum, zonal populations and employment will be required, together with the number of households, usually broken down by level of car ownership. Some breakdown by age and employment status is desirable, as is the availability of driving licences. The level of detail should be at least as much as that required for the implementation of the demand model: thus, if it is decided that the demand model should distinguish between different levels of income, then the model will require forecasts of the population at these different levels.

2.12.4 As a general guidance, the number of distinctions made within the demand model tends to be low. Since models of trip generation are relatively easy to develop, there is a case for allowing for a greater level of ‘segmentation’. At the same time, the DfT has developed forecasts at the local authority level which require data at a reasonable level of disaggregation: *a priori*, it makes sense to make use of these. Since the zones in the study area will typically be more detailed than local authorities, some method of spatial disaggregation will be required. In general, it will be desirable to ‘control’ the predicted growth to the DfT forecasts, at least at the modelled area or study area level.

2.12.5 The predictions about future growth in demand need to be expressed in the form of a forecast year demand curve, as illustrated in Figure 2.5. Consider a base year description of travel movements (set of matrices) assumed to be in equilibrium at point A - if the growth rates resulting from the socio-demographic changes just discussed are applied, the resulting set of movements, often referred to as a ‘reference case’ forecast, can be considered to be a forecast of what would happen if there were no changes in travel cost. This will represent a ‘point’ B on the future demand curve, corresponding to the base year costs. Hence, it can be seen as a way of locating the future demand curve, assuming a constant functional form.
Figure 2.5 The Shift in the Demand Curve Over Time
2.12.6 It is important to note that this ‘reference case’ is not intended to represent a realistic forecast of what might happen - i.e., it is not an equilibrium solution. Typically, the increased growth will lead to cost changes (e.g. greater congestion) through the supply relationships. Having located the future demand curve, there is a need to invoke the convergence process in order to derive the equilibrium solution at point C. Note that, in addition, there may be forecast changes in supply (essentially the distinction between ‘do-nothing’ and ‘do-minimum’).

2.12.7 In this context, cost forecasts relating to, for example, the price of petrol or public transport fares, can be viewed as changes in the supply functions. However, since the demand curves are invariably specified in terms of generalised cost, this leads to a somewhat problematic issue, which is bound up with the question of value of time.

2.12.8 Generalised cost, being a weighted combination of time and money, has no intrinsic units (though it is clearly possible to ‘measure’ it in terms of time units or money units). Unfortunately, in making the standard assumption that the demand functions do not change in form over time, it is necessary to address the question: “In what units are generalised costs assumed to be defined?” The result of defining it in time units would lead to different forecasts from what would be obtained by defining it in money units. The only case in which it does not matter is when there are no changes in the magnitudes of the time and money components, nor of the way in which they are weighted together (value of time): this is the least likely assumption.

2.12.9 Guidance in line with best practice would be to assume that generalised cost is defined in units of time, on the principle that time is more universal than money. It should be noted, however, that in terms of the demand model assumption of constancy into the future, this is an empirical question, and virtually no information is available to support or reject it.

2.12.10 At the same time, there is a general presumption that the value of time will rise with income. Although this is a controversial topic in its own right, it is usually assumed that values of time should increase over time in line with the forecast growth in GDP. The DfT issues recommendations about what assumptions should be made for changes in value of time into the future, and though these recommendations relate strictly to their use in appraisal, they may be taken as representing reasonable practice for modelling as well.

2.12.11 Taken together, the implied consequence is that money costs will represent a smaller part of generalised cost in the future, so that the sensitivity (elasticity) to money costs will decline. While this has some plausibility, extrapolation to the longer term, where the implied overall growth in GDP may be substantial, may produce results which are difficult to accept. Forecasts over substantial periods of time should always therefore be scrutinised for plausibility. If the results are judged unreasonable, different assumptions may have to be made. The most neutral assumption would be that the rise in money costs is ‘more or less’ in line with GDP, since this restores the balance between cost and time which would have existed at the time of estimating the demand model.

2.12.12 The concept of generalised cost is also used within highway assignment models as the criteria for route choice, whether this is modelled stochastically or deterministically. Although ideally the definition of generalised cost should correspond with that in the demand model, conventional practice in assignment has been to use a weighted average of time and distance, and allow the weighting to be determined on the basis of the plausibility of the predicted paths chosen.

2.12.13 With some effort, it is possible to interpret the weights in terms of a trade-off between in-vehicle time and car operating costs (the latter calculated on the
basis of a simplified form of the recommended COBA relationships): given this, the weights could be changed to reflect changes in operating costs (e.g., fuel prices) and values of time. However, this is not recommended practice: applying it naïvely can lead to implausible routes being chosen. The standard best practice is to keep the calibrated weights constant for future year assignments.

2.12.14 Although this leads to a possible incompatibility between route choice and other elements of the demand model, it is judged that this is the lesser of two evils. A possible complication, when equilibrium assignment techniques are being used, is that the chosen paths between any pair of zones do not all have the same generalised cost, when this is measured in terms of the demand model definition. In this case, the recommended approach to calculating the cost to use in the demand model is to take the flow weighted average of the different costs over all the paths used.

3 Spatially Detailed Transport Models

3.1 The Demand Model

3.1.1 A general description of the demand model is set out in the IHT’s Guidelines on Developing Urban Transport Strategies: Section 6.3 for ‘aggregate models’, and Section 6.4 for ‘disaggregate models’. The material is only summarised below.

3.1.2 The trip generation stage requires, for each modelled purpose, a prediction of the number of trips leaving each zone (Productions and Origins) and, in some cases, entering each zone (Attractions and Destinations). For those cases where the number of trips entering each zone is predicted by the distribution model, the trip generation stage is still required to estimate a measure of ‘relative attraction’. This stage corresponds with the ‘tour frequency’ module in disaggregate applications.

3.1.3 In principle, the level of trip making could be sensitive to network conditions (‘accessibility’), but there are very few practical applications of this. The default assumption is that trip rates do not depend on accessibility but only on socio-demographic characteristics.

3.1.4 The basic methodology is along the following lines:

- obtain available demographic forecasts;
- disaggregate as required (spatially, and by person-type);
- apply car ownership forecasts to disaggregate by car availability;
- apply estimated fixed trip rates to zonal quantities in each category;
- aggregate as appropriate.

3.1.5 In the absence of any existing data, this could be an onerous task. Population forecasts by age and sex are usually available for local authority areas, but in principle all the other tasks could be considered the remit of the modeller. ITEA Division of the DfT can provide much of the required information at the local authority level, and below via the TEMPRO program available on its web site. However, those data should be examined and any local anomalies and updated local projections identified. Currently, projections of households, forecasts of household car ownership and trip end forecasts for all modes are available. Although not directly available, both the car ownership and trip end forecasting procedures require a disaggregation by household and person types, and a published methodology is available. In general, then, apart from ensuring
conformity with the local zoning system, all the essential information is in the public domain. Although model zones will usually be rather smaller than local authority areas, the published methodology could in fact be applied at a more detailed level, provided only that the necessary demographic data is available at that level. This greater detail is usually available to local authorities, and it will usually be acceptable to disaggregate the trip end forecasts for local authorities on a relatively mechanistic basis.

3.1.6 In cases where there are serious doubts about the suitability of the national relationships incorporated in the DfT forecasts, it would be open to the model team to collect household interview data with a view to developing car ownership models and/or trip generation models. However, this should be very much an exceptional case.

3.1.7 In contrast to trip generation, the trip distribution and modal split changes will have to rely principally on local data, and furthermore, the collection of such data is problematical. Such models would ideally be based on household data: however, except in the case of the largest conurbations, the cost of collecting sufficient household data for this purpose can be prohibitive. This means that substantial reliance has to be placed on surveys made in course of travel (typically, roadside interviews (RSIs), and on-board public transport surveys). Although aggregate information such as traffic counts, may be of use for model validation, it lacks the dimensions of origin, destination, trip purpose and person-type that are needed for model building.

3.1.8 In most cases, matrices will be built independently by mode: it is essential that they are prepared on a ‘Production/Attraction’ (P/A) basis. To achieve this, the purpose should be recorded for both ends of the trip. Note that failure to do this is common in data collection, and is potentially disastrous to the modelling of demand (TAM RSI form in DMRB Volume 12.1.1.6 meets the requirements).

3.1.9 For highway matrices, based on RSIs, the methodology can follow that given in DMRB; separate matrices will be built by purpose and time of day, as a minimum. While in principle it should be possible to disaggregate this by further person-type segments, in practice the restrictions imposed by the RSI data collection format may make this infeasible.

3.1.10 On the public transport side, the format is less restrictive, and the data may be collected either at/near bus stops or railway platforms, or, with the operator’s permission, interviewers may ride with the passengers and collect information en route. In this later case, there are some sampling issues, since there will be a bias induced by the tendency to interview passengers who remain longer on the vehicle. It is, in any case, critical that the ultimate origin and destination are correctly recorded, not merely the boarding and alighting points of the journey.

3.1.11 In large conurbations, where the public transport system is denser, journeys are more likely to be complicated by the possibility of interchange. As much detail as is possible should be recorded, using the LATS on-board surveys as a model.

3.1.12 Unless there are external reasons for greatly increasing the effort applied in the collection of highway and public transport matrix data, it is likely, in the context of a single study, that the data collected will not cover all possible movements between the zones in the modelled area. This will almost invariably be true for private transport trips, although it may be possible to sample all trips by public transport, so avoiding the problem of having to synthesise any missing public transport trips. A decision then has to be made as to whether these ‘unobserved cells’ are zero by nature (because the actual amount of travel between the two zones is negligible, and likely to remain so in all conceivable scenarios), or are zero merely by the random process of sampling observations.
In the latter case, it will be necessary to ‘infill’ in some way.

3.1.13 In line with the earlier discussion, there is nothing inherently inappropriate about attempting to do this, and traffic count data are in principle valuable information. The problems reside in the detailed assumptions that are made in carrying out this process. There is abundant literature on the general procedure of ‘deriving matrices from counts’: crucial to the success of the exercise is that a substantial amount of individual data is collected, relative to the volume data (see Ortúzar and Willumsen, 1994).

3.1.14 The process of infilling is essentially similar to the construction of the demand model itself. This requires a matrix of costs, which will need to be obtained from an assignment stage. Since this matrix of costs, at least on the highway side, will be influenced by the volume of demand assumed, there is an inherent iterative sequence in all these elements which contributes to the building of the demand model and the current equilibrium (‘base situation’).

3.1.15 In the case of non-mechanised modes, the prospect of obtaining an acceptable matrix of movements from interviews in course of travel is far worse, for understandable reasons. Since the majority of these journeys are short, they can in principle be collected from diary information collected on a household interview basis. However, unless the area of interest can be heavily restricted, the costs of obtaining adequate coverage are likely to be prohibitive. In most cases, therefore, the matrices for non-mechanised modes will be almost entirely synthetic, built up from simple distance relationships from sources such as the National Travel Survey.

3.1.16 In the multi-modal context, it is obviously important that the data for different modes, whether observed or synthesised, is compatible, i.e. that the implied modal propensities are credible. The aim is to produce a set of base matrices by mode (and other segmentations, in particular purpose) which are both compatible with the demand model of mode and destination choice and consistent with the observed matrices for each mode. This may require further iterations of, and/or adjustments to, the mode and destination choice models.

3.1.17 For the journey to work, the Census data matrices may provide a useful source, both of the volume and pattern of movements, and of the modal proportions (see Data Sources (TAG Unit 3.1.5)).

3.1.18 The demand model itself will typically be of the logit type (which includes the traditional ‘gravity’ model for distribution, or destination choice), based on generalised cost. The iterative nature of the process for providing the base matrices poses potentially severe problems for model calibration: in practice, it is standard to derive the cost matrices compatible with an assumed ‘reasonable’ level of demand, and to then hold them constant while calibrating the demand model.

3.1.19 A particular issue for the calibration is the hierarchical structure between mode and destination choice. A structure of mode choice conditional on, or simultaneous with, destination choice is often adopted. However, there is, if anything, stronger empirical support for a structure of destination choice conditional on mode choice (see, for example, the LTS91 model for London and the CSTM3 model for Scotland). This is typically found when the choice is between public and private modes of travel. Whichever structure is adopted it is essential to ensure that the cost-sensitivity of the primary (upper level) choice is not larger than it is for the conditional (lower level) choice. The following advice is taken from DMRB Vol. 12 Section 1, Chapter 17: There are no overwhelming reasons for selecting a particular modelling procedure a priori, and decisions on modelling adequacy and sophistication must be based on information acquired through observation. Little information is readily available about the
performance of modal split models used in past studies. Model validation is, however, an essential part of the modelling process and efforts should, therefore, be made to determine how well the model performs against observed data.

3.1.20 Finally, as has often been pointed out, structures based on simple logit assumptions do not normally produce matrices of movements which accord closely with ‘observed’ data. In practice, either an incremental approach is adopted, or a sufficient number of constants (or ‘K-factors’) are added to the model specification to improve the fit. From a theoretical point of view, there is little difference between these two methods.

3.1.21 When the model distinguishes different time periods, the cost matrices are likely a priori to differ by time period, raising a question of which cost matrix should be used in the demand model. If a time of day choice component is also included (though this is virtually never done in a spatially detailed model), then, assuming, as is likely, that it is below the model(s) of mode and destination choice, there is a theoretically preferred approach: the cost matrices should be the ‘composite’ matrices over the available time periods. In practice, for reasons of simplicity, it is normally assumed that particular purposes are dominant in particular time periods, and the demand model is calibrated on the costs for the selected time periods only. For example, the Home-based Work model is calibrated on peak costs, while Home-based Other is calibrated on off-peak costs, as in LTS91. There are potential incompatibilities here, but they are usually not severe.

3.1.22 Note that prior to assignment, it is necessary to convert from a P/A basis to an O-D basis. This is described in more detail below.

3.2 The Supply Model

3.2.1 There is much useful discussion of the development of spatially-detailed road traffic and public transport passenger assignment models in Sections 6.10 and 6.11 of the IHT’s Guidelines on Developing Urban Transport Strategies, to which the reader is referred.

3.2.2 The calibration and validation stages for the supply element of transport models are even more closely intertwined than for the demand stage. It is frequently the case that the data used for assignment model validation is not truly independent. If the validation process shows the model to be deficient in some respect, then there is often no alternative but to use the validation data as part of any re-calibration process. This is particularly the case where a re-estimation of the matrix is deemed necessary and validation counts are the only available source of data.

3.3 The Road Traffic Assignment Model

3.3.1 Calibration of spatially detailed road traffic assignment models involves global procedures such as adjustment to the relative values of the generalised cost components, time and distance. At a more detailed level, adjustments to the coded network are made so that there is a closer representation of local traffic conditions. The validation process can be considered under three headings:

- matrix validation against screenline and cordon counts, and against observed trip movements;
- network validation procedures such as the checking of coded link lengths and examination of inter-zonal paths; and
- assignment validation involving comparison of observed and modelled data for link flows; turning movements; traffic queues and journey times.
3.3.2 Although the assignment stage is a route choice modelling exercise, it is rare for observed route information to be available for the model validation process. Assignment models generally need to be run many times before all significant problems associated with network and matrix definitions are removed.

3.4 The Public Transport Passenger Assignment Model

3.4.1 The validation process for a public transport passenger assignment model can also be divided into three levels:

- matrix validation against screenline and cordon counts and observed trip movements;
- network, route and service validation which primarily involves checking that the modelled flow of public transport vehicles is consistent with roadside counts; and
- assignment validation, which involves comparing modelled and observed:
  - passenger flows across screenlines and cordons, usually by sub-mode but sometimes at the level of individual bus or train services;
  - passengers boarding and alighting in urban centres; and
  - vehicle journey times.

3.4.2 Calibration of the model usually involves adjustments to the relative valuation of the generalised cost components, for example, walk time, wait time and interchange penalty. Where logit models are used within the multi-route and sub-mode choice processes, the degree to which they spread trips across competing routes can be adjusted. In common with highway assignment models, there is a tendency for independent validation data to be used within the calibration process, and thus the two stages become closely intertwined.

3.5 Seeking Equilibrium Between Demand and Supply

3.5.1 The management of the equilibrium process for spatially detailed models remains relatively unsophisticated. There is little experience of the use of ‘objective functions’ (as discussed in Section 1 above), though work with the NAOMI model has attempted to rectify this. Hence convergence is normally attempted by means of, at worst, a standard ‘cobweb’ (which may not converge), or, at best, some damping procedure applied to the demand estimates.

3.5.2 Within such an iterative sequence, it is often the case that relative arbitrary control procedures are applied: e.g., in relation to how many iterations of a particular process to carry out. The development of appropriate convergence statistics remains rudimentary.

3.5.3 One reason for this is that the demand and supply models for a spatially detailed system are intrinsically separate, and require quite an elaborate interface. In a multi-modal context, the demand models will operate on a person basis, and, as noted earlier, the matrices with which the model deals are in the P/A format. The supply model, on the other hand, is interested in the origin and destination of each particular movement, since the operation of capacity is essentially independent of at which end of the movement the trip is deemed to be ‘produced’. Additionally, on the highway side, capacity relates to vehicles, not persons.
3.5.4 Thus in moving from demand to supply, the following interface procedures are carried out.

- **Convert from P/A to O/D.**
  
  Typically this is done by applying purpose-specific and time-specific factors, relating to the proportion of outbound and return movements that occur in each time period by purpose. These factors may be assumed constant (usually derived from data which includes little or no spatial variation), or, in more exceptional circumstances, would be supplied, on a policy-specific basis, by a time of day choice model.

- **Converting from person to vehicle basis, for the car mode.**
  
  Again, this is normally done by assuming a constant occupancy (possibly varying with purpose and/or time of day - this could be derived from the RSI data, or national data such as NTS). In some demand models, however, the choice between car driver and car passenger may be explicitly represented, in which case the vehicle matrices are aligned with the car driver matrices, and the occupancy is derived from the modelled ratio of passengers to drivers.

- **Aggregating over purposes.**
  
  In most cases, the supply model will not be sensitive to purpose variation, though a possible exception occurs in the case of Business travel, where the value of time for route or sub-mode choice may play a role.

3.5.5 A final possibility for the interface is to allow, at the assignment stage, a modification of the demand model matrices to reflect more closely 'observations' of journeys on the networks, typically by means of sector-specific factors. This can be seen as a variant on the incremental demand procedures discussed earlier.

3.5.6 Given appropriate matrices, these are then passed for assignment to the supply models. The output is, essentially, matrices of generalised cost components (in-vehicle time, waiting time, money costs etc.), which need to be combined into appropriate matrices for the next iteration of the demand model. As noted earlier, there is often a potential incompatibility between the definitions of generalised cost in the supply and demand models, and this requires careful treatment where multiple routes between origins and destinations are allowed for in the supply model. The resolution depends, ideally, on the details of the assignment. From a practical point of view, the best approach is to use flow-weighted averages of the generalised cost components: however, not all software packages permit ready calculations of these quantities.

3.5.7 In the case of highway movements, whether operating costs are explicitly used in the supply model or need to be 'externally' calculated from the time, distance and speed characteristics of the chosen paths, it must be remembered that these are on a vehicle basis, and that the same factors used for the demand/supply interface need to be applied in reverse to place the generalised costs on a person-trip basis.

3.5.8 From the point of view of guidance, in the absence of an 'objective function' approach, it would be best to apply a volume-averaging technique to the demand estimate, prior to carrying out the demand/supply interface, and to test convergence on the cost component matrices.
3.6  Forecasting

3.6.1 Section 5.2 provides a summary of the forecasting data that ITEA division will be making available to modellers, and how these fit together to form a standard forecasting framework.

3.6.2 The recommendation is to apply appropriate zonal growth factors to the base matrices in order to derive a ‘reference case’ matrix, on the assumption of no change in costs. This locates the future demand curves. The subsequent iterative sequence begins by updating the supply model, to reflect network changes and global forecasts relating to fuel prices, public transport fares etc., and then proceeding to equilibrium in the standard way.

3.7  Data Requirements

3.7.1 The data requirements can be grouped under three major headings:

- planning data (including car ownership forecasts);
- network data; and
- travel data.

3.7.2 The first of these, apart from the issue of local zonal detail, can be provided by the DfT, ITEA division. Disaggregation to the zonal level for the study can be done on a more or less mechanistic basis. Network data are likely to be available at some level of detail, but will usually need to enhanced: while this may be time-consuming, the principles are straightforward.

3.7.3 It is undoubtedly in the travel data, which is crucial for providing matrices for the demand model, that the greatest difficulties will be experienced. RSI and on-board surveys will usually be required, plus volume data such as counts and ticket sales. While household data would be useful too, it will not normally be a feasible option, though any available data should certainly be used, and small ‘top-up’ surveys may have a role to play.

3.7.4 The Census Journey to Work matrices should be considered as a potentially useful form of data for the home-based work purpose.

3.7.5 For further information on data, see Data Sources (TAG Unit 3.1.5) in this Guidance and the DMRB.

3.8  Applicability

3.8.1 Models of this kind are most important when output relating to spatial detail is essential, such as when a transport plan is the required output. Although the possibility of a hierarchically zoned system should not be discounted, the preference is towards a single (spatial) level model with as much spatial detail as possible.

3.8.2 It will be rare that spatially detailed models can be developed at the level of demand disaggregation discussed here, and the implicit compromise is that the number of distinctions will be reduced. Nonetheless, it is unlikely that it will be acceptable to aggregate demand categories below the level of three purposes (home-based work, employers’ business, other) and two person-types (with car, without car). If the computational implications of such a shorn-down system are still too large, it will not be feasible to make use of spatially detailed models for the problem in hand.
4 Spatially Aggregate Transport Models

4.1 The Demand Model

4.1.1 A general description of the demand model is set out in the IHT’s Guidelines on Developing Urban Transport Strategies, in Section 6.6 under the heading of “Strategic Transport Models”. Note that the IHT Guidelines contains an additional category of “Policy Analysis Models” in Section 6.4: these are, however, highly specialist models which involve, in particular, a treatment of time of day choice which is likely to be too detailed for most studies.

4.1.2 In essence, the different stages are very close to those of the previous Section. However, a key distinction, facilitated by the relative lack of spatial detail, is a reliance on a set of base matrices from which the demand model ‘pivots’. It needs to be pointed out that these models have been almost entirely applied in urban areas where significant amounts of data, typically at a greater level of spatial detail, already exist. This means that the impact of the data problems has typically been of much less concern. Nonetheless, in the absence of such data, the problems in determining the base matrices is not appreciably less than that relating to spatially detailed applications.

4.1.3 Even assuming that a reasonable amount of spatially detailed travel data exists in the area, this will not generally extend to non-mechanised modes. These will therefore need to be synthesised in the same way as for spatially detailed models. However, given the larger zone sizes, much more attention needs to be given to the treatment of intra-zonals.

4.1.4 Working off a pivot matrix, the equivalent of the trip generation stage merely provides, for some or all modelled purposes, the sensitivity of the number of trips leaving each zone (Productions and Origins) to changes in overall accessibility. This ‘frequency’ component is thus in contrast to the standard assumption with spatially detailed models, in which it is normally assumed that the level of trip making is not sensitive to network conditions: nonetheless, the effect is usually small.

4.1.5 In form, apart from the use of an incremental or ‘pivot’ methodology, the trip distribution and modal split models correspond closely to their spatially aggregate counterparts. However, unlike them, the models are not usually calibrated: instead default parameters, applied to the change in generalised cost compared with the base, are used, based on evidence from reviews of other studies.

4.1.6 Alternative hierarchical structures are available as defaults, and these include a model of time of day choice. Typically, the main variation in hierarchy is by purpose. The demand models are almost exclusively of the (incremental) logit type, based on (changes in) generalised cost.

4.1.7 In line with the principles of spatial aggregation, the demand models typically include a large number of segments.

4.2 The Supply Model

4.2.1 The process of calibration and validation of the supply element of spatially aggregate models is in principle the same as for spatially detailed representations. However, the validation process in particular is complicated by the fact that the model does not output measures such as flows and journey times on individual roads. Therefore, whilst matrix validation is straightforward, it is usually only possible to undertake approximate network and assignment validations.
4.2.2 Assuming that the matrix flows are correct, the main purpose of the validation exercise for a spatially aggregate model relates to its ability to sensibly alter travel costs in response to demand changes. Note that with spatially detailed models, the assumption is made that the ability to represent in detail the base year link/turn flows and journey times is sufficient evidence of ability to respond in an appropriate way to demand changes. This is not the case with aggregate models, as such detailed tests cannot be carried out.

4.2.3 Where spatially aggregate highway supply representations have been derived directly from manipulation of a validated detailed model (see Section 1 above) to form a hierarchical modelling process, the following procedure should be applied:

- the total travel demand in the two models should be checked for comparability;
- factors (upward and downward) should be applied to both aggregate and detailed model trip matrices;
- factored matrices should be loaded onto the aggregate and detailed supply representations;
- inter-zonal journey times for the detailed representation should be aggregated (using a trip weighted averaging process) and compared with the aggregate model results.

4.2.4 A similar process can be used to compare estimates of flows on a strategic highway network made separately by detailed and aggregate supply representations, if such a network is a feature of the spatially aggregate model. Tests of a similar nature can also be applied for public transport flows and journey times if a spatially detailed public transport model is available.

4.2.5 Where a spatially detailed model is unavailable, it will be necessary to carry out base year comparisons of modelled flow and journey time with observed data, at the least aggregate level the model definition will support. Tests of the aggregate supply should be carried out with matrix factoring as defined above, and the results obtained compared against experience from other model validation exercises and published data on the form of aggregate speed/flow relationships.

4.3 Seeking Equilibrium Between Demand and Supply

4.3.1 Although, given the general programming structure in which these models are run, there would seem to be reasonable possibility for the use of ‘objective function’ methods, to the authors’ knowledge this has not been attempted. However, the reduced level of detail at the supply/demand interface means that the number of quantities which require to be tested is, relatively speaking, far more manageable. This has led to the formulation of relatively heuristic iterative systems, which generally yield satisfactory convergence, albeit in numbers of iterations which would be prohibitive in a more spatially detailed system.

4.3.2 The interfaces between supply and demand are essentially the same as those discussed in relation to Spatially detailed models: thus, adjustments for P/A to O/D, persons to vehicles, and aggregation over segments. However, by design these are all carried out within the overall model ‘shell’. Furthermore, because the supply model is far less detailed than in the spatially aggregate, network-based, approaches, it is far less computationally demanding.

4.3.3 The heuristic approach normally used assumes a pure cobweb as default, but evaluates after each iteration whether convergence has actually improved, and
if not, applies a ‘step-length’ procedure to average between successive iterations.

4.4 Forecasting

4.4.1 The basic forecasting methodology is identical to that of the ‘reference case’ approach for spatially detailed models. Up till now, however, because the spatially aggregate models have been explicitly multi-modal, and NTEM forecasts were only available for the car driver mode, it was necessary to make use of default trip rates within the context of an ‘External Forecasting Model’. Once all-mode NTEM trip ends are available, the forecasting process can be put on an entirely consistent basis. Contact ITEA division for further details.

4.5 Data Requirements

4.5.1 The ‘network’ needs to be set up, and there may be a requirement to derive appropriate aggregate speed/flow relationships. These can be obtained from existing conventional networks.

4.5.2 The main requirement is a set of base matrices representing existing travel, at a substantially segmented level of detail, although applying only to movements between and within large zones. As already noted, the means of providing these from scratch follows essentially the lines of the spatially detailed procedures, and does not represent a greatly reduced burden.

4.6 Applicability

4.6.1 In cases where base data are not readily available, the main advantage which the spatially aggregate models have is in terms of turn-round. Thus, they will be especially valuable when it is required to investigate a large number of relatively ‘global’ policies. In addition, their greater level of detail on the demand side makes them more appropriate when investigating more radical changes in cost. They are unable, however, to provide useful assessment of policies which are highly spatially specific, such as the impact of alternative lines of an LRT system. In summary, they are particularly appropriate for transport strategy development but not at all useful for transport plan studies.

5 Multi-Modal Forecasting

5.1 A standard Framework

Which demand responses should be modelled?

5.1.1 Research suggests that total trip rates vary relatively little between areas with quite different costs of travel, once significant differences between “person types” are allowed for, and all trips (including relatively short walk trips) included. However, trip lengths and mode choices (and thus the total travel by each mode) vary significantly according to the characteristics of the travel choices available.

5.1.2 A good simplification in multi-modal forecasting is, therefore, to treat the total number of trips as being constant within each planning scenario, but - at least in principle - to model changes in mode and destination choices in response to changes in generalised cost, which arise both from congestion and the impact of policy action.

5.1.3 In looking at the impact of different policy measures, the numbers of trip ends should be fixed, and based on new NTEM figures which will be provided by the Department. These may be adjusted to represent different local planning scenarios.
How should mode share change over time?

5.1.4 The new NTEM tripend growth figures will cover all modes combined - it is for the local model to predict any change from the base year split between modes, in response to changing land use patterns and travel conditions. The “pure demand” element of change in modal split should be represented by segmenting the model by car ownership band, so that, as car ownership increases over time, the overall modal split will shift towards that pattern of use characteristic of households with full car availability.

5.1.5 The Department will provide NTEM tripend growth factors by car ownership band. This is not a forecast - it is a reference case, based on an assumption that: existing land uses grow uniformly in a way that is consistent with NTEM planning data, perceived transport costs and value of time remain constant within each car ownership band, traffic by each mode will grow at the same rate.

5.1.6 Since within this reference case the same growth factor is applied to each mode, the forecasting process does not require the model to include all modes of travel. The forecast future year modal split from each study will depend on the local planning scenario fed into the model income-driven changes in car ownership and value of time changing costs arising from congestion, changes in the provision of public transport, and policy action.

5.1.7 The Department will also provide data to assist local modellers in representing the base year situation, including an estimate of base year (1998) trip ends split by mode, and average trip length distributions by mode, taken from the National Travel Survey.

Which costs are reliable enough to use in practice?

5.1.8 Most studies will have a “modelled area” in which all travel by the modelled modes is represented, so that network travel times can reasonably be derived as a function of the amount of travel on the relevant links/corridors (i.e. a supply curve). Public transport data can be obtained from local public transport operators. Modellers will thus have relatively good information on the generalised costs of trips from one zone to another within the modelled area.

5.1.9 For intra-zonal trips, both the cost estimates and the base number of trips are likely to be a lot less accurate, so care needs to be taken that results are not unduly influenced by figures which are not robust. Options to consider include:

- Making the zone size small enough such that intra-zonal trips everywhere are a negligible proportion of traffic, which can be omitted from the modelling entirely;

- Representing the contribution of intra-zonal trips to link costs (e.g., by pre-loading links of the network with an appropriate small amount of traffic), and including in the appraisal the impact on these trips of changes in network cost, but not allowing for any intra-zonal demand changes in response. [In other words, assuming that the change in intra-zonal trips is negligible so they can be treated on a fixed-matrix basis];

- Including intra-zonal trips in the demand model, using an appropriate average trip length for intra-zonal trips in each zone, taking speeds from relevant links of the network.

The choice will need to be guided by the relative importance of intra-zonal trips in terms of the problems that the study is addressing.

5.1.10 For trips with one or both ends outside the modelled area, base year link costs for the external links will need to be derived. Zones remote from the study area
are likely to be large, and costs correspondingly approximate. External trip ends should not be allowed to redistribute, but it may be appropriate to model modal split (both for internal↔external and external↔external trips). In general, the network should not include routes for external↔external traffic to avoid the modelled area, as it is difficult to ensure comparability of costs.

How should costs be specified?

5.1.11 It is important for models of behaviour to use realistic measures of generalised cost. For car travel, this might include elements of fuel cost, parking cost, travel time, parking/access time (the time - from arrival at the nearest point of the road network to the destination - needed to find a parking space, park the car, and proceed on foot to the destination itself). For public transport, generalised cost elements might include fare, travel time, access/egress time, waiting time (conventionally valued at twice travel time), and some form of interchange penalty. For walking and cycling, generalised cost is likely to be modelled as travel time only.

5.1.12 NTEM tripends will be segmented by car ownership band, to assist modellers in reflecting the different choices available to those with and without a car. The Department will provide standard assumptions on change in car occupancy over time, as a function of the car ownership projections underlying the NTEM tripends.

How do costs change over time?

5.1.13 Although we refer to “generalised cost”, it is usually appropriate to model this in time units, and assume that the sensitivity to a one-minute change is constant over time. Money cost elements in the cost function therefore need to be multiplied by a figure to represent the time-equivalent value of money (equivalent to dividing by the value of time).

5.1.14 For the forecasting stages of the studies, current best assumptions on growth over time in car occupancy, fuel cost and value of time are provided in HEN2 (DMRB Volume 13 Section 2). Study teams will need to consult local public transport providers and the Strategic Rail Authority to agree assumptions on change in public transport cost elements over time.

5.1.15 Changes in the journey time on the external road network should be taken from NRTF97. The Department will provide a table of speed changes by road type over time.

Policy action

5.1.16 Local Transport Plans and (where available) Regional Transport Strategies should be consulted to give an idea as to the sorts of measures currently being considered by local authorities, which the modelling work will need to build in to the different packages of measures being appraised.

5.1.17 It will generally be appropriate for studies to consider a range of local planning scenarios. It is important that such scenarios are realistic, and agreed with local planning authorities and study Steering Groups. At least one run of the model should be undertaken with unmodified NTEM planning data inputs, to provide a benchmark from which to assess the transport impacts of locally-generated alternative planning scenarios, which may involve more or less development.

5.1.18 Travel in each study area may be influenced by policy decisions taken in other areas, or by central government. (For example, a journey from London to Leeds may pass through a number of study areas, but be more influenced by parking policy in Leeds and road charging policy in London than by conditions in the study areas en route.)
5.1.19 Modelling is a tool for informing policy debate and decisions. Clearly each study cannot require as an input the policy decisions based on the outputs of all the other studies. Conversely, a study is of no use if its conclusions are immediately thrown into question by measures under consideration in adjacent study areas. Modellers will need to undertake sensitivity tests to ensure that conclusions are robust to “reasonable” measures taken by other authorities.

5.2 Summary of forecasting data available from ITEA

- All-modes tripend growth factors by car ownership band (which will supercede car driver tripend growth factors in TEMPRO), & associated planning data.
- Base year tripends by mode at ward level, and national trip length distributions by mode (from NTS), both for use in matrix estimation.
- NRTF97 speed changes by road type, for use on external network.

6 Further Information

The following documents provide information that follows on directly from the key topics covered in this TAG Unit.

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7 References


8 Document Provenance

This Transport Analysis Guidance (TAG) Unit is based on Appendix A, including Annex 1 of Guidance on the Methodology for Multi-Modal Studies Volume 2 (DETR, 2000).

Technical queries and comments on this TAG Unit should be referred to: Integrated Transport Economic Appraisal (ITEA) Division Department for Transport Zone 3/08 Great Minster House 76 Marsham Street London
Land-Use / Transport Interaction Models

TAG Unit 3.1.3

June 2005

Department for Transport

Transport Analysis Guidance (TAG)
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1 Introduction

1.1 This TAG unit provides an introduction to land-use/transport interaction models. It has two sections, as follows:

- in Section 2, the general principles of land-use modelling are set out; and
- in Section 3, the different kinds of land-use model are introduced.

2 General Principles of Land-Use Modelling

2.1 Introduction

2.1.1 Some studies may require the use of a land-use/transport interaction model rather than simply a transport model. In simple terms, the transport model requires inputs of land-use which have been forecast exogenously, whereas land-use/transport interaction models generate their own forecasts of land-use dependent on input land-use policies and the changes in accessibility brought about by conditions on the transport system. As land-use models are not in wide-spread use, the principles of land-use models are explained in some detail.

2.2 The Meaning of ‘Land-Use’

2.2.1 The term ‘land-use’ is used throughout this report to mean a range of human activities, the state of the built environment, and also to some aspects of the natural environment.

2.2.2 ‘Land-use’ so defined is of relevance to ‘transport’ for at least three reasons:

- land-using activities and the interactions between them generate the demands for transport;
- those activities and interactions are to a greater or lesser extent influenced by the availability of transport; and
- the linkages between transport and activities may be important to the appraisal of transport strategies - especially when trying to consider whether the transport system is providing the kinds of accessibilities that activities (i.e. people and businesses) require, rather than simply providing mobility.

2.2.3 Figure 2.1 illustrates the role of transport in relation to the different groups of people and organisations who are influenced by transport. It identifies three main categories of actors:

- the population, as individuals and as households;
- firms and other productive organisations; and
- government.
Figure 2.1 Actors and Markets in Land-Use/Transport Interaction Models
2.2.4 In addition, it identifies three particular categories of actors of special interest:

- property developers,
- transport infrastructure providers, and
- transport service providers (e.g. public transport operators),

which may be special cases either of firms, or of government activity, or both.

2.2.5 The term ‘land-use’ includes all of the elements and interactions in Figure 2.1 outside the area labelled ‘transport’, except for those particular effects which we define as ‘environmental’.

2.2.6 Transport influences the decisions of residents and firms in a number of ways, which are considered in more detail below. Residents and firms interact with each other through a number of markets, mainly:

- in property,
- labour, and
- goods and services.

2.2.7 Through these interactions, changes in transport may have indirect impacts on people or businesses who have no direct interest in the transport change at all. It may therefore be necessary to consider not only predicting the land-use consequences of transport change, but also the implications for appraisal of the way in which the influence of transport is passed on through the interactions of different actors.

2.2.8 It is important to recognise that the ‘land-use’ system is never static, and that ‘transport’ is only one of the factors that influence how it changes. The treatment of all the other factors - such as demographics, the workings of the development process, etc. - are among the things which distinguish the different approaches to land-use modelling reviewed below.

2.2.9 The following points also need to be noted in order to clarify the scope of the following discussion:

- the land-use impacts of a transport change may extend far beyond the spatial scope of the transport proposal itself - they can extend at least as far as the area in which the transport change affects accessibility, and secondary effects may extend further;

- a great deal of locational change takes place through changing occupation of existing buildings, with changes in either the density or the nature of the occupation (for example, one type of business replacing another, or retired persons occupying housing previously occupied by families with children);

- the value of property is an important influence on its occupation; if improvements in transport increase the demand for space in a particular location, the resulting increases in rents may affect households or businesses who have no direct interest in the transport change itself; and

- it follows from the above points (a) that in many cases changes in composition are likely to be more significant than changes in totals - for example, changes in provision for commuter travel may have a significant impact on where the working population and its dependants live, but a much smaller impact on the distribution of the total population (as
households without workers move into the areas that the workers are leaving); and (b) that significant land-use effects may occur within the market for existing property, with no new development and no formal change of use, and therefore beyond the control of the planning system.

2.2.10 It should also be noted that 'regeneration', 'socio-economic impacts' and so on are all particular cases of what are here referred to as land-use effects.

2.3 The Scope of Land-Use Models

2.3.1 The 'land-use' components of 'land-use/transport models' cover varying proportions of 'land-use' as defined above. In most cases their representation of the physical use of land is only a small part of the overall model. In some cases, the physical use of land is not considered at all.

2.3.2 A critical aspect in reviewing land-use models is not only to consider what categories of activities they represent, but what kinds of responses of those activities can be predicted - for example, whether households can choose not only to relocate, but also to change the type or size of dwelling they occupy. To begin this discussion, Figure 2.1 has been expanded so as to identify, in Figure 2.2, the main types of decisions made by the different categories of 'actors'. An additional category of actors has been added, that of 'investors', in the top right. In the conceptual model, this includes all those investors who may invest in the area under consideration, many of whom are resident outside the area itself.

2.3.3 For clarity, no attempt has been made to show within the diagram that many individuals are actors in more than one category - for example, self-employed persons are producers as well as residents, and many residents are also investors. Note also that one of the most important 'actors', government of all levels, is omitted, even though its intervention through regulation, taxation and investment is an actual or potential influence on almost all the decisions considered. Much of the development of operational models has been led by the need to consider the impact of such interventions, given the behaviour of all the other actors involved. It is important to keep in mind that in land-use modelling, the location of activities (and in many cases the location of the development they occupy) are outputs of the model, and that the models take a description of 'planning policy' as input; this contrasts with the conventional 'planning data' used in transport-only models, which corresponds with the outputs (e.g. population and jobs by zone) of land-use models.

2.3.4 The lines on the diagram show the major interactions between different categories of actors, classified so as to identify the main 'markets' in factors, goods and services. The directions of the arrows on the diagram are such that:

- the arrowheads show the delivery of a factor, good or service; and
- payment for that factor, good or service goes in the opposite direction to the arrow.
Figure 2.2 Actors and Markets in Land-Use/Transport Interaction Models: An Expansion
2.3.5 Information also flows in both directions along each of the relationships indicated by arrows. This represents the often very partial information which people and firms obtain from the interactions with the market. Other information is obtained in other ways, which may themselves involve purchasing goods and services (e.g. market research reports, special surveys, newspapers with job and property advertisements, etc).

2.3.6 The five markets are, from top to bottom of the diagram:

- the financial market(s);
- property markets;
- labour markets;
- product markets (including both goods and services); and
- transport markets.

2.3.7 Note that the first three of these are markets in the conventional factors of production (capital, land and labour), and that the markets in transport are a special case of the markets in services. No attempt has been made to separate categories of goods and services that are delivered via non-market mechanisms, such as, for example, public (state) education, and there are other whole sub-systems, such as taxation, welfare and benefits, which affect the behaviour of actors. The scope of the diagram as it stands is simply that which seems helpful to the discussion of ‘land-use/transport interaction models’. For this discussion, however, the possibilities are included that products may be:

- exported;
- consumed by the government; or
- used in fixed capital formation (the arrow from product markets to the ‘invest’ action of producers); and also that they may be;
- supplied by imports to the economy under consideration as well as by local production.

2.3.8 The bold lines linking the transport market to the rest of the system emphasise that transport is generally a ‘derived demand’, derived from some other aspect of the economy. In the diagram, the derivation of demands is split into five segments:

- transport demands associated with product markets, that is, with the delivery of goods and services (through the movement of goods and persons, including consumers going to purchase goods or services) to intermediate or final consumers;
- transport demands associated with labour markets - mainly the movement of persons travelling to work;
- other travel demands associated with the activities of producers - these represent all business demands, mainly for passenger travel, not directly associated with trade in goods or services (e.g. travel to conferences, to internal company meetings, to meetings with regulatory bodies, etc.);
- residents’ travel demands other than travel to work or to obtain goods and services, i.e. all other personal travel; and
transport demands associated with transport supply itself (e.g. the significant proportion of rail freight which is generated by maintenance and renewal of the railway itself).

2.3.9 The bullet points listed under some of the ‘actor’ headings are general descriptions of key types of decisions that have to be taken by these categories of actors. The conduct of business by producers is generalised into:

- where to locate the business unit;
- investment in the unit - how much to invest, in what equipment;
- recruitment - what categories of staff to employ, how many, for what hours, at what wage rates, etc;
- purchasing - what intermediate goods and services to purchase, from whom;
- production - how much of what to make and when; and
- marketing - which markets to try to sell in, what to do to achieve this, etc.

Many decisions, particularly major ones, will of course deal simultaneously with most or all of these areas.

2.3.10 For residents, activities are classified into five headings:

- where to locate (and hence what land and floorspace to occupy);
- training - what (if anything) to do to obtain/maintain employable skills;
- work - whether or not to work, for whom, doing what, when, etc;
- purchasing - how to spend (or save - note link to investors) income derived from work or other sources; and
- other activities - everything else.

Note that the first three determine each person’s involvement or otherwise in the labour market, and hence collectively the ‘labour supply’, whilst ‘labour demand’ is determined by the location and recruitment decisions of producers.

2.3.11 The diagram, and the discussion of it, could of course be further elaborated, and it should be emphasised that it is a partial view of the world. As it is currently drawn, attention is drawn to just a few other influences on activities and decisions, indicated in brackets. These are:

- technological progress as an ‘exogenous’ influence on producers (in the sense that even if firms are technological leaders and innovators in their particular fields, they are strongly influenced by the development of technology in other aspects of the economy);
- natural demographic processes (ageing) and social effects (marriage/cohabitation, separation) on residents and their grouping into households; and
- network effects (congestion) in the transport system (as distinct from the deliberate responses of transport operators and suppliers).

2.3.12 There are of course many models which represent particular processes or effects (such as local demographic change) without relating it to transport. To
be of interest to the present studies, a model or modelling package must include:

- some form of spatial representation of producers, residents, and transport supply (not necessarily traced back to transport suppliers);
- links from the transport markets to the activities and markets which use transport, such that changes in transport have at least some impact on some decisions or responses of producers and residents; and
- scope for links from producers and residents, and/or from labour and product markets, to transport markets, as the main or only process by which transport demands are derived.

2.3.13 If it is decided that a particular study needs to model the impact of transport on land use (including economic and social impacts, etc.), there will be two options:

- to apply a simple model which predicts the land-use impact of transport change on the assumed planning data, but does not include the feedback from that land-use impact back to transport; or
- to apply a more complex model which includes both linkages, i.e. a full land-use/transport interaction model.

Note that, in the former simple model case, some other part of the modelling system will need to convert the assumed planning data into future transport demand; in the case of a full land-use/transport interaction model, this will be a central part of the overall model system.

2.3.14 The DSC/ME&P Report to SACTRA discusses the scope of various models, including sketching out their coverage of actors and markets as defined in Figure 2.2; the significance of this is considered further in Section 3.

2.4 The Main Approaches Available

2.4.1 The range of models currently available is considered below, along with the extent to which they address the scope for modelling defined above. At this point in the discussion, it is useful to introduce one major distinction which allows the available models to be classified in two broad approaches.

2.4.2 The discussion around Figures 2.1 and 2.2 has already mentioned that the subject of ‘land-use’ includes both the location of activities (and various aspects of their behaviour in those locations) and the economic interactions between activities in the various markets. These economic interactions - such as the flow of labour from homes to workplaces, or of goods from producers to consumers - are not generally identical with transport demands, but are clearly closely related to them. There is equally clearly a close relationship or identity, in many cases, between the measures of economic interaction and certain measures of activity location: for example, the row or ‘home’ totals of a matrix of labour (measured in workers) flowing from homes to workplaces must equal the number of working residents living in each zone, whilst the column totals of that matrix must equal the number of filled jobs in each zone.

2.4.3 Models can be classified according to how they link the location of activities and the spatial interactions between activities. This classification is important both to understanding the thinking behind different models and to practical questions of how they are implemented and used to appraise policies.

2.4.4 One approach takes the interactions between activities as the key variables. These are predicted, and then the location of activities is calculated from the
total levels of interaction. For example, the number of households living in a zone is found by predicting the number of workers commuting from that zone to each possible workplace, finding the total workers resident, and then factoring from workers to households. The patterns of interaction are also factored, from persons to trips, to give transport demand matrices. This approach may be called the “interaction-location” or IL approach, since the central feature is that the predicted interactions determine the location of activities. Such land-use/transport models can also be called “integrated” models, since the distribution of transport demand is wholly predicted within the land-use model. This means that the land-use and transport components of the overall model system cannot be separated.

2.4.5 The alternative approach first predicts the location of land-using activities, and then models the interactions between those located activities. This can obviously be called the “location-interaction” (LI) approach. This allows the number and location of the different kinds of activities to be determined by separate sub-models. These can consider any appropriate influences, but include measures of zonal accessibility, which reflect the scope for interactions from each zone. Hence, for example, a sub-model for residential location will include measures of accessibility to work and to other destinations. The interactions between activities are then controlled by the location of activities. These interactions may be modelled in economic terms, or may be predicted directly in terms of travel demand.

2.4.6 This LI approach leaves the distribution of transport demand at least partly to the transport model. The overall model therefore consists of a complete transport model linked to a land-use model, rather than part of the transport model being embedded within the land-use model. The approach can therefore be described as “linked”, in contrast to the “integrated” approach described above.

2.4.7 Various points about these alternative approaches should be noted.

2.4.8 Firstly, IL or integrated models tend to be defined in terms of finding the equilibrium location and interaction of the different activities considered, given certain fixed variables such as a “basic” or exporting sector of employment and the supply of land or floorspace. This is necessary because of the way in which the number and location of activities is built up from their interactions with other activities. For example, this approach generally requires that households are “generated” by the demand for their labour, and that demand depends in part on households’ demands for services. This linkage has to be run to equilibrium, otherwise households and jobs will disappear from the system.

2.4.9 In contrast, the LI or linked approach need not have any equilibrium between the location and number of different activities – it can for example readily predict an increasing supply of labour in an area of decreasing demand, and the resulting unemployment.

2.4.10 Secondly, IL models by definition predict matrices of interactions which can be converted into matrices of the demand for transport. This may be useful in circumstances where observed transport demand data is unavailable or where a synthetic matrix is needed as input to a matrix-refinement process.

2.4.11 Thirdly, the fact that LI or linked models incorporate a distinct transport model which represents the complete range of transport-user responses is likely to make it easier both:

- to develop a land-use/transport model where a suitable transport model already exists, by adding an appropriate land-use element; and
• to carry out transport-only tests, and hence to produce transport-only calculations of benefit which are currently required as part of the appraisal process.

2.5 Land-Use/Transport Modelling and Strategy or Plan Appraisal

2.5.1 It is probably helpful to split the issue of appraisal in relation to land-use/transport modelling into two subjects: first, the appraisal of transport strategies or plans, with land-use policy held constants, and secondly, the appraisal of alternative land-use policies, alone or in combination with alternative transport strategies or plans. Note that, for the reasons already explained, holding land-use policy constant does not mean that the land-use patterns will remain constant - they may be changed by the effects of the transport strategy or plan.

2.6 Appraisal of Transport Strategies or Plans

2.6.1 The first point to note is that it is currently not possible to conduct a cost/benefit analysis in which land-use changes feed through into travel demand changes. The reason is that, at present, the way in which land-use responses and transport responses are represented mathematically in land-use/transport interaction models are not sufficiently consistent to allow the calculations to be undertaken in a manner which accords with the theory on which transport cost/benefit is currently based.

2.6.2 The economist’s conventional view of the land-use impacts of transport change has been that such impacts change the distribution of costs and benefits - for example, transport benefits initially enjoyed by travellers may be captured by real estate owners through increasing rents - but that they do not modify the total net value resulting. This view would imply that it is not necessary to assess the benefits associated with the land-use impacts at all, because they are simply transformations of the benefits which can be estimated on the basis of a transport-only analysis. There are at least three objections to this view.

2.6.3 The first is that the distribution of benefits is often of concern, both spatially and socially. Most governments have policies which are intended (for example) to redistribute jobs to high unemployment areas, and transport investments which support such policies should be regarded as more beneficial than those which work against them.

2.6.4 The second is that the view that land-use impacts transform and redistribute transport benefits has been shown to be valid only under conditions of perfect competition (Jara-Díaz, 1986). More recent work (Martínez and Araya, 1998) has shown how unrealistic these conditions are, and has started to show how much the measures of benefit are modified by land-use effects. Whilst it appears highly significant, there is much more work to be done both on the issues it raises about how benefits should be evaluated, and if appropriate to implement suitable methods of benefit calculation within other land-use models.

2.6.5 The third, which is perhaps a less formal view of the second, is that if the costs and benefits of a transport scheme change as one expands the scope of the transport analysis, it is implausible that the costs and benefits should not differ further if the analysis is extended into ‘land-use’ effects. For example, the appraisal of a major motorway project will produce one result if it is based upon a fixed matrix of person-trips by road, but a different result if modal choice is taken into account and public transport operator response to changing demand is taken into account (e.g. if transfer from rail to road will lead to a decline in rail services). It is hard to see why further extension to include location and development effects would not lead to further modifications of benefit, especially when one notes that the location effects may be influenced by environmental
externalities as well as by (variables derived from) the generalised cost of transport.

2.6.6 At present, there appear to be two approaches to appraisal in land-use/transport modelling practice.

2.6.7 One effectively ignores the issues identified above, and carries out a relatively conventional transport-only calculation of benefits (based primarily on time and money savings) by testing the alternative transport strategies with land-use held constant. This could be extended by carrying out the test under both the reference case land-use pattern and the modified land-use pattern resulting from the land-use impacts of the strategy being tested; this would show whether benefits increased or decreased as land-use responded. Neither of these sets of calculations would yield the net benefit arising from the combined effect of the transport strategy and the resulting land-use response nor would it tell us how the land-use effects would redistribute benefits.

2.6.8 However, it is possible to examine the predicted land-use effects and to include separately in the appraisal (as envisaged in the new Appraisal Summary Table, see Transport Appraisal and the New Green Book (TAG Unit 2.7)) any impacts which are identified as being particularly desirable or undesirable. Desirable impacts would include regeneration (however defined, e.g. new development, new jobs, or reduced unemployment) in areas where that is a policy objective; undesirable impacts could include very much the same effects in areas where they are considered undesirable (e.g. increased demand for housing and associated pressure for development in National Parks or AONBs).

2.6.9 At the other extreme, at least one modelling package attempts to carry out a comprehensive appraisal of benefits in the land-use system. This does respect the requirement to take land-use effects into account, as outlined above. This, of course, produces measures of benefit different from those in transport-only analysis; it should include the benefit (or disbenefit) that households or firms obtain from paying different levels of rent, from living at lower or higher densities, from being in different (e.g. more or less attractive) locations, and so on. This clearly goes well beyond a conventional transport cost/benefit analysis; however desirable such an extended analysis is, it may come up against the institutional or administrative problems because it is unfamiliar and difficult to relate to the analyses from more conventional models.

2.6.10 Such analysis also raises more technical complications in terms of dealing with the lagged responses to transport in most land-use models. It is no coincidence that the most advanced application of the analysis of both land-use and transport benefits within a land-use model is based upon a system in which the land-use and transport systems are calculated so as to be in complete equilibrium with each other. The more sophisticated the dynamics of the land-use modelling, the more complicated it will be to establish sensible measures of benefit calculated within the land-use system.

2.6.11 There is also an issue of the assessment of environmental effects. In some land-use models, residents (and potentially firms) are influenced in their location decisions by the environmental impacts of transport. Negative transport impacts (e.g. increases in noise and in local air pollution) would decrease the willingness to pay to live in the locations affected, and would generate disbenefits (e.g. to the owners of property in those locations). This might start to duplicate environmental impacts which have conventionally been considered as separate parts of the overall appraisal process.
2.7 Appraisal of Land-Use or Combined Land-Use/Transport Strategies

2.7.1 A major attraction of the comprehensive appraisal of benefits (including the benefits derived from transport) in a land-use model is that such an approach should in principle be able to carry out a consistent appraisal of any combination of land-use and transport elements. This needs to be considered not only as an extension of transport strategy appraisal, but also in terms of its possible role in the land-use planning process.

2.7.2 The idea of a consistent, combined appraisal of land-use and transport choices has a theoretical appeal, and should help to ensure that the wider objectives of land-use planning are not made subordinate to the narrower objectives of transport planning. However, it is beyond the scope of the current practice, and therefore this Guidance, to investigate the complexities of assessing costs and benefits in this area. It is, however, appropriate to note that existing land-use models can provide a wide range of indicators (not just transport indicators) about the impact of alternative land-use strategies, alone or in combination with transport strategies. These indicators are the kind of information expected by current approaches to assessment in both fields of planning, under headings of ‘regeneration’ or ‘socio-economic impacts’ as well as ‘land-use’ itself.

3 Land-Use/Transport Interaction Models

3.1 Introduction

3.1.1 Although land-use/transport interaction (LUTI) models have been in use for many years now, their use in transport strategy development in this country has been, until now, quite limited. As a consequence, there is much less familiarity among practitioners about these models than with the various forms of transport model. Other information on land-use/transport interaction models is in Transport Models (TAG Unit 3.1.2).

3.2 The Main Types of Model Available

3.2.1 The various kinds of LUTI models are classified in Figure 3.3. The first layer of the tree, starting from the top, separates out a group of models whose purpose is to optimise urban systems rather than to predict their behaviour. Such models are intended as tools which can find a ‘design’ to optimise a particular function, and are therefore quite distinct from the majority of models which respond to a ‘design’ input by the user. These optimising models may be informative for research and long-term planning, but in general they require a substantial model development effort in order to link them to the practical planning problems of individual cities or regions. Accordingly, they are not considered further here.
3.2.2 The second layer of the tree distinguishes between ‘static’ and ‘dynamic’ models. Static models represent a single point in time, whereas dynamic models run for a series of time periods, with transport changes generally taking one or more such periods to have an impact on land-use. Much of the early work in land-use modelling consisted of static models which attempted to predict the location of certain variables taking other simultaneous variables as given (see, in particular, Lowry, 1964, and the whole range of Lowry-inspired models considered in Batty, 1976). Such models obviously cannot represent in any ‘realistic’ way the processes of urban change which, by their nature, take time to react to any changing situation. For this reason, static models had ceased to represent the state-of-the-art by the time the ISGLUTI project began around 1980 (see note on ISGLUTI, following the references at the end of the TAG Unit). Static models have, however, retained some relevance to cases where a dynamic land-use/transport model is unaffordable.

3.2.3 Returning to Figure 3.3, it is rather more difficult to classify dynamic models, but it is possible to distinguish three approaches:

- models based originally upon the analogies with statistical mechanics ("entropy") pioneered by Alan Wilson in the 1970s;
- models based primarily upon the integration into a spatial (multizonal) form of separately developed (and often non-spatial) economic models; and
- models based primarily upon representation of the different processes affecting the different types of activities considered.
3.2.4 The range of available models within each of the above groups is now outlined, concentrating on those developed or used in Europe and likely to be available to the present studies. A similar review on a wider basis, including more non-European and research-oriented examples, can be found in the DSC/ME&P Report to SACTRA.

3.3 Static Models

3.3.1 Static models ceased to represent the ‘state of the art’ in land-use modelling some 20 years ago, but are still sometimes used for two reasons:

- as a means of adding a land-use impact dimension to existing transport models, without embarking on the extra work needed to create a dynamic model; and/or
- because the static model represents an equilibrium state which is of interest in itself.

3.3.2 The category of static models can be divided into:

- models which estimate the pattern of land-use given one set of transport inputs; and
- models which estimate changes in land-use given two sets of transport inputs.

3.3.3 The Swedish IMREL model is representative of the single-input approach, whilst DSCMOD is representative of the two-input approach. DSCMOD has been developed by DSC since 1990 for the practical objective of adding a land-use dimension to what would otherwise be transport-only studies. IMREL (developed by Anderstig and Mattsson in Sweden, 1991 and 1992) has been used for both research and planning purposes. These models are described in more detail in Annex A of the DSC/ME&P Report to SACTRA. Many other static models were developed in the 1960s and 1970s for specific studies.

3.3.4 All of these models are linked to separate and usually pre-existing transport models. IMREL estimates equilibrium patterns of land-use corresponding with the accessibilities output by the transport model. DSCMOD, in contrast, assumes that the ‘base case’ land-use forecast is in equilibrium with the ‘base case’ transport strategy, and calculates changes in land-use from the accessibilities produced by alternative transport strategies. In DSCMOD, these accessibility changes may be the only influence on location choice, or may be combined in a more complex mechanism with floorspace constraints and market clearing using rent adjustments.

3.3.5 These models are generally urban models. However, a regional employment version of DSCMOD (Simmonds, 1992; Simmonds and Jenkinson, 1993) has been developed which represents only employment and uses a measure of economic potential (accessibility factored by zonal employment) to relocate jobs.

3.4 Entropy-Based Models

3.4.1 The main UK example of an entropy-based model was the LI LT (Leeds Integrated Land-Use Transport) package (Mackett, 1979 and 1983), which, when developed in the late 1970s, was the most substantial land-use/transport model application for a British city. It is understood, however, that this package is not available for new applications.
3.5 Spatial-Economic Models: MEPLAN and TRANUS

3.5.1 MEPLAN (Echenique et al, 1990) and TRANUS (de la Barra, 1989) are both commercial packages developed from a set of models devised at the Martin Centre at the University of Cambridge. Both MEPLAN and TRANUS have been applied in policy and research studies both in the UK and abroad since the 1980s. Each package includes both a land use model and a multi-modal transport model, and is usually implemented as a quasi-dynamic model. There are many similarities in the broad approach adopted by the two packages.

3.5.2 MEPLAN and TRANUS are the key examples of interaction-location models (see 2.29). The interactions (‘economic trades’) between activities are determined by input-output analysis, and these interactions are used to derive the demand for transport. Location choices, transport mode choices and assignment are determined in a multi-level choice structure based on random utility theory. The location behaviour of households, firms and property developers is based on competitive markets, with incomes and rents determined endogenously in each time period.

3.5.3 A new package, MENTOR, is currently being tested. MENTOR is a land use package that can be interfaced to existing transport models. It builds on the theoretical structures of MEPLAN but operates on a more detailed segmentation of activities and is designed to be more straightforward to set up and calibrate. It retains the key characteristic that the distribution of transport demand is explicitly derived from the interactions modelled within the land-use model.

3.5.4 The MEPLAN package, its application to LASER (a model of London and the South East, which focuses on residential location and the journey to work, shopping and schools) and EUNET (a model of the Transpennine corridor, which places emphasis on industrial location and the movement of freight), and the MENTOR package are all described further in Annex C of the DSC/ME&P Report to SACTRA (DSC and ME&P, 1999). Information on the TRANUS package, including its application in Swindon (which gives particular emphasis to the consumption of energy and generation of polluting emissions) may be found on the internet at http://www.modelistica.com.

3.6 Activity Models

3.6.1 Activity based models are defined by their focus on the different processes of change which affect activities and the spaces they occupy; they are location-interaction models, typically characterised by more detailed segmentation of activities, and more elaborate treatment of both the decision to move and location choice. In contrast to other models, they do not relocate all activities in a time period, but separate the decision to move (which will affect only a proportion of total activities) and the search for a new location. These models also represent demographic change in more detail than any of the models so far considered.

3.6.2 The best-developed model of this type is IRPUD (Wegener, 1982), a model of Dortmund (Germany) developed for research purposes over a long period. The one UK example is the DELTA package, which has been developed by DSC since 1994 (see Simmonds and Still, 1998; Simmonds, forthcoming). DELTA has been applied to Edinburgh and to Greater Manchester, and in an extended regional form (see below) to the Trans-Pennine region. A rather similar model,

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1 For an outline of the history of these models, see Hunt and Simmonds (1993); for more detail, see the 1994 special issue of the journal Environment and Planning B containing urban and regional modelling papers from the Martin Centre 25th Anniversary Conference (see note to the references).
URBANSIM, is currently being applied in the USA to Eugene/Springfield (Oregon) and is to be applied to the Salt Lake City region.

3.6.3 These models are designed to be linked to transport models developed in separate packages\(^2\). Each consists of a number of sub-models representing different processes of change; in the DELTA case, these are physical development, improvement or decline in area quality, car ownership, demographic and economic change, location and the property market, and employment status. One of the characteristics of the focus on processes of change is that the design and calibration of the model draw much more upon other aspects of urban research (in economics, geography, sociology, etc) rather than drawing purely upon other modelling work. Another characteristic is that different processes are likely to predominate at different spatial scales.

3.6.4 A regional version of DELTA has recently been developed and has been applied to the whole of the Trans-Pennine Corridor. This version retains the original processes of urban change within each of the conurbations and other areas, but additional processes of migration and of regional economic change are added to represent the demographic and economic interactions between them. This contrasts with the Martin Centre of representing different scales, from city to continent, by modelling different variables within the same spatial-economic framework.

3.6.5 More details of DELTA can be found in Annex E of the DSC/ME&P Report to SACTRA.

3.7 Modelling Effects, Decisions and Markets

3.7.1 Much of the literature on land-use/transport modelling is concerned with description and comparison of how the models work - what may be called the 'model mechanisms' and the theories or assumptions underlying them. Such presentations do not necessarily make it clear to the non-specialist what connections are made by the models, and how these are made. Chapter 4 of the DSC/ME&P Report to SACTRA tries to remedy this, by summarising:

- what interactions between supply and demand are represented in the transport model;
- what information is passed from the transport model to the land-use model;
- what impacts changes in transport have within the land-use model (and whether these are immediate or lagged); and
- what information is passed back from the land-use model to the transport model.

3.7.2 These points represent a useful checklist for gaining an appreciation of any particular model. Another important aspect of understanding is to know which effects within the land-use model (out of the range discussed around Figure 2.2) are explicitly represented as decisions of particular kinds of 'economic actors' (households, firms, etc), or as other appropriate and explicit processes,

\(^2\) The nature of this linkage has caused some confusion. Many of the land-use/transport models developed by linking separate land-use and transport modelling packages require manual intervention to transfer data from one model to another. In some cases, the linked packages are on different computers with different operating systems. For practical, rather than research, studies, it is desirable that a complete forecast of the combined system can be initiated by a single command and left to run without further intervention. This level of automation is, of course, inherent in the integrated land-use/transport modelling packages.
and which are represented only implicitly by fixed relationships or as being
determined by other decisions. (As an example of an effect determined by
other decisions, service employment in the Martin Centre models is not
modelled as a decision by the retail sector, but is calculated wholly as a
consequence of consumers’ decisions on where to shop.) Differences in
representation cannot generally be described as ‘right’ or ‘wrong’, but particular
approaches may well be ‘appropriate’ or ‘inappropriate’ to particular studies: the
relationship between economic change and population change, and between
both of those and the development process, are points which should be
considered carefully.

3.7.3 One way of looking at these points is to consider the ways in which different
models represent the markets, in labour, in goods and services, and in property.
Summaries of the representation of decisions and of the resulting treatment of
non-transport markets in a number of current models can again be found in
Chapter 4 of the DSC/ME&P Report to SACTRA.

3.7.4 It must, however, be noted at this point that the modelling software in use
consists of ‘packages’ which generally offer considerable scope for different
applications within one broad approach. The detailed representation of
response to transport in non-transport markets could be significantly different in
future application of these packages. There is scope for fine-tuning to the
requirements of particular studies, though the constraints on this should also be
noted: above all, that the modelling of choices in the ‘land-use’ system, just like
the modelling of choices in transport, is only valid if the set of possible choices
is correctly specified. This makes it difficult, and at present largely impossible,
to build a meaningful land-use/transport model for a small area around a
scheme, or for a one-dimensional corridor between two places. This difficulty
also applies to modelling the distribution of travel, and has already been
identified in the Fearon Report.

3.8 Data Requirements

3.8.1 The land-use/transport models considered in this section all include or require
an operational transport model. It is therefore appropriate to consider under
‘data requirements’ only those requirements which are additional to those for
transport modelling, i.e. the extra data needed for land-use modelling. Since
some of the land-use models include functions which elsewhere are left to the
transport model, this division is not exact; these points are noted where
applicable in what follows.

3.8.2 Data requirements can to some extent be split into two categories:

- data required to implement the model, i.e. the variables which have to be
  introduced in order to make the model represent the chosen city or
  region, and which are either direct inputs to the working model or are
  automatically reproduced by the working model (see paragraphs 3.7.4
to 3.7.6); and

- additional data or information required to calibrate the model to reproduce
  the behaviour of the chosen system or the processes at work within it
  (see paragraphs 3.7.7 to 3.7.10).

3.8.3 Two other types of input also need to be noted:

- the range of inputs which can be used to specify future scenarios (see
  paragraphs 3.7.11 to 3.7.12), and
the range of policies that can be tested (see paragraphs 3.7.13 to 3.7.14).

The following sections deal with these in turn. It should be noted at the outset that only a broad and general description of requirements and possibilities can be given; the details will depend on the design of each particular model application, and in nearly all cases the model implementation process can be adapted to the availability or otherwise of particular types of information.

3.8.4 Data requirements for model implementation. In general, the requirements for the implementation category of data are quite firm - there must be one number for each variable in each zone - but at least in the early stages of model implementation there is a lot of scope for choice in the definition of variables (e.g. how many household types, how many employment categories). In contrast, the requirements for calibration are much less precise - although some of the packages have automated calibration routines which require particular inputs, these are not the only way of arriving at the eventual coefficient values. The data requirements are summarised in Table 3.1.
Table 3.1: Implementation Data for Land-Use/Transport Interaction Models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Static Models</th>
<th>Dynamic Models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IMREL etc</td>
<td>DSCMOD</td>
</tr>
<tr>
<td>Households/population</td>
<td>Few categories – to reproduce</td>
<td>Few categories – input as base situation</td>
</tr>
<tr>
<td>Employment (status of residents)</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Employment (by workplace)</td>
<td>Few categories – to reproduce</td>
<td>Few categories – input as base situation</td>
</tr>
<tr>
<td></td>
<td>Few categories – split into endogenous component, input, and endogenous, to reproduce</td>
<td>Few or many categories – inputs for base year and earlier</td>
</tr>
<tr>
<td>Floorspace by type</td>
<td>Required for base and alternative situations</td>
<td>Optional</td>
</tr>
<tr>
<td>Rents</td>
<td>Required for base situation</td>
<td>Optional required for base situation</td>
</tr>
<tr>
<td>Household incomes</td>
<td>not used</td>
<td>Optional for base situation</td>
</tr>
<tr>
<td>Matrices of labour to work</td>
<td>(in transport model)</td>
<td>(in transport model)</td>
</tr>
<tr>
<td>Matrices of goods and/or services to consumers</td>
<td>(possibly implicit in transport model)</td>
<td>(possibly implicit in transport model)</td>
</tr>
<tr>
<td>Development under construction in base year</td>
<td>see floorspace, above</td>
<td>see floorspace, above</td>
</tr>
</tbody>
</table>

---

**Notes:**
- IMREL etc: Few categories – to reproduce.
- DSCMOD: Few categories – input as base situation.
- Martin Centre: Few categories – input as base situation.
- DELTA: Few or many categories – inputs for base year and earlier.
- Employment (status of residents): Not applicable.
- Employment (by workplace): Few categories – to reproduce.
- Floorspace by type: Required for base and alternative situations.
- Rents: Required for base situation.
- Household incomes: not used.
- Matrices of labour to work: (in transport model).
- Matrices of goods and/or services to consumers: (possibly implicit in transport model).
- Development under construction in base year: see floorspace, above.
3.8.5 Table 3.1 tends to confirm that the more complex models have rather similar data requirements except that:

- at the urban level the DELTA approach does not consider the pattern of trade in goods and services, only in labour;
- the DELTA approach generally requires rather more information about previous years (in line with its lesser assumptions of equilibrium); and
- a number of variables have to be reproduced by calibration in the Martin Centre models but are simply input to DELTA.

3.8.6 In relation to this last point, it should be noted that:

- it may mean that the calibration is optimised to reproduce all the cells of the matrix as well as possible, or simply that some characteristic of the matrix (such as the average travel to work distance) is reproduced, and that in the latter case the matrix itself may not be used at all (if for example average travel to work distance is obtained from a household survey); and
- data which is input may itself be synthesised, and especially in the case of matrices will always involve some element of synthesis. (In general there is decreasing difference between methods which synthesise their base situation but are adjusted (e.g. by residual disutility methods) so as to reproduce all the confidently-known features of the observed base data, and those which are intended to take the observed base data as input but require a pre-model synthesis of those cells which are not known with confidence.)

3.8.7 Approaches to calibration. It is worth emphasising that the design of DELTA does not envisage that all of these behavioural coefficients should be estimated on local data; it is seen as a positive advantage that they should be based on wider research, supplemented by local experience. The Martin Centre approach, in contrast, places much more emphasis on reproducing many aspects of the initial situation; it therefore lends itself to a rather more statistical form of calibration based on that reproduction in terms of simultaneous relationships, but it involves relatively few coefficients that relate to recognisable processes of change over time.

3.8.8 Approaches to calibration: Martin Centre Models. Table 3.2 (based on Hunt, 1994, and Hunt and McMillan, 1995) attempts to identify the coefficients which have to be set up in the cross-sectional elements of a typical Martin Centre-type model. All these are used in the “reproduced by calibration” elements of the database.
Table 3.2: Coefficients of Typical Martin Centre Models

<table>
<thead>
<tr>
<th>Coefficient or relationship</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>units of labour (in households, by seg) required per job in each sector</td>
<td>can be initially derived from Census data</td>
</tr>
<tr>
<td>units of services (in jobs by sector) required per household of each seg</td>
<td>can be initially derived from Family Expenditure data, adjusted to Study Area totals</td>
</tr>
<tr>
<td>relationships between sectors: input/output matrix (in employment units)</td>
<td>(not usually included in urban applications)</td>
</tr>
<tr>
<td>household utility levels</td>
<td>(adjusted to reproduce income levels, given expenditure patterns)</td>
</tr>
<tr>
<td>household expenditure patterns</td>
<td>can be derived from Family Expenditure data</td>
</tr>
<tr>
<td>relationship of space-per-employee to rent-per-unit-space, by sector</td>
<td></td>
</tr>
<tr>
<td>dispersion parameter for travel to work by seg</td>
<td>(equivalent to distribution coefficient on travel to work in a transport model)</td>
</tr>
<tr>
<td>dispersion parameter for distribution of goods and services by sector</td>
<td>(equivalent to distribution coefficient on various other purposes in a transport model)</td>
</tr>
</tbody>
</table>

3.8.9 In addition, the Martin Centre models involve a relatively limited set of incremental sub-models which estimate changes (typically subtractions and additions separately) over time in:

- exogenous employment by sector;
- exogenous households\(^3\) by socio-economic group; and
- floorspace by category.

The increments (positive and negative) in these are exogenous to the model.

3.8.10 Approaches to calibration: DELTA. Table 3.3 lists the more purely behavioural coefficients of DELTA (as implemented for the Greater Manchester Strategy Planning Model (GMSPM) - see the Fearon report for further details). All of these are calibrated primarily on the basis of previous national or international research, supplemented where necessary with professional judgement and where appropriate with adjustment to the scale of the particular model. Note that the car ownership model in GMSPM is an adaptation of the current national model (MVA, 1996).

\(^3\) Exogenous households are those which do not supply labour to employment sectors; all other households, ie “endogenous households”, are generated in proportion to the demand for labour. Note that exogenous households have to be calculated and located before endogenous households (in contrast with DELTA, where non-working persons are the residual working-age adults after jobs have been filled with workers).
Table 3.3: Coefficients of DELTA (urban application)

<table>
<thead>
<tr>
<th>Actor</th>
<th>Response type</th>
<th>Coefficient</th>
<th>Notes/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household s (individual)</td>
<td>Car ownership</td>
<td>Saturation level of car ownership</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Income effect</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Licence-holding effect</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Income/accessibility interaction term</td>
<td>Optional</td>
</tr>
<tr>
<td>Location</td>
<td>Expenditure preferences (housing vs other goods and services)</td>
<td>Used in calculating utility of consumption obtained from expenditure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Response to change in utility of consumption</td>
<td>Response is to change since likely year of last location/relocation; this is specified by a lag for each household type.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Response to change in accessibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Response to change in area quality</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Response to change in environmental quality (in practice, local environmental impact of transport)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Probability of relocating in each year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household s (collective)</td>
<td>Area quality response</td>
<td>Impact on quality of vacant housing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact on quality of changes in average household income</td>
<td></td>
</tr>
<tr>
<td>Firms</td>
<td>Location/relocation</td>
<td>Probability of relocating in each year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Response to change in cost of location</td>
<td>Response is to change since likely year of last location/relocation; this is specified by a lag for each employment sector.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Response to change in accessibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developers</td>
<td>Total development (before planning constraints)</td>
<td>Elasticity with respect to average profitability of each floorspace type</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Response to overall planning constraints</td>
<td>Decreasing supply of permissions may lead to slowdown in development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Location of development</td>
<td>Response to profitability of alternative locations</td>
<td>Subject to planning constraints</td>
</tr>
</tbody>
</table>
to be considered within the model but which are independent, or largely independent, of the strategies to be tested. In practice, this usually means the modelled area economic and demographic changes for each future period to be modelled. Note that the allocation of economic activity and population to zones is done within the land-use model, and is generally responsive both to land-use policy and to changes in transport provision.

3.8.12 The exact form in which scenarios are specified can vary greatly between models. This is illustrated for some current models in the following paragraphs. Note that in both types of models considered, the specification of the economic and demographic scenario in the land-use model should automatically generate the corresponding transport demand scenario - for example, in GMSPM, changing the economic scenario by specifying a more positive rate of growth in jobs will typically lead to:

- more people in work, and hence more travel to work (and possibly slightly less other home-based travel on weekdays);
- a proportion of households with higher incomes and hence higher car-ownership, with resulting changes in the mode split of all their journeys;
- changes in the location of households, influenced both by their higher incomes and by their increased car ownership; and
- changes in the location of employment, due to the increased competition for commercial space.

3.8.13 The following notes on the specification of scenarios consider only the land-use elements. In some cases, it may be necessary to make corresponding changes in transport parameters (notably value of time) in order to maintain the consistency of the model. (If the disaggregation of the transport model exactly matched that of the land-use model, in terms of the cross-classification of person types, household socio-economic and car ownership status, etc, then this consistency would automatically be maintained without the need for changes in parameters.)

3.8.14 The need to specify economic and demographic scenarios in particular forms can appear as an extra burden on the forecasting process. This is not necessarily the case; if the simplest approach is taken, it should be possible to reproduce the economic and demographic scenarios already established in TEMPRO without too much effort. A more positive view, however, is that the ability to run tests consistently under different scenarios makes it possible to examine whether recommended strategies are appropriate under a range of different conditions. Testing strategies for their robustness in this way recognises and deals as well as possible with the familiar problem that errors in economic forecasts, are a major source of error in transport forecasts.

3.8.15 The scenario-defining elements in DELTA are set out in Table 3.4.
### Table 3.4: Scenario-Defining Elements in DELTA

<table>
<thead>
<tr>
<th>Model Area</th>
<th>Input</th>
<th>Notes/sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic change</td>
<td>Household transition rates (formation, transformation and dissolution)</td>
<td>An initial set of coefficients is developed from Census, survey and official registration sources, and is then adjusted to reproduce a demographic scenario (households and population) developed using specialised regional models.</td>
</tr>
<tr>
<td></td>
<td>Migration – proportion of households by type leaving study area in each period, ratio of in-migrants to out-migrants</td>
<td>(Migration between modelled area is endogenous to regional version.)</td>
</tr>
<tr>
<td></td>
<td>Persons per household (by type)</td>
<td></td>
</tr>
<tr>
<td>Economic change</td>
<td>Growth/decline in employment by sector</td>
<td>(Sectoral employment determined via input-output model from partly exogenous final demand in regional version.)</td>
</tr>
<tr>
<td></td>
<td>Socio-economic composition of jobs in each sector</td>
<td>(note that this relationship features as input to most urban models, but little work seems to have been done on forecasting it)</td>
</tr>
<tr>
<td></td>
<td>Household incomes</td>
<td>Note that this is average income for a household of a particular composition, including employment status; changes in income due to changing employment status or due to natural change (e.g. going from working age to retired) come about through transfers between household categories</td>
</tr>
<tr>
<td>Car ownership</td>
<td>Increase in driving licence holding</td>
<td>Influence on car ownership</td>
</tr>
<tr>
<td></td>
<td>Costs of car ownership</td>
<td></td>
</tr>
<tr>
<td>Development</td>
<td>Cost of development by floorspace type and greenfield/brownfield</td>
<td></td>
</tr>
</tbody>
</table>

3.8.16 The scenario-defining elements in MEPLAN are as follows (those for TRANUS are broadly similar):

- totals of exogenous employment, exogenous households, construction and demolition to be allocated by incremental models;
- changes to input-output or social-accounting relationships;
- changes in household utility levels (which will give rise to changes in incomes);
- changes in employment or economic activity may be brought about either by changing the exogenous demands (which are allocated by the incremental models) or by changing the input-output relationships; and
changes in population may be implemented either by allocating more ‘exogenous’ households to the incremental models, or by changing the relationship of household to jobs in the social-accounting matrix (which will cause more households to be generated).

3.9 Scope for Testing Land-Use Policies

3.9.1 Static models are largely limited to testing the effect of transport policies given exogenously defined allocations of floorspace or housing to each zone; they do not permit the testing of land-use policies (i.e. predicting how development and land-using activities will respond to those allocations) as such.

3.9.2 The abilities of land-use models to test land-use policies depends very much upon the details of the particular application. It is also difficult to define the policy-testing scope even of a specific model; as with the more elaborate transport models, there is generally a set of policies which can be ‘directly’ modelled by inserting or changing numbers in pre-defined fields, and a larger set of policies which can be less directly modelled, by some form of intervention in the operation of the model or with the addition of an additional set of calculations. Table 3.5 attempts to indicate a typical set of capabilities for an ‘urban’ model and a ‘regional’ model, under the conventional headings of regulation, pricing and investment.

Table 3.5: Typical Policy-Testing Capabilities of Land-Use Models

<table>
<thead>
<tr>
<th>Policy intervention type</th>
<th>Examples in urban modelling</th>
<th>Examples in regional modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td>Allocation of land to development (by zone, by development type, by year)</td>
<td>Permitted density of development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum density of use of space</td>
</tr>
<tr>
<td>Pricing</td>
<td>Taxes/subsidies to development</td>
<td>Taxes/subsidies on occupation of property</td>
</tr>
<tr>
<td></td>
<td>Taxes/subsidies on production</td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td>Exogenous development (i.e. exogenously defined additions to building stock)</td>
<td>Exogenously added (or subtracted) activities, e.g. major new employers or closures</td>
</tr>
<tr>
<td></td>
<td>Redevelopment (i.e. exogenously defined reduction in the building stock, followed by development)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exogenously added (or subtracted) activities, e.g. major new employers or closures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Investment in utilities may be a prerequisite to new development</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

1. the table lists only land-use strategy components; the scope for testing transport strategies is determined by the associated transport model
2. the model operation is generally the same whatever strategies are being tested, i.e. the introduction of policy variations changes the quantitative results of the model but does not require different modules or processes to be applied.
3. Combined urban/regional models are possible.

3.10 The Appropriateness of Alternative Approaches to Land-Use Modelling

3.10.1 The following paragraphs do not attempt to deal with all the issues that have to be considered in deciding whether or not to model land-use explicitly in the course of a transport study. They simply consider those issues which should affect the choice of approach if land-use modelling is to be pursued.
3.10.2 The choice of modelling approach can be considered as a sequence of choices, along the lines of Figure 3.3:

- static model or dynamic?
- if dynamic, which kind of approach is most appropriate?

3.10.3 A static model may be appropriate if:

- the planning policy for the study area is clearly defined and there is no need to test the effect of alternative planning policies within the study; or
- it will suffice to obtain general indications of the most direct land-use effects of the transport strategies to be considered.

3.10.4 If, on the other hand

- different planning policies are to be considered (particularly if they are being proposed as part-solutions to transport problems),
- there are hopes or concerns that transport changes will have more profound impacts on the local economy, or
- there is concern to examine the profile of change over time (e.g. for how long a particular course of action will relieve traffic problems),

then a dynamic model would (resources allowing) be more appropriate.

3.10.5 The choice between different approaches to dynamic modelling is less dependent on what is actually to be done with the model. The two main approaches, the interaction-location models represented by MEPLAN and TRANUS, and the location-interaction models represented by DELTA + transport model, generally do similar things in very different ways. Some of the points of contrast are summarised in Table 3.6. In each row, it is reasonable to say (at present) that the commissioning organisations should exercise their professional judgement as to which approach is most appropriate in each particular case - there are no clear grounds for defining that either one is right or wrong in specific situations.
Table 3.6: Factors Influencing Whether to Use either an Interaction-Location or a Location-Interaction Model

<table>
<thead>
<tr>
<th>Area</th>
<th>Interaction-location (MEPLAN, MENTOR, TRANUS)</th>
<th>Location-interaction (DELTA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical basis</td>
<td>Integration of different areas of economic theory</td>
<td>More eclectic: takes ideas from demographics, urban economics, etc.</td>
</tr>
<tr>
<td>Main drivers of change</td>
<td>Input output model generates households from demand for labour and service employment from demands for services</td>
<td>Separate demographic processes and economic processes or trends</td>
</tr>
<tr>
<td>Calibration</td>
<td>Can be calibrated to base-year data</td>
<td>Parameters typically based on previous research</td>
</tr>
<tr>
<td>Validation over time</td>
<td>Requires a major project; implications for model not necessarily clear</td>
<td>Would require a major project for full validation, but validation/adjustment of selected sub-models should be relatively straightforward</td>
</tr>
<tr>
<td>Relationship to transport model</td>
<td>Generation and distribution of transport determined primarily by land-use model</td>
<td>Most demands for transport generated and distributed within transport model, given land-use changes</td>
</tr>
<tr>
<td>Scope for appraisal</td>
<td>May be capable of a comprehensive calculation of benefits within the land-use model. Conventional appraisal of transport benefits may be restricted by limited nature of transport model.</td>
<td>Comprehensive appraisal not yet possible; conventional appraisal of transport benefits possible using associated transport model</td>
</tr>
</tbody>
</table>

4 Further Information

The following documents provide information that follows on directly from the key topics covered in this TAG Unit.

<table>
<thead>
<tr>
<th>For information on:</th>
<th>See:</th>
<th>TAG Unit number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Appraisal Summary Table</td>
<td>Transport Appraisal and the New Green Book</td>
<td>TAG Unit 2.7</td>
</tr>
</tbody>
</table>

5 References


Notes to the references.

The book edited by Webster et al (1988) is commonly referred to as “the ISGLUTI Report”, but covers only the first phase of ISGLUTI’s activities. The second phase, which involved applying several models to each city, was reported in a series of papers in Transport Reviews, concluding with that by Paulley and Webster (1991).

A number of papers on urban and regional modelling, originally delivered at the Martin Centre 25th Anniversary Conference, 1992, were published in Volume 25 number 5 of Environment and Planning B: Planning and Design. These included papers on the design and calibration of MEPLAN-based urban models (Williams, 1994 and Hunt, 1994, respectively) and regional models (Rohr and Williams, 1994) and experience with the TRANUS model in Venezuela (de la Barra, 1994), as well as a paper on the strengths and weaknesses of the Martin Centre modelling approach by Simmonds (1994). The issues covered in the last of these formed part of the background to the subsequent development of the DELTA package.

6 Document Provenance

This Transport Analysis Guidance (TAG) Unit is based Appendix B of Guidance on the Methodology for Multi-Modal Studies Volume 2 (DETR, 2000)

Technical queries and comments on this TAG Unit should be referred to:

Integrated Transport Economic Appraisal (ITEA) Division
Department for Transport
Zone 3/08 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
Freight Modelling

TAG Unit 3.1.4

June 2003

Department for Transport

Transport Analysis Guidance (TAG)

This Unit is part of a family which can be accessed at www.webtag.org.uk
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1 Freight Modelling

1.1 Introduction

1.1.1 The following factors distinguish freight transport from passenger transport. On the demand side:

- freight (other than livestock) is entirely passive, and the arrangements for loading and unloading are therefore critical; in many cases, these involve specialised infrastructure and/or equipment;

- most freight requires packing, often in several stages (e.g. packets in boxes on pallets in a container); the type of packing used is related both to its handling during transport and to the requirements of the shipper and recipient, including their arrangements for storage;

- many freight vehicles, especially railway wagons and bulk-carrying trucks or trailers, are specialised units for the carriage of a particular type of goods;

- the ‘unit of decision’ (which for passenger travel is ultimately the person- or group-journey, though influenced by other decisions such as car ownership and season ticket purchase) for freight can vary from the despatch of a single parcel to a contract running for several years and involving hundreds of thousands of tonnes of goods; and

- the characteristics of the journey itself are of very little importance to some consignments of freight (e.g. non-urgent shipments of bulk materials) but more critical than for passengers in other cases (e.g. the requirements of temperature-sensitive or very-high-value goods).

1.1.2 On the supply side:

- prices are much less well known than in passenger transport - the majority of transactions (except for small volume users of public services such as post and parcel delivery) are commercially confidential;

- it can be difficult to define the supply of freight transport services without going into a lot of detail about the characteristics of available terminals, especially on the railway network - and these are not fixed, since the cost of changing the characteristics may be modest compared with the overall transport costs involved; supply characteristics such as frequency and capacity are undefined until a potential shipper makes an enquiry; and

- since the movement of freight itself is nearly always one-way, the economics of freight haulage are considerably complicated by the scope for back-hauling, i.e. the possibility that the truck or wagon can carry a revenue-earning load on the return journey rather than running empty.

1.1.3 Some of these factors have analogies in passenger transport which can be taken into account in some forms of passenger transport modelling - for example, group size (and the resulting sharing of car costs) can be taken into account more readily in disaggregate choice modelling than in aggregate approaches. Others have no equivalent at all.
1.1.4 The main implications of these factors are that

- the classification of freight is highly complex, and many of the obvious classifications (e.g. bulk, containerised, other) are reflections of transport decisions rather than independent dimensions; and

- the generalised cost of the individual trip or tour (which in passenger modelling is - rightly or wrongly - the main variable through which supply is described in choice modelling) will in many cases be less important than the arrangements for packaging and handling, which often though not always represent medium-term decisions comparable with, but much more complex than, the household car-ownership decision.

1.1.5 These in turn mean that the kind of choice model proposed elsewhere in this document for passenger modelling is less obviously applicable to freight mode choice. This does not mean that it cannot or should not be done; the conclusion of the National Transport Policy Model Feasibility Study (MVA et al., 1997) was that a choice model similar to the passenger choice model should be applied (that Study also listed a number of previous projects and the ways in which they had classified freight; some of these involved building such choice models). Disaggregate models would seem to offer considerable advantages, in that they can take account of a wide range of characteristics (such as the characteristics of the consignor and consignee, whether the shipment is regular, occasional or one-off, and the characteristics of the shipment itself) without having to process large numbers of very sparse matrices. However, it would seem highly desirable that more should be done to develop methods for modelling the medium- to long-term decisions about investment in (or leasing of) particular types of equipment, infrastructure and freight handling methods.

1.1.6 In terms of the origin-destination pattern of freight, the choice would seem to be between:

- simple factoring of observed base-year matrices;

- adjusting matrices by growth factors based on changes in planning data;

- a simple spatial interaction model; or

- a spatial input-output model.

1.1.7 Factoring methods would assume that the supply of transport had no impact on the volume or origin-destination pattern of freight within the modelled area. A simple spatial interaction model, with origins and destinations being factored up in proportion to appropriate planning data, would hypothesise some response to transport cost, with flows tending to increase where costs were reduced. A spatial input-output model would go further and would relate the patterns of trade to the interactions between different industries.

1.1.8 Spatial input-output models can be applied either

- as the dominant component of interaction-location models (see Appendix B) in which case the location of industry is determined by the pattern of interactions; or

- as a less critical component of location-interaction models, in which case the location of industry is directly influenced by a wider set of factors.
1.1.9 Three points should however be noted about spatial input-output models:

- they may, in their most sophisticated forms, predict how sectors will substitute one input for another in response to changes in cost (whether transport cost or others), but they cannot in themselves predict technical innovation or the way that this will affect the linkages between sectors;

- the input-output modelling itself almost inevitably works in units of value (e.g. £X worth of goods and services sold from sector $m$ in region $i$ to consumers and businesses in region $j$); the conversion of trade by value into physical units of freight (and associated passenger movement) is a critical but relatively under-researched topic; and

- these models are dependent on input-output tables produced as part of the national accounts to specify the relationships between different sectors; they do not automatically predict growth in freight demand associated with increased intra-firm movements or with the use of third-party logistics contractors (who store and distribute goods, rather than just moving them), since these are not fully reflected in the set of transactions upon which the accounts are based.

1.1.10 For individual urban areas and small corridors, the factoring methods are probably the only ones directly applicable, since too large a proportion of freight movements will have one or both ends well outside the area that is likely to be modelled. (There will in such studies be a need to consider the impact of policies which affect the movement of freight within the urban area, such as lorry restrictions or time-specific bans; for many such policies, the transport effect follows automatically from the policy (e.g. deliveries must be made outside the hours when trucks are banned) and the main concern should be the impact on the businesses whose access is affected, and hence on the economic viability of the area.) The interaction and input-output models are likely to be applicable if the modelled area represents at least most of a region, and best applicable for studies which need to model more than one region.

2 References


3 Document Provenance

This Transport Analysis Guidance (TAG) Unit is based on Appendix C of *Guidance on the Methodology for Multi-Modal Studies Volume 2* (DETR, 2000).

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Integrated Transport Economic Appraisal (ITEA) Division
Department for Transport
Zone 3/08 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
The Accidents Sub-Objective

TAG Unit 3.4.1

June 2005

Department for Transport

Transport Analysis Guidance (TAG)
1 The Accidents Sub-Objective

1.1 Introduction

1.1.1 There are methodological differences in the way that accidents are appraised for road schemes and other modes. The approach described below should be used for appraising changes in the number of road accidents. Where proposals are expected to have a significant impact on railway accidents, these should be noted. Further advice on how these impacts should be appraised should be sought from the SRA, see Appraisal Criteria (SRA, April 2003).

1.1.2 Transport accidents impose a range of impacts on people and organisations, including:

- medical and healthcare costs*;
- lost economic output*;
- pain, grief and suffering*;
- material damage†;
- police and fire service costs†;
- insurance administration; and
- legal and court costs†.

1.1.3 Those impacts marked (†) are closely related to the number of accidents, while those marked (*) are related to the number of casualties. Therefore, numbers of accidents and numbers of casualties are the key quantitative indicators for the assessment of proposals. Combining these numbers with values for the prevention of casualties and accidents provides a monetary estimate of the accident benefits of proposals.

1.1.4 The impact of casualties differs according to the severity of the injuries sustained. Three groups are usually differentiated; these are defined in the following way:

- fatality = death within 30 days from causes arising out of the accident;
- serious injury = casualties who require hospital treatment and have lasting injuries, but who do not die within the recording period for a fatality; and
- slight injury = casualties whose injuries do not require hospital treatment, or, if they do, the effects of the injuries quickly subside.

More detailed information on classification of particular types of injury can be found in Hopkin and Simpson, 1995.

1.1.5 Values for the prevention of a casualty should be those currently used for road appraisal, contained in the latest DfT advice (DMRB Volume 13, Section 1 and Highways Economics Note 1, 1999f).

1.1.6 The impact of accidents varies also according to severity. For road accidents, the accident-related costs to be used should again be those specified in the latest DfT advice (DMRB Volume 13, Section 1, 1996 and HEN1, 1999f).

1.1.7 Standard processes exist for forecasting the numbers of accidents and casualties and the accident reduction benefits arising from changes to the road network. For most major proposals, forecasts should be generated using the methods and accident rates contained in the COBA Manual (DMRB Volume 13, Section 1) and embodied in the computer program COBA. The techniques used to measure the change in the number of accidents (with differing degrees
of severity) are based on established parameters for the number of accidents per million vehicle-kms on different types of road. As the number of vehicle-kms on the network change as a result of the introduction of an intervention, so the number of accidents will also alter. Thus, if the impact of an intervention is to reduce the number of vehicle-kms travelled, then this will tend to reduce the number of accidents on the network. Similarly, if the intervention causes a reduction in the number of vehicle-kms on one type of road but an increase for a second type of road, then the net impact on the number of accidents will depend upon the relative accident rates for the two types of road.

1.1.8 Application of the guidance set out above will provide estimates of the change in the numbers of road user accidents and of the monetised present value of accident reduction benefits. These values should be reported in the AST, for all options, whether they include road or public transport components or combinations of the two. This will ensure consistent comparison of impacts between options.

1.1.9 However, when assessing the likelihood that public transport options will qualify for subsidy or grant, accident reduction benefits will need to be adjusted to comply with the different assumptions specified in the appropriate guidelines. For further guidance, see Detailed Guidance on Major Scheme Appraisal in Local Transport Plans (Tag Unit 3.9). Analysts should ensure that their assessment of accident reduction benefits are sufficiently disaggregate to enable these adjustments to be made.

2 Application of TAG to Highway Schemes

This section provides advice on the links between TAG’s treatment of the accidents sub-objective and the advice given in Volume 11 of the Design Manual for Roads and Bridges (DMRB), which deals with the environmental assessment of highway projects. An explanation of the correspondence between the advice set out in TAG and DMRB is given in Applying the multi-modal new approach to appraisal to highway schemes (TAG Unit 2.6).

2.1 Methods and Worksheets

2.1.1 The methodology for accident calculations is given in the COBA manual (DMRB Vol 13, Section 1, 1996). However, the parameters used in calculations in the Volume 13 are superseded by those given in the Interim COBA11 Guidance. Changes have been made to:

- Accident rates, severity splits and costs have been revised in accordance with latest data;

- Unit values. These are now expressed in 2002 market prices; and

- Accident rates and severity splits now change over time, in order to be consistent with observed trends and likely policy developments.

2.1.2 The quantitative entry is the change in number of total personal injury accidents, and casualties by severity, over the 60 year period. The Present Value of Benefits for accidents should be expressed in 2002 market prices, discounted to 2002.

2.1.3 TUBA does not include calculation of the PVB of accident savings. The COBA11 program should be used to calculate the PVB of accidents for traffic forecasts using both fixed and variable trip matrices.

2.1.4 COBA can be used to assess the safety impacts of both fixed and variable trip matrix appraisals.
2.1.5 QUADRO may be used to perform calculations for accidents during construction and accidents during maintenance. An updated version of the program will be available in Spring 2001.

3 References


SRA (April 2003) *Appraisal Criteria*

4 Document Provenance

This Transport Analysis Guidance (TAG) Unit is based on Chapter 5, Section 2 of *Guidance on the Methodology for Multi-Modal Studies Volume 2* (DETR, 2000).

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Integrated Transport Economics and Appraisal (ITEA) Division
Department for Transport
Zone 3/08 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
The Transport Economic Efficiency Sub-Objectives

TAG Unit 3.5.2

April 2004

Department for Transport

Transport Analysis Guidance (TAG)
1 The Transport Economic Efficiency Sub-objectives

The two transport economic efficiency sub-objectives are identical in concept and method of calculation and are therefore covered together in this TAG Unit.

1.1 The Transport Economic Efficiency (TEE) Table

1.1.1 The purpose of the Transport Economic Efficiency (TEE) table (provided as Table 1) is to summarise and present transport user benefits. Transport User Benefit Calculation (TAG Unit 3.5.3) provides further information about the nature of the user benefit calculations.

1.1.2 The TEE table presents the net user benefits disaggregated by group (i.e. consumers on the one hand and business, including transport operators, on the other), by mode of transport and by impact (time, vehicle operating costs, etc). All the impacts in the TEE table are usually expressed in money terms. (Note, however, that impacts on pedestrians, cyclists, equestrians and others may be presented as qualitative scores based on an analysis of quantitative factors – see Impacts on Pedestrians, Cyclists and Others (TAG Unit 3.5.5)). The table aggregates the results for each group to provide the information needed for the Appraisal Summary Table (AST) – see Transport Appraisal and the New Green Book (TAG Unit 2.7). A TEE table should be completed for each option and, in common with the AST, the TEE table should show the change brought about by the option relative to the do-minimum case.

1.1.3 All entries in the TEE table should be Present Values - that is, streams of costs and benefits occurring over the appraisal period should be discounted to the Department’s standard base year using the Department's standard discount rate. This implies that benefits received far in the future are given less weight than benefits received today, in line with social preferences. Further discussion of the process of establishing Present Values of Benefits is provided in Cost Benefit Analysis (TAG Unit 3.5.4).

1.1.4 In the TEE table, costs should appear as negative numbers while revenues, grants and subsidies should appear as positive numbers.

1.1.5 The following text discusses the calculations required for the main groups of user represented in the TEE Table (and in the TEE row in the AST).

1.2 Calculation of User Benefits

1.2.1 The calculation of transport user benefits is based on the conventional consumer surplus theory. Consumer surplus theory is discussed in Transport User Benefit Calculation (TAG Unit 3.5.3), where the following topics are covered: the use of consumer surplus theory for the assessment of user benefits; and the disaggregation of user benefits by mode and by the components of perceived cost. It is important to note that the phrase ‘user benefits’ is used here and in the TEE table to denote user benefits net of the costs incurred by users. The following paragraphs outline what is required for the TEE table and discuss key parameters to be used in the assessment.

1.2.2 For the main groups of user, both personal travel and freight movement are accommodated within the TEE table (impacts on non-motorised travel should be included under ‘other’). If the option is predicted to affect both these parts of the transport sector then all the relevant boxes of the table will need to be

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1 The term ‘benefits’ is used here and in subsequent discussion to include disbenefits - ‘negative’ benefits or ‘costs’.
completed. This will usually be the case and if options are developed which are reported as having no impact on goods vehicles or freight within the TEE table, this should prompt a reassessment of whether the full implications of the option have been identified. For example, public transport priority measures in urban areas may have knock-on impacts on freight if the peak-hour car and freight traffic congestion on the network is either significantly reduced or significantly increased as a result. These effects should be open to analysis through the transport model, whose outputs for goods vehicles as well as passengers and private vehicles should be taken forward into the user benefit calculations.

1.2.3 The benefits estimated for both personal travel and freight are attributed to changes in travel time, vehicle operating costs and user charges (including fares, tolls and tariffs). In all of these cases, if an option leads to a benefit to users of the transport system, then the impact should be recorded as a positive amount. For example, if benefits attributed to consumers’ travel time savings are valued (after discounting) at £35 million, then the figure of £35 million would be entered into the TEE table in the cell for ‘Consumers: User benefits: ALL MODES TOTAL’. Conversely, disbenefits to transport users should be recorded as a negative amount. So, for example, if the strategy is also attributed a small overall disbenefit of £3 million to consumers’ vehicle operating cost changes, the entry in the ‘Consumers: User Benefits: ALL MODES TOTAL’ cell would be - £3 million. Where impacts on non-motorised travel have been assessed using qualitative methods, they should not be disaggregated - the overall qualitative score should be entered in the rows headed ‘NET CONSUMER BENEFITS’ and ‘NET BUSINESS IMPACT’ under the ‘OTHER’ column.

1.2.4 The sub-totals for Consumers and Business give an indication of the distribution of gains (and, potentially, losses) from the option. Efficiency gains in the freight sector will be of particular interest to manufacturing industries and to all forms of business for whom the efficient shipment of inputs or outputs has an impact on costs or performance. More efficient travel will benefit consumers travelling for a whole gamut of reasons – such as education, shopping, leisure or on personal business – and will contribute to reducing the travel component of business costs and to opening new market opportunities.

1.2.5 **Key economic parameter values.** The items to be included when estimating user benefits are:

- changes in travel time;
- changes in user charges, including fares, tariffs and tolls; and
- changes in vehicle operating costs met by the user (that is, for private car and goods vehicle transport).

1.2.6 It should be noted that the travel time to be included here is the expected travel time (that is, the statistical mean taken from the range of actual or predicted travel times). Changes in the variability of travel time (which have been shown to be extremely important for freight users in particular) are dealt with separately under the reliability sub-objective – see *The Reliability Sub-Objective* (TAG Unit 3.5.7) and should not be reported in the TEE table nor included in the Consumers or Business rows in the AST.

1.2.7 **Values of time.** An important factor in the assessment of the transport options is the impact on the time spent travelling, for both personal travel and freight. In order to include these impacts in the estimation of user benefits, it is necessary to put a money value on time savings. In the appraisal process, the general premise is that the value of resources used or saved is reflected in their market prices. This is the principle underlying the valuation of working time savings. However, in the case of non-working time savings, in general there is no market in which time can be traded for money, and therefore no directly-observable market price exists. Instead, values are derived from users’ willingness to trade
money for time, obtained from either revealed preference (RP) or stated preference (SP) surveys.

The values of time and the factors for uprating them which are given in *Values of Time and Operating Costs* (TAG Unit 3.5.6) should normally be adopted.

1.2.8 **Transport Supply Costs.** Those costs which are incurred by the individual traveller and are therefore included in the perceived generalised costs of travel feature in the traveller benefits/disbenefits derived from the change in consumer surplus. More specific guidance on the costs which should be included in the TEE table can be found in *The Treatment of Costs* (TAG Unit 3.5.9).

1.2.9 For the calculation of user benefits, the private vehicle fuel and non-fuel operating cost models specified in *Values of Time and Operating Costs* (TAG Unit 3.5.6) should be used. Separate parameters are specified for cars, light goods vehicles, and two classes of other goods vehicles. All of these include allowances for car and goods vehicle purchase.

1.2.10 As for values of time, the parameters for perceived costs should be used, for both fuel and non-fuel related costs.

1.2.11 In working time, the perceived cost of fuel is the cost perceived by businesses. Businesses are generally viewed as perceiving costs in the factor unit of account as most business costs are free of indirect taxation because they can claim the tax back. However, businesses cannot reclaim fuel duty and therefore the perceived value of fuel in working time is equal to the resource cost plus fuel duty. In non-working time, the perceived cost of fuel is the cost perceived by the individual consumer. Consumers perceive costs in market prices and therefore the perceived value of fuel in non-working time is equal to the market price.

1.2.12 The perceived cost of the non-fuel related costs differs for work and non-work time. In the case of time during work, the perceived cost is the cost perceived by businesses and is therefore equal to the resource cost. In the case of non-working time, the perceived cost is the cost perceived by the consumer and is therefore equal to the market price.

1.2.13 In addition to the costs of owning and operating private vehicles, road users may also incur charges for the use of infrastructure. Where tolls or congestion charges are considered, they should be treated as perceived costs incurred by road users. Where significant changes in parking charges are envisaged as part of an option, they should be treated in the same way.

1.2.14 For public transport users, the transport supply costs to be used in the calculation of user benefits are those actually incurred by users. These are the fares and other charges paid by users of public transport. All other costs of public transport supply are incurred by operators or providers and are taken into account in the calculation of impacts on private sector provider impacts in the TEE table (or in the calculation of the Public Accounts PVC – see *The Public Accounts Sub-Objective* (TAG Unit 3.5.1)).

1.3 **Impacts during construction and maintenance**

1.3.1 Costs to existing transport users due to the construction of a project and costs (or benefits) to users arising during future maintenance should be recorded in the TEE tables where they are likely to be significant.

1.3.2 For options affecting inter urban road users, the Department's QUADRO program should be used. For options affecting urban road users, delays to traffic resulting from construction and/or future maintenance may be estimated by using the same congested assignment package as used to predict the overall traffic effects of the scheme. Models may also be useful for options affecting public transport users if significant diversion is expected during construction.
and/or future maintenance. In other cases, simplified approaches to the estimation of delays to public transport users may be sufficient. The TUBA program may be used to value delays to road and/or public transport users, using standard economic parameters.

1.3.3 In some circumstances, it may be sufficient to use a simplified approach, based on evidence of unit costs per kilometre from other schemes. For road user delays, unit costs will vary with traffic levels, and thus it will be important to demonstrate that they are appropriate for the option being considered.

1.3.4 For options affecting public transport, the impact on operators’ revenues should also be considered. For heavy rail, estimates should be based on the compensation regime between the train operators and infrastructure authority, typically Network Rail.

1.4 Impacts on pedestrians, cyclists and others

1.4.1 Where not explicitly quantified in the modelling approach, the costs or benefits to pedestrians, cyclists and others should be assessed using the method set out in Impacts on Pedestrians, Cyclists and Others (TAG Unit 3.5.5). This method is broadly similar to the more formal consumer surplus approach in that it is based on an assessment of the total change in ‘person-minutes’ of the journey times of pedestrians and other non-motorised travellers. The method is designed to produce a qualitative score on a seven point scale. This should be entered in the ‘NET CONSUMER BENEFITS’ and ‘NET BUSINESS IMPACT’ boxes under the ‘OTHER’ heading on the TEE worksheet, but no adjustment should be made to the overall estimate of user benefit or disbenefit transferred to the AST. However, where these benefits are significant, a comment should be included in the Qualitative column of the AST.

1.5 Impacts on private and public sector transport providers

1.5.1 Impacts on private sector transport providers are recorded in the TEE table, where rows are provided to record changes in: operating costs; operator revenues; investment costs; and public sector grant and subsidy. A comparable set of rows is provided in the Public Accounts table for public sector providers (local highway authorities or the Highways Agency, for example) - see The Public Accounts Sub-Objective (TAG Unit 3.5.1).

1.5.2 The question of whether a provider of transport should be regarded as private sector or public sector is a matter for consideration. Advice on default assumptions is given in Supporting Analysis (TAG Unit 3.8). These assumptions may be changed where appropriate.

1.5.3 Transport providers are broadly defined to include operators of services and providers of infrastructure. Furthermore, the example disaggregations by mode are fairly broad: ‘Road infrastructure’, ‘Bus and coach’, ‘Rail’ and ‘Other’. For the rail mode, the column heading is simply ‘Rail’, so that any additional operator costs due to the option can be reported in this table without the need to allocate shares of those costs between the track authorities and service providers (through Network Rail Track Access Charges, for example).

1.5.4 Revenues are related to the user charges used in the first section of the table, since user charges (fares, tolls and so on) represent money transfers from users to operators which become revenues from the operator’s point of view. However, this does not mean that the economic benefit of changes in user charges is the same to the traveller and the operator. In fact, for travellers, the economic benefit of a change in charges is the resultant change in their consumer surplus. For those who do not change their behaviour, the change in consumer surplus is the same as the change in money paid, but for those who do change their behaviour, this is not the case. For operators, however, the
economic benefit of a change in charges is simply the change in net revenue received. Therefore, the values for User Charges under User Benefits and the values for Revenues under Private and Public Sector Providers will usually not be equal in size.

1.5.5 Changes in operator revenues should be calculated by subtracting total operator revenues in the do-minimum from the corresponding do-something value, taking account of any changes in the numbers of journeys: \((T^1M^1 - T^0M^0)\). Where there are significant public sector revenues (from tolling, for example), a comment should be included in the Qualitative column of the AST. Note that, if the option leads to an increase in revenue, then that should be recorded as a positive amount in the TEE table.

1.5.6 **Investment and operating costs.** Advice on the treatment of investment and operating costs in the Public Accounts table can be found in *The Treatment of Costs* (TAG Unit 3.5.9). Investment and operating costs should always be recorded in the TEE table as negative amounts.

1.5.7 **Grant/subsidy.** Advice on the treatment of grants and subsidies in the TEE table can be found in *The Treatment of Costs* (TAG Unit 3.5.9). Grants and subsidies should always be recorded as positive amounts in the TEE table.

1.6 **The Entries in the Business Users and Providers and Consumer Users Rows in the AST**

1.6.1 The results of the TEE appraisals should be presented in the Business Users and Providers and Consumer Users rows of the AST as follows.

- The Qualitative column should record any special considerations and any simplifications adopted in the analysis.

- The Quantitative column should identify the expected source(s) of the benefits of the proposal and provide appropriate quantitative indicators. Indicators should be chosen to reflect the magnitude of the effect and the numbers of users. For a highway scheme which only benefits road users, this could be the total vehicle hours saved, and the opening year peak and inter-peak journey time changes in minutes. For proposals where some of the beneficiaries would be (or become) rail users (rail service frequency enhancement, for example), the indicator could be opening year change in numbers of travellers per day. Care should be taken to ensure that indicators are broadly comparable between modes. In general, the mode(s) most affected by the proposal should receive the most attention. All options that have an impact on road congestion must include an estimate of the total vehicle hours saved (or added) by the option in the opening year. This indicator provides a measure of the extent to which the option contributes to the Department’s congestion target. The Treatment of 10 Year Plan Targets in Multi-Modal Study Recommendations is covered in *Supporting Analysis* (TAG Unit 3.8).

- The Assessment column should show the Present Values of Benefits for Business Users and Providers and Consumer Users as calculated in the TEE table. These will be in £m in prices in the Department’s standard base year using the Department’s standard discount rates.

1.6.2 **Analysis during the early stages of option development.** Carrying out a full TEE appraisal to provide the results outlined above will require significant effort. In particular, the estimation of present values for the Assessment column of the AST will usually require repeated runs of the transport model to enable the estimation of a stream of benefits. During the early stages of option development, this level of detail may not always be necessary. Satisfactory conclusions may be drawn on the basis of forecast year benefits instead of
present values of benefits. However, final decisions should always be based on full analyses leading to Present Values of Benefits if the results are to provide sufficient information to enable robust decisions to be made.

1.7 Software

1.7.1 So that the TEE appraisals may be conducted on a comparable basis across all studies, the Department has prepared standard software to estimate User benefits for all modes, called TUBA. This software also estimates Public and Private sector provider revenues and Government indirect tax revenues, as discussed above, for input to both the TEE and Public Accounts tables. This software is to be used for all Multi-Modal Studies. Additional software, suitable for the appraisal of some highway schemes is also available – see below.

1.8 Transport Economic Efficiency Appraisal of Major Highway Schemes

1.8.1 For highway schemes, the quantitative entries noted in paragraph 1.6.1 may be taken direct from the traffic model. Two kinds of information are required: total vehicle-hours saved; and peak and inter-peak journey time savings. Both should be estimated for the project opening year.

1.8.2 The estimate of total vehicle hours is intended to provide an indicator of the extent to which the project will contribute to the Government’s target to reduce road congestion. This target is focussed on the inter-urban trunk road network and on large urban areas. Thus, for trunk road projects, the calculation should be restricted to the hours saved on the trunk road network. Projects in large urban areas may take account of the hours saved throughout the modelled network. Where projects do not fit into either of these groups, a note should be made in the AST’s Qualitative column. Where possible, estimates should include hours saved in all 8760 hours of the year.

1.8.3 The estimates of peak and inter-peak journey time changes provide an indicator of the extent to which congestion will be relieved for those using the scheme itself. For trunk road schemes, values should be calculated for trunk road users only.

1.8.4 As is now standard, the TEE appraisal should be undertaken using the method of willingness to pay and should be presented in the market prices unit of account. They may be calculated using either TUBA (for fixed or variable matrix cases, including cases where URECA would have been used in the past) or COBA11 (for fixed matrix cases).

1.8.5 The outputs produced by COBA11 are consistent with the method of willingness to pay and are presented in the market price unit of account. Note that COBA also produces results in the factor cost unit of account – these should not be used in either the TEE table or the AST.

1.8.6 Table 2 in this TAG Unit is a modified version of the standard TEE table that will be suitable for many highway projects. Note that money values associated with accidents should not be included anywhere in the TEE table, or in the TEE calculations. Furthermore, if QUADRO outputs are used for the estimation of user benefits during construction or maintenance, accident costs should be removed from these QUADRO outputs. The costs and number of additional/reduced accidents caused by road works should be added to the AST under the Safety objective.

1.8.7 The QUADRO4 computer program may be used to produce values for delay during construction or during future maintenance. The QUADRO4 program will provide results that are fully consistent with those produced by COBA11.
1.8.8 The assessment programs TUBA and COBA11 allow the user to input estimates of ‘delays during maintenance’ and ‘delays during construction’. Both programs assume these are all time benefits/disbenefits and do not attempt to allocate these to vehicles types. This is an approximation, but it may be considered adequate in some instances.

1.8.9 Further advice on the TEE appraisal of major highway schemes can be found in *Detailed Guidance on Major Scheme Appraisal in Local Transport Plans* (TAG Unit 3.9).

1.9 **Transport Economic Efficiency Appraisal of Major Public Transport Schemes**

1.9.1 Advice on the TEE appraisal of major public transport schemes can be found in *Detailed Guidance on Major Scheme Appraisal in Local Transport Plans* (TAG Unit 3.9).
## Table 1: Economic Efficiency of the Transport System (TEE)

<table>
<thead>
<tr>
<th>Consumers</th>
<th>ALL MODES</th>
<th>ROAD</th>
<th>BUS &amp; COACH</th>
<th>RAIL</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>User benefits</strong></td>
<td><strong>TOTAL</strong></td>
<td><strong>Private Cars and LGVs</strong></td>
<td><strong>Passengers</strong></td>
<td><strong>Passengers</strong></td>
<td></td>
</tr>
<tr>
<td>Travel time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle operating costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>User charges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During Construction &amp; Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NET CONSUMER BENEFITS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Business</th>
<th><strong>User benefits</strong></th>
<th><strong>Goods Vehicles</strong></th>
<th><strong>Business Cars &amp; LGVs</strong></th>
<th><strong>Passengers</strong></th>
<th><strong>Freight</strong></th>
<th><strong>Passengers</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle operating costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>User charges</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During Construction &amp; Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Private sector provider impacts</strong></th>
<th><strong>Revenue</strong></th>
<th><strong>Operating costs</strong></th>
<th><strong>Investment costs</strong></th>
<th><strong>Grant/subsidy</strong></th>
<th><strong>Subtotal</strong></th>
<th><strong>Freight</strong></th>
<th><strong>Passengers</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(3)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **Other business impacts** | **Developer contributions** | **(4)** | | | | |
|----------------------------|-----------------------------|---------| | | | |
| **NET BUSINESS IMPACT** | | | | | | (5) = (2) + (3) + (4) |

| **TOTAL** | **Present Value of Transport Economic Efficiency Benefits** | | | | | (6) = (1) + (5) |
|-----------|-----------------------------------------------------------| | | | | |

**Notes:** Benefits appear as positive numbers, while costs appear as negative numbers. All entries are discounted present values, in 2002 prices and values.
### Table 2 Economic Efficiency of the Transport System (TEE) for the Appraisal of Major Highway Schemes

#### Consumer User Benefits

<table>
<thead>
<tr>
<th>User benefits</th>
<th>TOTAL</th>
<th>CARS AND PRIVATE LGVS</th>
<th>GOOS VEHICLES AND BUSINESS LGVS</th>
<th>BUS AND COACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle operating costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel time and vehicle operating costs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NET CONSUMER BENEFITS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Business

<table>
<thead>
<tr>
<th>User benefits</th>
<th>TOTAL</th>
<th>CARS AND PRIVATE LGVS</th>
<th>GOOS VEHICLES AND BUSINESS LGVS</th>
<th>BUS AND COACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle operating costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel time and vehicle operating costs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Private sector provider impacts

<table>
<thead>
<tr>
<th>Operating costs</th>
<th>TOTAL</th>
<th>CARS AND PRIVATE LGVS</th>
<th>GOOS VEHICLES AND BUSINESS LGVS</th>
<th>BUS AND COACH</th>
</tr>
</thead>
</table>

#### Other business impacts

<table>
<thead>
<tr>
<th>Developer and other contributions</th>
<th>TOTAL</th>
<th>CARS AND PRIVATE LGVS</th>
<th>GOOS VEHICLES AND BUSINESS LGVS</th>
<th>BUS AND COACH</th>
</tr>
</thead>
</table>

**NET BUSINESS IMPACT**

**TOTAL**

<table>
<thead>
<tr>
<th>Present Value of Transport Economic Efficiency Benefits</th>
<th>TOTAL</th>
<th>CARS AND PRIVATE LGVS</th>
<th>GOOS VEHICLES AND BUSINESS LGVS</th>
<th>BUS AND COACH</th>
</tr>
</thead>
</table>
2 Further Information

The following documents provide information that follows on directly from the key topics covered in this TAG Unit.

<table>
<thead>
<tr>
<th>For information on:</th>
<th>See:</th>
<th>Link:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appraisal Summary Table</td>
<td>Transport Appraisal and the New Green Book</td>
<td>TAG Unit 2.7</td>
</tr>
<tr>
<td>Affordability and Financial Sustainability (AFS) Analysis</td>
<td>Supporting Analysis</td>
<td>TAG Unit 3.8</td>
</tr>
<tr>
<td>Treatment of 10 Year Plan Targets in Multi-Modal Study Recommendations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The TEE appraisal of major highway schemes and major public transport schemes</td>
<td>Detailed Guidance on Major Scheme Appraisal in Local Transport Plans</td>
<td>TAG Unit 3.9</td>
</tr>
</tbody>
</table>

3 References


Highways Agency DMRB Volume 13 (The COBA Manual) and DfT (2003) Interim COBA11 Guidance and Accompanying COBA11 software


4 Document Provenance

This Transport Analysis Guidance (TAG) Unit is based on Chapter 6 Section 2 of Guidance on the Methodology for Multi-Modal Studies Volume 2 (DETR, 2000) amended to reflect the changes outlined in Transport Appraisal and the New Green Book (TAG Unit 2.7).

Technical queries and comments on this TAG Unit should be referred to:

Integrated Transport Economics and Appraisal (ITEA) Division
Department for Transport
Zone 3/08 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
Values of Time and Operating Costs

TAG Unit 3.5.6

February 2007

Department for Transport

Transport Analysis Guidance (TAG)
1 Values of Time and Operating Costs

1.1 Introduction

1.1.1 This TAG Unit provides the latest values of time, occupancy figures, purpose splits, GDP growth rates and vehicle operating costs recommended by the Department for Transport (DfT) for use in economic appraisals of transport projects in England, as well as the rest of Great Britain with the relevant Overseeing Organisation’s permission. This TAG Unit replaces the Transport Economics Note (TEN) dated March 2001.

1.1.2 The values presented in this Unit are suitable for use in COBA, TUBA and QUADRO computer programs, although this list is not exhaustive. Further advice relating to their application may be obtained from the DfT.

1.1.3 This Unit aims, as far as possible, to cover all modes of transport. However in certain parts of the Unit, notably vehicle occupancies and vehicle operating costs, a lack of available data means that all modes have not been covered.

1.1.4 Revision of the March 2001 TEN was necessary to allow implementation of the recommendations contained in the latest research for the DfT on valuation of non-working travel time savings (Values of Travel Time Savings in the UK, Institute for Transport Studies, University of Leeds, 2003). The research recommends three levels of appraisal with differing methodologies. This Unit implements the recommendations for ‘level 1’ appraisals; further guidance will be provided for level 2 and 3 appraisals in due course.

Methods of Cost Benefit Analysis

1.1.5 Cost benefit analysis aims to take account of all the ways in which a project affects people, irrespective of whether those effects are registered in conventional financial accounts. The method of cost benefit analysis for appraisal is the calculus of ‘willingness to pay’ using a market price unit of account. A full discussion of the methodology is given in Cost Benefit Analysis (TAG Unit 3.5.4).

Units of Account

1.1.6 The market price unit of account expresses prices in market prices. Market price refers to the price paid by consumers for goods and services in the market and therefore includes all indirect taxation (indirect taxation refers to taxation levied on a product and therefore includes excises, duties and VAT). Prices that do not include taxation (e.g. public transport fares) are still perceived by consumers in the market price unit of account.

1.1.7 The factor cost unit of account expresses prices in resource costs. Resource costs are costs that are net of indirect taxation. The prices paid by Government for goods and services are not subject to indirect taxation as any tax that is paid by Government bodies such as the Highways Agency is recovered by Government and thus may be ignored. Government expenditure is therefore in the factor cost unit of account. Business costs and benefits are also assumed to be in the factor cost unit of account as businesses are free of indirect taxation because they can claim it back. An exception to this is fuel duty, which businesses cannot claim back.

1.1.8 Costs can be converted to (or from) market prices by multiplying (or dividing) by the indirect tax correction factor, \((1+t)\), where \(t\) is 20.9% - the average rate of indirect taxation in the economy.

1.1.9 Perceived costs are those which are actually experienced by users. Perceived costs are different for work and non-work trips because businesses can claim
back VAT on purchases. Businesses cannot, however, claim back fuel duty and therefore this is included in their perceived cost. (N.B. certain classes of PSV can claim back fuel duty. This should be treated as a subsidy). Note that business users perceive costs in the factor cost unit of account, while consumers perceive costs in the market price unit of account.

1.2 Values of Time

1.2.1 This section provides the latest values of time recommended by the DfT for use in most routine economic appraisals of transport projects. All items are expressed in average 2002 values and prices.

1.2.2 The Department accepts that different values of time may be needed in other circumstances, such as appraisal of strategic analysis, road user charging and toll roads. The Department will issue further guidance on appropriate values and methods to use for these appraisals. For most routine appraisals the guidance in this document is relevant.

Values of Working Time per Person

1.2.3 Time spent travelling during the working day is a cost to the employer’s business. It is assumed that savings in travel time convert non-productive time to productive use and that, in a free labour market, the value of an individual’s working time to the economy is reflected in the wage rate paid. This benefit is assumed to be passed into the wider economy and to accrue in some proportion to the producer, the consumer and the employee, depending on market conditions.

1.2.4 Working time values apply only to journeys made in the course of work. This excludes commuting journeys. The perceived value of working time is the value as perceived by the employer. Businesses perceive costs in the factor cost unit of account and therefore the perceived cost and the resource cost are the same for values of working time. The resource cost is calculated as being equal to the gross wage rate plus non-wage labour costs such as national insurance, pensions and other costs which vary with worker hours. The 24.1% mark-up for non-wage labour costs used in the March 2001 edition of TEN has been revised down to 21.2%, a figure derived using more recent data from the 2000 Labour Cost Survey.

1.2.5 Values for car drivers and passengers; rail, bus, underground and taxi passengers; walkers; cyclists; motorcyclists and average of all persons were derived from the 1999 – 2001 National Travel Survey (NTS), based on individual incomes. Values for the occupational groups (bus, OGV, taxi and LGV occupants) were obtained from the 2002 New Earnings Survey.

1.2.6 It may appear that the use of different values for each mode will introduce inconsistency in appraisal, since it suggests that those transferring between modes change their values of time in the process. This is not the case. The key to understanding this is to realise that the values of time used in appraisal are average values. For any group - bus passengers, car drivers and so on - there will be a distribution of values around the average value for the group. Thus, the value of time for any specific traveller within a group need not be the average value for the group as a whole. In addition, it is likely that there is a good deal of overlap between the distributions for different groups. This immediately resolves the apparent illogicality of the mode switcher: he retains his value of time, but takes up a different position in the distribution of values of time for his new mode, compared with that for his old mode. For example, a car driver with a value of time higher than the average for all car drivers could switch to rail, where his value of time might be lower than the average for all rail passengers.
1.2.7 The use of working time values for modal groups may be criticised because the values remain fixed even though the distribution of users between modes might be affected by some options. In circumstances where large changes in mode are expected, the values by mode for the do-something might be significantly different from the values for the do-minimum. An alternative approach avoiding this problem might be to segment travellers into groups that would not be affected by options – income groups, for example. Each group could be assigned its own working value of time. The value of working time for each mode would then be an output of the modelling process, rather than an input to the appraisal process. However, this assumes that the modelling process will be relatively highly disaggregated. That might be feasible for spatially aggregate models, but could pose serious problems for spatially detailed models – this is discussed in more depth in Modelling (TAG Unit 3.1). Where this approach is considered, analysts should carry out tests to demonstrate that the segmentation adopted will adequately reflect the variation in modal values.

1.2.8 In certain circumstances it may be appropriate to make the simple assumption of a common working value of time for all travellers, in which case the average of all workers value given in Table 1 should be used. Where this approach is adopted, sensitivity tests should be carried out, using values disaggregated by modal group.

1.2.9 In the appraisal process, changes in travel time on employer’s business are valued the same whatever stage of the journey is involved, i.e. there is no weighting applied to take account of the reluctance of passengers to walk to/from or wait for transport services. This is because the time spent or saved is assumed to be lost or gained in productive working time - the travel activity taking up the time is therefore deemed irrelevant. In cases of staged journeys, the value of working time for the main mode should be used, where the main mode refers to the mode for the longest journey by distance.

1.2.10 The Department recognises that use of mode specific values may increase the possibility of not taking into account people who switch between modes. To reduce this risk, values in Table 1 should not be used where the number of people switching modes is high compared to the number of existing users. In these special circumstances, please contact ITEA Division, DfT for further advice.
Table 1: Values of Working Time per person
(£ per hour, 2002 prices and values)

<table>
<thead>
<tr>
<th>Vehicle Occupant</th>
<th>Resource Cost</th>
<th>Perceived Cost</th>
<th>Market Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car driver</td>
<td>21.86</td>
<td>21.86</td>
<td>26.43</td>
</tr>
<tr>
<td>Car passenger</td>
<td>15.66</td>
<td>15.66</td>
<td>18.94</td>
</tr>
<tr>
<td>LGV (driver or passenger)</td>
<td>8.42</td>
<td>8.42</td>
<td>10.18</td>
</tr>
<tr>
<td>OGV (driver or passenger)</td>
<td>8.42</td>
<td>8.42</td>
<td>10.18</td>
</tr>
<tr>
<td>PSV driver</td>
<td>8.42</td>
<td>8.42</td>
<td>10.18</td>
</tr>
<tr>
<td>PSV passenger</td>
<td>16.72</td>
<td>16.72</td>
<td>20.22</td>
</tr>
<tr>
<td>Taxi driver</td>
<td>8.08</td>
<td>8.08</td>
<td>9.77</td>
</tr>
<tr>
<td>Taxi/Minicab passenger</td>
<td>36.97</td>
<td>36.97</td>
<td>44.69</td>
</tr>
<tr>
<td>Rail passenger</td>
<td>30.57</td>
<td>30.57</td>
<td>36.96</td>
</tr>
<tr>
<td>Underground passenger</td>
<td>29.74</td>
<td>29.74</td>
<td>35.95</td>
</tr>
<tr>
<td>Walker</td>
<td>24.51</td>
<td>24.51</td>
<td>29.64</td>
</tr>
<tr>
<td>Cyclist</td>
<td>14.06</td>
<td>14.06</td>
<td>17.00</td>
</tr>
<tr>
<td>Motorcyclist</td>
<td>19.78</td>
<td>19.78</td>
<td>23.91</td>
</tr>
<tr>
<td>Average of all working persons</td>
<td>22.11</td>
<td>22.11</td>
<td>26.73</td>
</tr>
</tbody>
</table>

Values of Non-Working Time per Person

1.2.11 The majority of journeys do not take place during working hours, but in the traveller’s own time. However, people implicitly put a value on their own time, in that they will trade a cheaper, slower journey against a faster, more expensive one. It is therefore appropriate to take account of this value in assessing the impact of different transport strategies or plans.

1.2.12 This ‘willingness to pay’ will vary considerably, depending on such factors as the income of the individual traveller, the value of the journey purpose and its urgency, and the comfort and attractiveness of the journey itself. Different values may therefore correctly be attributed to:

- time spent on the same activity by different people, whose incomes and journey characteristics may vary; and
- time spent by the same individual on different journeys or parts of journeys.

1.2.13 One important specific application of this second type of variability is that time spent walking to/from and waiting for public transport services is commonly valued much more highly than time spent actually travelling. There is consistent evidence that people will pay more to save walking and waiting time than they will for an equivalent saving in ride time. This approach should normally be adopted for multi-modal transport appraisal.

1.2.14 Time savings to travellers in their own time typically make up a large proportion of the benefits of transport investment. If values of time for appraisal are based on an individual’s willingness to pay (behavioural values) which are related to income, then strategies and plans will be biased towards those measures which most benefit travellers with higher incomes (which may favour some modes over others). Investment will then be concentrated into high-income areas, and the
interests of those on lower incomes, who may already suffer from relatively lower mobility and accessibility, will be given less weight. For this reason, multi-modal transport appraisal should normally adopt the values for non-working time which is common across all modes and journey purposes.

1.2.15 The values for non-working time apply to all non-work journey purposes, including travel to and from work, by all modes. It is based on research conducted by the Institute for Transport Studies (ITS) for the Department for Transport, reported in 2003, and published as *Values of Travel Time Saving in the UK*. The value given in the ITS report was in end 1997 prices. These values were converted to 2002 values and prices by uprating in proportion to changes in values of time growth and changes in prices (using the Retail Price Index).

1.2.16 ‘Commuting’ is travelling to and from the normal place of work. ‘Other’ is travel for other non-work purposes, for example leisure trips. There is no differentiation of ‘commuting’ and ‘other’ values of time by mode.

1.2.17 The recommended values for all non-working trips are shown in Table 2. The values given in this table are averages which include retired persons in the calculations.

1.2.18 Individual consumers perceive costs in the market price unit of account and therefore the perceived cost and the market price are the same for ‘commuting’ and ‘other’ purposes.

1.2.19 The values for non-working time (‘commuting’ and ‘other’) spent waiting for public transport is two and a half times the ‘commuting’ and ‘other’ values.

1.2.20 Where walking and cycling is used as a means of inter-changing between modes of transport, the non-working values (‘commuting’ and ‘other’) of walking and cycling is twice the ‘commuting’ and ‘other’ values.

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Resource Cost</th>
<th>Perceived Cost</th>
<th>Market Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td>4.17</td>
<td>5.04</td>
<td>5.04</td>
</tr>
<tr>
<td>Other</td>
<td>3.68</td>
<td>4.46</td>
<td>4.46</td>
</tr>
</tbody>
</table>

### Table 2: Values of Non-Working Time per person (£ per hour, 2002 prices and values)

#### Annual Rates of Growth in Values of Time

1.2.21 The value of non-working time is assumed to increase with income, with an elasticity\(^2\) of 0.8. Working values of time are assumed to grow in line with income, with an elasticity of 1. The measure of income used is GDP per head. Forecasts for GDP are produced by HM Treasury and forecasts for population growth produced by ONS. Forecast growth in the real value of time is shown in Table 3.

---

1 Based on research conducted by the Institute for Transport Studies (ITS) for the Department for Transport, reported in 2003, and published as *Values of Travel Time Saving in the UK*.

2 Elasticity is the relative response of one variable to changes in another variable. The phrase “relative response” is best interpreted as the percentage change. In this context, the inter-temporal income elasticity of the value of time, is the percentage change in the value of time (over time) measured against the percentage change in income (over time).
Table 3: Forecast Growth in the Working and Non-Working Values of Time

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2002 – 2003</td>
<td>2.25</td>
<td>0.27</td>
<td>1.98</td>
<td>1.58</td>
</tr>
<tr>
<td>2003 – 2004</td>
<td>2.50</td>
<td>0.27</td>
<td>2.22</td>
<td>1.78</td>
</tr>
<tr>
<td>2004 – 2005</td>
<td>3.50</td>
<td>0.28</td>
<td>3.21</td>
<td>2.57</td>
</tr>
<tr>
<td>2005 – 2006</td>
<td>3.25</td>
<td>0.28</td>
<td>2.96</td>
<td>2.37</td>
</tr>
<tr>
<td>2006 – 2007</td>
<td>2.75</td>
<td>0.28</td>
<td>2.46</td>
<td>1.97</td>
</tr>
<tr>
<td>2007 – 2011</td>
<td>2.50</td>
<td>0.29</td>
<td>2.20</td>
<td>1.76</td>
</tr>
<tr>
<td>2011 – 2021</td>
<td>2.25</td>
<td>0.31</td>
<td>1.94</td>
<td>1.55</td>
</tr>
<tr>
<td>2021 – 2031</td>
<td>1.75</td>
<td>0.20</td>
<td>1.55</td>
<td>1.24</td>
</tr>
<tr>
<td>2031 – 2051</td>
<td>2.00</td>
<td>0.01</td>
<td>1.99</td>
<td>1.59</td>
</tr>
<tr>
<td>2051 – 2061</td>
<td>1.75</td>
<td>-0.06</td>
<td>1.81</td>
<td>1.45</td>
</tr>
<tr>
<td>2061 onwards</td>
<td>2.00</td>
<td>0.00</td>
<td>2.00</td>
<td>1.60</td>
</tr>
</tbody>
</table>

1.2.22 The annual growth rates in Table 3 should be applied to work and non-work values of travel time over the appraisal period.

Vehicle Occupancies

1.2.23 Car occupancy figures are shown in Table 4. These figures were derived from the 1999 - 2001 National Travel Survey and show the sum of driver occupancy (always 1) and passenger occupancy. Occupancies in the top half of Table 4 are expressed in per vehicle kilometre and those in the bottom half are per trip.

Table 4: Car Occupancies (2000)

<table>
<thead>
<tr>
<th>Journey Purpose</th>
<th>Weekday Occupancy Per Vehicle Kilometre Travelled</th>
<th>Weekend Average</th>
<th>All Week Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Commuting</td>
<td>1.23 1.19 1.17 1.18 1.20 1.28 1.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1.16 1.15 1.13 1.13 1.14 1.14 1.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Car</td>
<td>1.71 1.78 1.82 1.77 1.78 1.97 1.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Car</td>
<td>1.45 1.68 1.60 1.52 1.61 1.88 1.68</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.2.24 Occupancies for all other vehicles are shown in Table 5. These figures also show the sum of driver and passenger occupancy. Occupancies for different times of the day are only available for cars. For LGVs, different occupancy
figures are available for a weekday and the weekend. For all other vehicles, only all week average occupancy figures are available. These should be used for all time periods. Values for heavy and light rail are not included as it is assumed that, if a public transport project is being appraised, a project specific public transport model will be used which will give appropriate details of passenger occupancy. Average PSV occupancy figures are given, as these are required for highways scheme appraisal.

<table>
<thead>
<tr>
<th>Vehicle Type and Journey Purpose</th>
<th>Weekday Average</th>
<th>Weekend Average</th>
<th>All Week Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVG Work (freight)</td>
<td>1.20</td>
<td>1.26</td>
<td>1.20</td>
</tr>
<tr>
<td>LVG Non Work (commuting and other)</td>
<td>1.46</td>
<td>2.03</td>
<td>1.59</td>
</tr>
<tr>
<td>Average LGV</td>
<td>1.23</td>
<td>1.35</td>
<td>1.25</td>
</tr>
<tr>
<td>OGV1 Work only</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>OGV2 Work only</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>PSV Driver</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>PSV Passenger</td>
<td>12.20</td>
<td>12.20</td>
<td>12.20</td>
</tr>
</tbody>
</table>

1.2.25 Table 6 shows the predicted decline in car passenger occupancies as an annual percentage until 2036, after which car passengers are assumed to remain constant. The occupancy of all other vehicle types should be assumed to remain unchanged over time.

<table>
<thead>
<tr>
<th>Journey Purpose</th>
<th>Weekday</th>
<th>Weekend</th>
<th>All Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>-0.48</td>
<td>-0.44</td>
<td>-0.45</td>
</tr>
<tr>
<td>Non – Work (commuting and other)</td>
<td>-0.67</td>
<td>-0.59</td>
<td>-0.56</td>
</tr>
</tbody>
</table>

**Journey Purpose Splits**

1.2.26 Data from the National Travel Survey (1999 – 2001) has been used to produce journey purpose splits for work and non-work travel (commuting and other), based on distance travelled and trips made. These purpose splits are necessary in order to calculate values of time per vehicle for the average vehicle. Journey purpose splits are assumed to remain constant over time.
1.2.27 The purpose splits based on distance travelled in work and non-work time are given in Table 7.

Table 7: Proportion of Travel in Work and Non-Work Time

<table>
<thead>
<tr>
<th>Mode /Vehicle Type &amp; Journey Purpose</th>
<th>Weekday</th>
<th>Weekend Average</th>
<th>All Week Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7am – 10am</td>
<td>10am – 4pm</td>
<td>4pm – 7pm</td>
</tr>
<tr>
<td>Percentage of Distance Travelled by Vehicles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>18.1</td>
<td>19.9</td>
<td>13.0</td>
</tr>
<tr>
<td>Commuting</td>
<td>46.0</td>
<td>11.4</td>
<td>40.8</td>
</tr>
<tr>
<td>Other</td>
<td>35.9</td>
<td>68.7</td>
<td>46.2</td>
</tr>
<tr>
<td>LGV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work (freight)</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
</tr>
<tr>
<td>Non – Work (Commuting and Other)</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>OGV1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>OGV2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Percentage of Distance Travelled by Occupants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>15.4</td>
<td>13.8</td>
<td>10.2</td>
</tr>
<tr>
<td>Commuting</td>
<td>38.3</td>
<td>8.1</td>
<td>32.2</td>
</tr>
<tr>
<td>Other</td>
<td>46.4</td>
<td>78.1</td>
<td>57.6</td>
</tr>
<tr>
<td>PSV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>3.9</td>
<td>2.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Commuting</td>
<td>30.0</td>
<td>11.1</td>
<td>36.6</td>
</tr>
<tr>
<td>Other</td>
<td>66.1</td>
<td>86.9</td>
<td>59.5</td>
</tr>
<tr>
<td>Heavy Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>14.1</td>
<td>22.4</td>
<td>16.4</td>
</tr>
<tr>
<td>Commuting</td>
<td>51.9</td>
<td>10.2</td>
<td>55.9</td>
</tr>
<tr>
<td>Other</td>
<td>34.1</td>
<td>67.4</td>
<td>27.7</td>
</tr>
<tr>
<td>Light Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>1.9</td>
<td>0.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Commuting</td>
<td>82.4</td>
<td>8.5</td>
<td>75.7</td>
</tr>
<tr>
<td>Other</td>
<td>15.7</td>
<td>91.3</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Note: The shaded areas in the table indicate a small sample, hence these figures should be treated with caution.
1.2.28 The purpose splits based on trips made in work and non-work time are given in Table 8.

### Table 8: Proportion of Trips Made in Work and Non-Work Time

<table>
<thead>
<tr>
<th>Mode /Vehicle Type and Journey Purpose</th>
<th>Weekday</th>
<th></th>
<th></th>
<th></th>
<th>Weekend Average</th>
<th>All Week Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7am – 10am</td>
<td>10am – 4pm</td>
<td>4pm – 7pm</td>
<td>7pm – 7am</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Car</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>6.8</td>
<td>8.3</td>
<td>5.5</td>
<td>3.6</td>
<td>6.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Commuting</td>
<td>40.6</td>
<td>11.6</td>
<td>32.3</td>
<td>26.4</td>
<td>25.4</td>
<td>9.1</td>
</tr>
<tr>
<td>Other</td>
<td>52.7</td>
<td>80.1</td>
<td>62.2</td>
<td>70.0</td>
<td>68.1</td>
<td>89.3</td>
</tr>
<tr>
<td><strong>LGV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work (freight)</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
</tr>
<tr>
<td>Non – Work (Commuting and Other)</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td><strong>OGV1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>OGV2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**Note:** The shaded areas in the table indicate a small sample, hence these figures should be treated with caution.
Values of Time per Vehicle

1.2.29 The market price values of time per vehicle are given in Table 9. These values were calculated by multiplication of the appropriate figures from Tables 1, 2, 4, 5 and 6. Average car, average LGV and average PSV values also use the journey purpose split data from Table 7 as weights. The values are based on distance travelled.

<table>
<thead>
<tr>
<th>Vehicle Type and Journey Purpose</th>
<th>Weekday 7am – 10am</th>
<th>10am – 4pm</th>
<th>4pm – 7pm</th>
<th>7pm – 7am</th>
<th>Average Weekday</th>
<th>Weekend</th>
<th>All Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Work</td>
<td>30.74</td>
<td>30.00</td>
<td>29.61</td>
<td>29.81</td>
<td>30.18</td>
<td>31.68</td>
<td>30.18</td>
</tr>
<tr>
<td>Car Commuting</td>
<td>5.84</td>
<td>5.79</td>
<td>5.69</td>
<td>5.69</td>
<td>5.74</td>
<td>5.74</td>
<td>5.74</td>
</tr>
<tr>
<td>Car Other</td>
<td>7.58</td>
<td>7.89</td>
<td>8.08</td>
<td>7.86</td>
<td>7.90</td>
<td>8.74</td>
<td>8.21</td>
</tr>
<tr>
<td>Car Average</td>
<td>10.97</td>
<td>12.05</td>
<td>9.90</td>
<td>9.77</td>
<td>10.88</td>
<td>9.22</td>
<td>10.46</td>
</tr>
<tr>
<td>LGV Non – Work (Commuting and Other)</td>
<td>6.70</td>
<td>6.70</td>
<td>6.70</td>
<td>6.70</td>
<td>6.70</td>
<td>9.31</td>
<td>7.29</td>
</tr>
<tr>
<td>LGV Average</td>
<td>11.55</td>
<td>11.55</td>
<td>11.55</td>
<td>11.55</td>
<td>11.55</td>
<td>12.41</td>
<td>11.63</td>
</tr>
<tr>
<td>OGV1 Working</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
</tr>
<tr>
<td>OGV2 Working</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
</tr>
<tr>
<td>PSV (Occupants) Work</td>
<td>19.80</td>
<td>15.11</td>
<td>19.80</td>
<td>24.24</td>
<td>18.57</td>
<td>13.88</td>
<td>17.33</td>
</tr>
<tr>
<td>PSV Commuting</td>
<td>18.45</td>
<td>6.83</td>
<td>22.50</td>
<td>23.43</td>
<td>15.68</td>
<td>3.94</td>
<td>12.61</td>
</tr>
<tr>
<td>PSV Other</td>
<td>35.97</td>
<td>47.28</td>
<td>32.38</td>
<td>30.58</td>
<td>38.69</td>
<td>50.06</td>
<td>41.68</td>
</tr>
<tr>
<td>PSV Total</td>
<td>74.21</td>
<td>69.22</td>
<td>74.68</td>
<td>78.25</td>
<td>72.93</td>
<td>67.87</td>
<td>71.62</td>
</tr>
</tbody>
</table>

1.2.30 From Table 9, using national average vehicle proportions for 2002, the market price value of an average vehicle is £11.28.
1.3 Vehicle Operating Costs

1.3.1 The use of the road system by private cars and lorries gives rise to operating costs for the user. These include the obvious costs of fuel, oil and tyres, and an element of vehicle maintenance. The models for car and goods vehicle operating costs also include allowances for the purchase of new vehicles, as discussed below.

1.3.2 The distance-related costs to private households and business of car purchase are included in the car non-fuel operating costs by inclusion of an allowance for mileage related depreciation. In addition, for business cars, an allowance is also made for the decline in vehicle capital value (other than that accounted for by mileage related depreciation).

1.3.3 The costs to freight carriers of goods vehicle purchases are taken into account under goods vehicle non-fuel operating costs. As with private cars, it is assumed that the decision to purchase goods vehicles is independent of the transport policy option pursued. However, changes in congestion on the road system will influence the productivity with which any given fleet of goods vehicles can be used, and this element is taken into account in computing goods vehicle operating costs.

1.3.4 This section provides the latest vehicle operating cost (VOC) values recommended by the Department for use in economic appraisals of transport projects. VOCs are separated into fuel VOCs and non-fuel VOCs and are discussed separately within this section. All parameters are expressed in average 2002 values and prices.

Vehicle Operating Costs- Fuel

1.3.5 Fuel consumption is estimated using a function of the form:

\[ L = a + b.v + c.v^2 + d.v^3 \]

Where:
- \( L \) = consumption, expressed in litres per kilometre;
- \( v \) = average speed in kilometres per hour; and
- \( a, b, c, d \) are parameters defined for each vehicle category.

1.3.6 The parameters needed to calculate the fuel consumption element of VOCs are given in Table 103.

---

3 This has been derived from an equation given by AEA Technology's National Environmental Technology Centre (NETCEN) which estimates carbon emissions in grams per kilometre travelled, based on laboratory testing of different vehicle types over different journey cycles (including varying degrees of accelerating, decelerating idling and stop-starts, as well as travelling at constant speeds). The equations are consistent with those that are used to compile the National Atmospheric Emissions Inventory (NAEI). The NETCEN relationship has been adapted to reflect fuel consumption in litres per kilometre travelled by making use of the fact that carbon emissions and fuel consumption are directly proportional.
1.3.7 In Table 10a the VOC parameters have been converted into pence per kilometre by multiplying by the resource cost of fuel reported in Table 11. OGV1, OGV2 and PSV are assumed to be diesel driven and therefore parameters for these vehicles have been multiplied by the resource cost of diesel. The parameters for average car and average LGV are calculated as the average of the parameters for petrol and diesel cars / LGVs weighted according to the proportions of total traffic (vehicle kms) that are petrol and diesel. In the absence of more specific evidence it has been assumed that the proportions of traffic that are diesel and petrol are broadly equivalent to the proportions of diesel and petrol vehicles in the fleet. For the proportions of diesel and petrol cars in the fleet, see Table 12. The proportion of LGV traffic that is diesel is assumed to be constant through time, at 85%.

### Table 10: Fuel VOC Formulae Parameter Values (litres per km, 2002)

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>A</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol Car</td>
<td>0.18804764</td>
<td>-0.00437947</td>
<td>0.00005068</td>
<td>-0.0000001691</td>
</tr>
<tr>
<td>Diesel Car</td>
<td>0.14086613</td>
<td>-0.00285222</td>
<td>0.00002867</td>
<td>-0.0000000693</td>
</tr>
<tr>
<td>Average Car</td>
<td>0.17813952</td>
<td>-0.00405874</td>
<td>0.00004606</td>
<td>-0.0000001481</td>
</tr>
<tr>
<td>Petrol LGV</td>
<td>0.25246149</td>
<td>-0.00486999</td>
<td>0.00004424</td>
<td>-0.0000000753</td>
</tr>
<tr>
<td>Diesel LGV</td>
<td>0.18637593</td>
<td>-0.00268049</td>
<td>0.00001172</td>
<td>0.0000000823</td>
</tr>
<tr>
<td>Average LGV</td>
<td>0.19628876</td>
<td>-0.00300892</td>
<td>0.00001659</td>
<td>0.0000000587</td>
</tr>
<tr>
<td>OGV1</td>
<td>0.76833752</td>
<td>-0.02257303</td>
<td>0.00031766</td>
<td>-0.0000013544</td>
</tr>
<tr>
<td>OGV2</td>
<td>1.02443156</td>
<td>-0.03021812</td>
<td>0.00044285</td>
<td>-0.0000020059</td>
</tr>
<tr>
<td>PSV</td>
<td>0.63468687</td>
<td>-0.01898970</td>
<td>0.00027431</td>
<td>-0.0000012161</td>
</tr>
</tbody>
</table>
### Table 10a: Fuel VOC Formulae Parameter Values (pence per km, 2002)

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Parameter Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td>Petrol Car</td>
<td>3.38485753</td>
</tr>
<tr>
<td>Diesel Car</td>
<td>2.76097615</td>
</tr>
<tr>
<td>Average Car</td>
<td>3.25384244</td>
</tr>
<tr>
<td>Petrol LGV</td>
<td>4.54430659</td>
</tr>
<tr>
<td>Diesel LGV</td>
<td>3.65296841</td>
</tr>
<tr>
<td>Average LGV</td>
<td>3.78666892</td>
</tr>
<tr>
<td>OGV1</td>
<td>15.05941530</td>
</tr>
<tr>
<td>OGV2</td>
<td>20.07885853</td>
</tr>
<tr>
<td>PSV</td>
<td>12.43950601</td>
</tr>
</tbody>
</table>

1.3.8 The cost of fuel is shown in Table 11. These figures are actual figures published in *Transport Statistics Great Britain* (DfT 2005). Figures for average cars and average LGVs represent the weighted averages of the corresponding petrol and diesel figures where the weights used are the proportions of total car / LGV fuel consumption that are forecast to be petrol and diesel in each year.

### Table 11 Fuel Costs, Fuel Duty and VAT Rates (in 2002 prices)

<table>
<thead>
<tr>
<th>Year</th>
<th>Resource Cost (pence per litre)</th>
<th>Duty (pence per litre)</th>
<th>VAT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Petrol</td>
<td>Diesel</td>
<td>Av. Car</td>
</tr>
<tr>
<td>2002(actual)</td>
<td>18.0</td>
<td>19.6</td>
<td>18.2</td>
</tr>
<tr>
<td>2003(actual)</td>
<td>20.2</td>
<td>22.4</td>
<td>20.6</td>
</tr>
<tr>
<td>2004(actual)</td>
<td>18.0</td>
<td>19.2</td>
<td>18.3</td>
</tr>
<tr>
<td>2005(actual)</td>
<td>23.5</td>
<td>26.8</td>
<td>24.1</td>
</tr>
<tr>
<td>2006(actual)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.3.9 The resource cost of fuel VOCs is net of indirect taxation. The market price is gross of indirect taxation and is therefore the sum of the resource cost and fuel duty, plus VAT of 17.5% (that is, market price = [resource cost + fuel duty] x 1.175). In work time the perceived cost of fuel VOCs is the cost perceived by businesses. Businesses are generally viewed as perceiving costs in the factor cost unit of account as most business costs are free of indirect taxation because they can claim it back. However, businesses cannot reclaim fuel duty and therefore the perceived value of fuel VOCs in work time is equal to the resource cost plus fuel duty. In non-work time, the perceived cost of fuel VOCs is the cost as perceived by the individual consumer. Consumers perceive costs in the market prices unit of account and therefore the perceived value of fuel VOCs in non-working time is equal to the market price.

1.3.10 Fuel duty is assumed to remain constant in real terms beyond the increases announced in the 2006 Budget that are reflected in Table 11.

1.3.11 Table 12 provides forecasts of the proportions of diesel and petrol vehicles in the car fleet4. These forecasts are used in the COBA and TUBA software programs when subdividing the total number of cars into petrol or diesel.5

<table>
<thead>
<tr>
<th>Year</th>
<th>Petrol</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>79</td>
<td>21</td>
</tr>
<tr>
<td>2003</td>
<td>78</td>
<td>22</td>
</tr>
<tr>
<td>2004</td>
<td>77</td>
<td>23</td>
</tr>
<tr>
<td>2005</td>
<td>76</td>
<td>24</td>
</tr>
<tr>
<td>2006</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>2007</td>
<td>74</td>
<td>26</td>
</tr>
<tr>
<td>2008</td>
<td>72</td>
<td>28</td>
</tr>
<tr>
<td>2009</td>
<td>71</td>
<td>29</td>
</tr>
<tr>
<td>2010</td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td>2025 onwards</td>
<td>decreasing to 57</td>
<td>increasing to 43</td>
</tr>
</tbody>
</table>

**Rates of Change in Fuel VOCs**

1.3.12 There are two causes of changes in fuel VOC over time: improvements in vehicle efficiency; and changes in the cost of fuel. For cars, changes in fuel VOCs also reflect changes in the proportion of traffic using either petrol or diesel (see Table 12).

---

4 The figures for the proportion of car fleet using petrol or diesel in the previous version of this unit have been revised to reflect the use of a more reliable source of evidence.

5 Ideally we would use the proportions of total traffic (vehicle kms) that are petrol and diesel in COBA and TUBA. The car fleet split is used here in the absence of forecasts of the car traffic split.
1.3.13 Vehicle efficiency assumptions are shown in Table 13. These figures show changes in fuel consumption and therefore negative figures indicate an improvement in vehicle efficiency. It should be noted that the figures for average car and average LGV represent the change in the fuel consumption of the petrol and diesel cars / LGVs weighted according to the proportion of car / LGV traffic driven by vehicles of each fuel type. The changes in average car fuel efficiency also reflect the increasing proportion of traffic that is diesel over time, and that diesel cars are expected to remain more fuel efficient than petrol cars.

### Table 13: Assumed Vehicle Fuel Efficiency Improvements

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol Car</td>
<td>-0.74</td>
<td>-0.75</td>
<td>-0.76</td>
<td>-4.18</td>
<td>-5.96</td>
<td>-7.18</td>
</tr>
<tr>
<td>Diesel Car</td>
<td>-1.18</td>
<td>-1.19</td>
<td>-1.21</td>
<td>-5.95</td>
<td>-5.84</td>
<td>-6.03</td>
</tr>
<tr>
<td>Average Car</td>
<td>-1.08</td>
<td>-1.10</td>
<td>-1.11</td>
<td>-6.49</td>
<td>-7.62</td>
<td>-8.21</td>
</tr>
<tr>
<td>Petrol LGV</td>
<td>-1.22</td>
<td>-1.56</td>
<td>-1.78</td>
<td>-7.24</td>
<td>-7.24</td>
<td>-7.24</td>
</tr>
<tr>
<td>Diesel LGV</td>
<td>0.97</td>
<td>-1.40</td>
<td>-1.78</td>
<td>-7.24</td>
<td>-7.24</td>
<td>-7.24</td>
</tr>
<tr>
<td>Average LGV</td>
<td>0.64</td>
<td>-1.42</td>
<td>-1.78</td>
<td>-7.24</td>
<td>-7.24</td>
<td>-7.24</td>
</tr>
<tr>
<td>OGV1</td>
<td>0.46</td>
<td>0</td>
<td>0</td>
<td>-6.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OGV2</td>
<td>-0.17</td>
<td>0</td>
<td>0</td>
<td>-6.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PSV</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1.3.14 The forecast changes in the cost of fuel are shown in Table 14. The forecast changes in the resource cost of petrol and diesel are based on data provided by the Department for Trade and Industry for unleaded petrol and diesel. The figures for average car and average LGV represent the change in resource cost per litre for the average car / LGV. The changes in each year for the average car reflect changes in the resource costs of petrol and diesel, the forecast increase in the proportion of traffic that are diesel cars, and that the resource cost of diesel is forecast to remain above the resource cost of petrol.
### Table 14: Forecast Growth in the Resource Cost of Fuel

<table>
<thead>
<tr>
<th>Range of Years</th>
<th>Petrol (% pa)</th>
<th>Diesel (% pa)</th>
<th>Average Car (% pa)</th>
<th>Average LGV (% pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006 – 2007</td>
<td>-6.37</td>
<td>-6.30</td>
<td>-6.27</td>
<td>-6.31</td>
</tr>
<tr>
<td>2008 – 2009</td>
<td>-8.06</td>
<td>-7.91</td>
<td>-7.93</td>
<td>-7.93</td>
</tr>
<tr>
<td>2009 – 2010</td>
<td>-6.93</td>
<td>-6.79</td>
<td>-6.70</td>
<td>-6.81</td>
</tr>
<tr>
<td>2010 – 2015</td>
<td>0.80</td>
<td>0.78</td>
<td>0.93</td>
<td>0.79</td>
</tr>
<tr>
<td>2015 – 2020</td>
<td>0.86</td>
<td>0.84</td>
<td>0.97</td>
<td>0.84</td>
</tr>
<tr>
<td>2020 – 2025</td>
<td>0</td>
<td>0</td>
<td>0.03</td>
<td>0</td>
</tr>
<tr>
<td>2025 +</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1.3.15 The Department is aware that the accuracy of the cubic equation in representing the relationship between speed and fuel consumption, lessens at low speeds. The Department is engaged in research to further improve the robustness of this relationship at low speeds.

#### Vehicle Operating Costs- Non Fuel

1.3.16 The elements making up non-fuel vehicle operating costs include oil, tyres, maintenance, depreciation and vehicle capital saving (only for vehicles in working time). The non-fuel elements of VOC are combined in a formula of the form;

\[ C = a_1 + \frac{b_1}{V} \]

where;

C = cost in pence per kilometre travelled,
V = average link speed in kilometres per hour,
a_1 is a parameter for distance related costs defined for each vehicle category, and b_1 is a parameter for vehicle capital saving defined for each vehicle category. (This parameter is only relevant to working vehicles).

1.3.17 The parameters needed to calculate the non-fuel vehicle operating costs are given in Table 15. These parameters are in pence per kilometre at 2002 prices.
Table 15: Non-Fuel VOC Formulae Parameters (pence per km, 2002 prices)

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Resource Cost Parameters</th>
<th>Perceived Cost Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a1</td>
<td>b1</td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>4.069</td>
<td>111.391</td>
</tr>
<tr>
<td>Non-Work Car</td>
<td>3.151</td>
<td>-</td>
</tr>
<tr>
<td>(commuting and other)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Car</td>
<td>3.308</td>
<td>19.048</td>
</tr>
<tr>
<td>LGV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>5.910</td>
<td>38.603</td>
</tr>
<tr>
<td>Non-Work Car</td>
<td>5.910</td>
<td>-</td>
</tr>
<tr>
<td>(commuting and other)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average LGV</td>
<td>5.910</td>
<td>33.970</td>
</tr>
<tr>
<td>OGV1</td>
<td>5.501</td>
<td>216.165</td>
</tr>
<tr>
<td>OGV2</td>
<td>10.702</td>
<td>416.672</td>
</tr>
<tr>
<td>PSV</td>
<td>24.959</td>
<td>569.094</td>
</tr>
</tbody>
</table>

1.3.18 Non-fuel VOC parameters for work and non-work cars (commuting and other) and private LGVs have been derived in accordance with previous methods outlined in Review of Vehicle Operating Costs in COBA (EEA Division, DoT 1990-91). Non-fuel parameters for all other vehicles have been updated from the Transport Economics Note (DfT 2001) by the ratio of average 1998 and 2002 Retail Price Indices.

1.3.19 The resource cost of non-fuel VOCs is net of indirect taxation and the market price is gross of indirect taxation. The perceived cost of non-fuel VOCs differs for work and non-work time. In work time, the perceived cost is the cost perceived by businesses and is therefore equal to the resource cost. In non-work time, the perceived cost is the cost perceived by the consumer and is therefore equal to the market price.

1.3.20 The perceived cost of non-fuel LGV operating costs differ in work and non-work time by the indirect tax correction factor (described in paragraph 1.1.8). However, the difference between non-fuel car operating costs is not explained entirely by the indirect tax correction factor as account is also taken of the difference in the composition of vehicle fleet in work and non-work time. In work time, a large proportion of total mileage is by cars with large engine sizes and these cars have higher non-fuel VOCs.

1.3.21 The marginal resource costs of oil, tyres, mileage and maintenance related depreciation, are assumed to be fixed costs per kilometre and appear in the ‘a’ term. The ‘b’ term in the non-fuel costs represents changes in the productivity of commercial vehicles and cars in working time, all goods vehicles and PSVs.
1.3.22 The time component of depreciation is excluded since it does not vary with distance or speed. For OGVs and PSVs depreciation is assumed to be totally time related; this is based on evidence from trade sources which suggest that factors such as obsolescence and condition are more important determinants of vehicle value than mileage *per se*. For cars and LGVs evidence from second hand prices indicates that part of their depreciation is related to mileage; and therefore this element is recorded as a marginal resource cost.

**Rates of Change in Non-Fuel VOCs**

1.3.23 Non-fuel VOCs are assumed to remain constant in real terms over the forecast period. This assumption is made because the main elements which make up non-fuel VOCs are subject to less volatility than fuel VOCs.

**Bus Operating Costs**

1.3.24 In a simple highway appraisal, buses are treated as part of the traffic flow, and the operating cost formulae described above are applied, using the appropriate parameter values for PSVs. In a multi-modal study, however, different options may result not only in faster or slower running times for existing bus services, but in the need for more or different levels and patterns of bus service provision. In these cases, the impact of options on the costs of bus service provision have to be considered in more detail.

1.3.25 The bus operating model requires assumptions to be input on various operational characteristics, such as sickness rates, working days per week, holiday allowances, employers’ costs, engineering spares etc and also unit cost rates for each grade of staff, fuel and tyres etc. Vehicle fleet requirements and costs are considered as capital expenditure outside the model and are included in option costs. *The Overall Approach: The Steps in the Process* ([TAG Unit 2.1](#)) gives an overview of how costs are covered in the appraisal process. *The Estimation and Treatment of scheme costs* ([TAG Unit 3.5.9](#)) provides further detail on estimating and treating costs for use in the appraisal process.

1.3.26 Bus operating costs vary by region and by service type. Information on the operating cost of local bus services, by area, can be found in *Focus on Public Transport* and in *The Passenger Transport Industry in Great Britain Facts* (Confederation of Passenger Transport 1999-2000). Where no other information is available, these costs should be used as default indicators of the operating cost of bus services. However, more detailed information on bus costs should be sought where bus based measures are likely to play a significant part in a strategy. Study consultants may be able to provide more detailed cost estimates using bus operating cost models. The validity of such costs should be cross-checked with other data sources, including the range of values given in the national statistics. Where possible, the co-operation and views of local bus operators should be sought. The Confederation of Passenger Transport (CTP) may also be able to provide assistance in estimating the costs of bus operation.

**Rail Operating Costs**

1.3.27 Information on rail operating cost assumptions can be obtained by discussion with the Department.

2  **Further Information**

The following documents provide information that follows on directly from the key topics covered in this Unit.
## 3 References


Confederation of Passenger Transport (1999-2000), *Focus on Public Transport*


ITEA Division, Department for Transport (2001), Transport Economics Note

EEA Division, Department of Transport (1990-91), Review of Vehicle Operating Costs in COBA

Department for Transport (2005), Transport Statistics Great Britain.

## 4 Document provenance

1. This Transport Analysis Guidance (TAG) Unit is based on Appendix H of *Guidance on the Methodology for Multi-Modal Studies Volume 2* (DETR, 2000), the Transport Economics Note (DfT, 2001) and Netcen’s Carbon Emission and Fuel Consumption Parameters for the National Transport Model (NETCEN, 2005).

2. January 2007
   (i) Parameters in Table 10 rounded.
   (ii) Corrections to Table 15.

Technical queries and comments on this Unit should be referred to:

Integrated Transport Economic Appraisal (ITEA) Division
Department for Transport
Zone 3/08 Great Minster House
76 Marsham Street
London SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198

### For information on:

<table>
<thead>
<tr>
<th>See:</th>
<th>TAG Unit number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Appraisal Process</td>
<td>The Overall Approach: The Steps in the Process</td>
</tr>
<tr>
<td></td>
<td>The Appraisal Process</td>
</tr>
<tr>
<td>Modelling</td>
<td>Modelling</td>
</tr>
<tr>
<td>Estimating and Treating Scheme Costs</td>
<td>The Estimation and Treatment of Scheme Costs</td>
</tr>
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</table>
Values of Time and Operating Costs

TAG Unit 3.5.6

December 2008

Department for Transport

Transport Analysis Guidance (TAG)
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1 Values of Time and Operating Costs

1.1 Introduction

1.1.1 This TAG Unit provides the latest values of time, occupancy figures, purpose splits, GDP growth rates and vehicle operating costs recommended by the Department for Transport (DfT) for use in economic appraisals of transport projects in England, as well as the rest of Great Britain with the relevant Overseeing Organisation’s permission. This TAG Unit replaces the Transport Economics Note (TEN) dated March 2001.

1.1.2 The values presented in this Unit are suitable for use in COBA, TUBA and QUADRO computer programs, although this list is not exhaustive. Further advice relating to their application may be obtained from the DfT.

1.1.3 This Unit aims, as far as possible, to cover all modes of transport. However in certain parts of the Unit, notably vehicle occupancies and vehicle operating costs, a lack of available data means that all modes have not been covered.

1.1.4 Revision of the March 2001 TEN was necessary to allow implementation of the recommendations contained in the latest research for the DfT on valuation of non-working travel time savings ([Values of Travel Time Savings in the UK](#), Institute for Transport Studies, University of Leeds, 2003). The research recommends three levels of appraisal with differing methodologies. This Unit implements the recommendations for ‘level 1’ appraisals; further guidance will be provided for level 2 and 3 appraisals in due course.

Methods of Cost Benefit Analysis

1.1.5 Cost benefit analysis aims to take account of all the ways in which a project affects people, irrespective of whether those effects are registered in conventional financial accounts. The method of cost benefit analysis for appraisal is the calculus of ‘willingness to pay’ using a market price unit of account. A full discussion of the methodology is given in [Cost Benefit Analysis](#) (TAG Unit 3.5.4).

Units of Account

1.1.6 The market price unit of account expresses prices in market prices. Market price refers to the price paid by consumers for goods and services in the market and therefore includes all indirect taxation (indirect taxation refers to taxation levied on a product and therefore includes excises, duties and VAT). Prices that do not include taxation (e.g. public transport fares) are still perceived by consumers in the market price unit of account.

1.1.7 The factor cost unit of account expresses prices in resource costs. Resource costs are costs that are net of indirect taxation. The prices paid by Government for goods and services are not subject to indirect taxation as any tax that is paid by Government bodies such as the Highways Agency is recovered by Government and thus may be ignored. Government expenditure is therefore in the factor cost unit of account. Business costs and benefits are also assumed to be in the factor cost unit of account as businesses are free of indirect taxation because they can claim it back. An exception to this is fuel duty, which businesses cannot claim back.

1.1.8 Costs can be converted to (or from) market prices by multiplying (or dividing) by the indirect tax correction factor, \((1+t)\), where \(t\) is 20.9% - the average rate of indirect taxation in the economy.

1.1.9 Perceived costs are those which are actually experienced by users. Perceived costs are different for work and non-work trips because businesses can claim...
back VAT on purchases. Businesses cannot, however, claim back fuel duty and therefore this is included in their perceived cost. (N.B. certain classes of PSV can claim back fuel duty. This should be treated as a subsidy). Note that business users perceive costs in the factor cost unit of account, while consumers perceive costs in the market price unit of account.

1.2 Values of Time

1.2.1 This section provides the latest values of time recommended by the DfT for use in most routine economic appraisals of transport projects. All items are expressed in average 2002 values and prices.

1.2.2 The Department accepts that different values of time may be needed in other circumstances, such as appraisal of strategic analysis, road user charging and toll roads. The Department will issue further guidance on appropriate values and methods to use for these appraisals. For most routine appraisals the guidance in this document is relevant.

Values of Working Time per Person

1.2.3 Time spent travelling during the working day is a cost to the employer's business. It is assumed that savings in travel time convert non-productive time to productive use and that, in a free labour market, the value of an individual's working time to the economy is reflected in the wage rate paid. This benefit is assumed to be passed into the wider economy and to accrue in some proportion to the producer, the consumer and the employee, depending on market conditions.

1.2.4 Working time values, apply only to journeys made in the course of work. This excludes commuting journeys. The perceived value of working time is the value as perceived by the employer. Businesses perceive costs in the factor cost unit of account and therefore the perceived cost and the resource cost are the same for values of working time. The resource cost is calculated as being equal to the gross wage rate plus non-wage labour costs such as national insurance, pensions and other costs which vary with worker hours. The 24.1% mark-up for non-wage labour costs used in the March 2001 edition of TEN has been revised down to 21.2%, a figure derived using more recent data from the 2000 Labour Cost Survey.

1.2.5 Values for car drivers and passengers; rail, bus, underground and taxi passengers; walkers; cyclists; motorcyclists and average of all persons were derived from the 1999 – 2001 National Travel Survey (NTS), based on individual incomes. Values for the occupational groups (bus, OGV, taxi and LGV occupants) were obtained from the 2002 New Earnings Survey.

1.2.6 It may appear that the use of different values for each mode will introduce inconsistency in appraisal, since it suggests that those transferring between modes change their values of time in the process. This is not the case. The key to understanding this is to realise that the values of time used in appraisal are average values. For any group - bus passengers, car drivers and so on - there will be a distribution of values around the average value for the group. Thus, the value of time for any specific traveller within a group need not be the average value for the group as a whole. In addition, it is likely that there is a good deal of overlap between the distributions for different groups. This immediately resolves the apparent illogicality of the mode switcher: he retains his value of time, but takes up a different position in the distribution of values of time for his new mode, compared with that for his old mode. For example, a car driver with a value of time higher than the average for all car drivers could switch to rail, where his value of time might be lower than the average for all rail passengers.
1.2.7 The use of working time values for modal groups may be criticised because the values remain fixed even though the distribution of users between modes might be affected by some options. In circumstances where large changes in mode are expected, the values by mode for the do-something might be significantly different from the values for the do-minimum. An alternative approach avoiding this problem might be to segment travellers into groups that would not be affected by options – income groups, for example. Each group could be assigned its own working value of time. The value of working time for each mode would then be an output of the modelling process, rather than an input to the appraisal process. However, this assumes that the modelling process will be relatively highly disaggregated. That might be feasible for spatially aggregate models, but could pose serious problems for spatially detailed models – this is discussed in more depth in Modelling (TAG Unit 3.1). Where this approach is considered, analysts should carry out tests to demonstrate that the segmentation adopted will adequately reflect the variation in modal values.

1.2.8 In certain circumstances it may be appropriate to make the simple assumption of a common working value of time for all travellers, in which case the average of all workers value given in Table 1 should be used. Where this approach is adopted, sensitivity tests should be carried out, using values disaggregated by modal group.

1.2.9 In the appraisal process, changes in travel time on employer’s business are valued the same whatever stage of the journey is involved, i.e. there is no weighting applied to take account of the reluctance of passengers to walk to/from or wait for transport services. This is because the time spent or saved is assumed to be lost or gained in productive working time - the travel activity taking up the time is therefore deemed irrelevant. In cases of staged journeys, the value of working time for the main mode should be used, where the main mode refers to the mode for the longest journey by distance.

1.2.10 The Department recognises that use of mode specific values may increase the possibility of not taking into account people who switch between modes. To reduce this risk, values in Table 1 should not be used where the number of people switching modes is high compared to the number of existing users. In these special circumstances, please contact ITEA Division, DfT for further advice.
Table 1: Values of Working Time per person
(£ per hour, 2002 prices and values)

<table>
<thead>
<tr>
<th>Vehicle Occupant</th>
<th>Resource Cost</th>
<th>Perceived Cost</th>
<th>Market Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car driver</td>
<td>21.86</td>
<td>21.86</td>
<td>26.43</td>
</tr>
<tr>
<td>Car passenger</td>
<td>15.66</td>
<td>15.66</td>
<td>18.94</td>
</tr>
<tr>
<td>LGV (driver or passenger)</td>
<td>8.42</td>
<td>8.42</td>
<td>10.18</td>
</tr>
<tr>
<td>OGV (driver or passenger)</td>
<td>8.42</td>
<td>8.42</td>
<td>10.18</td>
</tr>
<tr>
<td>PSV driver</td>
<td>8.42</td>
<td>8.42</td>
<td>10.18</td>
</tr>
<tr>
<td>PSV passenger</td>
<td>16.72</td>
<td>16.72</td>
<td>20.22</td>
</tr>
<tr>
<td>Taxi driver</td>
<td>8.08</td>
<td>8.08</td>
<td>9.77</td>
</tr>
<tr>
<td>Taxi/Minicab passenger</td>
<td>36.97</td>
<td>36.97</td>
<td>44.69</td>
</tr>
<tr>
<td>Rail passenger</td>
<td>30.57</td>
<td>30.57</td>
<td>36.96</td>
</tr>
<tr>
<td>Underground passenger</td>
<td>29.74</td>
<td>29.74</td>
<td>35.95</td>
</tr>
<tr>
<td>Walker</td>
<td>24.51</td>
<td>24.51</td>
<td>29.64</td>
</tr>
<tr>
<td>Cyclist</td>
<td>14.06</td>
<td>14.06</td>
<td>17.00</td>
</tr>
<tr>
<td>Motorcyclist</td>
<td>19.78</td>
<td>19.78</td>
<td>23.91</td>
</tr>
<tr>
<td>Average of all working persons</td>
<td>22.11</td>
<td>22.11</td>
<td>26.73</td>
</tr>
</tbody>
</table>

Values of Non-Working Time per Person

1.2.11 The majority of journeys do not take place during working hours, but in the traveller’s own time. However, people implicitly put a value on their own time, in that they will trade a cheaper, slower journey against a faster, more expensive one. It is therefore appropriate to take account of this value in assessing the impact of different transport strategies or plans.

1.2.12 This ‘willingness to pay’ will vary considerably, depending on such factors as the income of the individual traveller, the value of the journey purpose and its urgency, and the comfort and attractiveness of the journey itself. Different values may therefore correctly be attributed to:

- time spent on the same activity by different people, whose incomes and journey characteristics may vary; and
- time spent by the same individual on different journeys or parts of journeys.

1.2.13 One important specific application of this second type of variability is that time spent walking to/from and waiting for public transport services is commonly valued much more highly than time spent actually travelling. There is consistent evidence that people will pay more to save walking and waiting time than they will for an equivalent saving in ride time. This approach should normally be adopted for multi-modal transport appraisal.

1.2.14 Time savings to travellers in their own time typically make up a large proportion of the benefits of transport investment. If values of time for appraisal are based on an individual’s willingness to pay (behavioural values) which are related to income, then strategies and plans will be biased towards those measures which most benefit travellers with higher incomes (which may favour some modes over others). Investment will then be concentrated into high-income areas, and the
interests of those on lower incomes, who may already suffer from relatively lower mobility and accessibility, will be given less weight. For this reason, multi-modal transport appraisal should normally adopt the values for non-working time which is common across all modes and journey purposes.

1.2.15 The values for non-working time apply to all non-work journey purposes, including travel to and from work, by all modes. It is based on research conducted by the Institute for Transport Studies (ITS) for the Department for Transport, reported in 2003, and published as *Values of Travel Time Saving in the UK*. The value given in the ITS report was in end 1997 prices. These values were converted to 2002 values and prices by uprating in proportion to changes in values of time growth and changes in prices (using the Retail Price Index).

1.2.16 ‘Commuting’ is travelling to and from the normal place of work. ‘Other’ is travel for other non-work purposes, for example leisure trips. There is no differentiation of ‘commuting’ and ‘other’ values of time by mode.\(^1\)

1.2.17 The recommended values for all non-working trips are shown in Table 2. The values given in this table are averages which include retired persons in the calculations.

1.2.18 Individual consumers perceive costs in the market price unit of account and therefore the perceived cost and the market price are the same for ‘commuting’ and ‘other’ purposes.

1.2.19 The values for non-working time (‘commuting’ and ‘other’) spent waiting for public transport is two and a half times the ‘commuting’ and ‘other’ values.

1.2.20 Where walking and cycling is used as a means of inter-changing between modes of transport, the non-working values (‘commuting’ and ‘other’) of walking and cycling is twice the ‘commuting’ and ‘other’ values.

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Resource Cost</th>
<th>Perceived Cost</th>
<th>Market Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td>4.17</td>
<td>5.04</td>
<td>5.04</td>
</tr>
<tr>
<td>Other</td>
<td>3.68</td>
<td>4.46</td>
<td>4.46</td>
</tr>
</tbody>
</table>

**Table 2: Values of Non-Working Time per person**  
(£ per hour, 2002 prices and values)

Annual Rates of Growth in Values of Time

1.2.21 The value of non-working time is assumed to increase with income, with an elasticity\(^2\) of 0.8. Working values of time are assumed to grow in line with income, with an elasticity of 1. The measure of income used is GDP per head. Forecasts for GDP are produced by HM Treasury and forecasts for population growth produced by ONS. Forecast growth in the real value of time is shown in Table 3.

---

\(^1\) Based on research conducted by the Institute for Transport Studies (ITS) for the Department for Transport, reported in 2003, and published as *Values of Travel Time Saving in the UK*.

\(^2\) Elasticity is the relative response of one variable to changes in another variable. The phrase “relative response” is best interpreted as the percentage change. In this context, the inter-temporal income elasticity of the value of time, is the percentage change in the value of time (over time) measured against the percentage change in income (over time).
### Table 3: Forecast Growth in the Working and Non-Working Values of Time

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2002 – 2003</td>
<td>2.25</td>
<td>0.27</td>
<td>1.98</td>
<td>1.58</td>
</tr>
<tr>
<td>2003 – 2004</td>
<td>2.50</td>
<td>0.27</td>
<td>2.22</td>
<td>1.78</td>
</tr>
<tr>
<td>2004 – 2005</td>
<td>3.50</td>
<td>0.28</td>
<td>3.21</td>
<td>2.57</td>
</tr>
<tr>
<td>2005 – 2006</td>
<td>3.25</td>
<td>0.28</td>
<td>2.96</td>
<td>2.37</td>
</tr>
<tr>
<td>2006 – 2007</td>
<td>2.75</td>
<td>0.28</td>
<td>2.46</td>
<td>1.97</td>
</tr>
<tr>
<td>2007 – 2011</td>
<td>2.50</td>
<td>0.29</td>
<td>2.20</td>
<td>1.76</td>
</tr>
<tr>
<td>2011 – 2021</td>
<td>2.25</td>
<td>0.31</td>
<td>1.94</td>
<td>1.55</td>
</tr>
<tr>
<td>2021 – 2031</td>
<td>1.75</td>
<td>0.20</td>
<td>1.55</td>
<td>1.24</td>
</tr>
<tr>
<td>2031 – 2051</td>
<td>2.00</td>
<td>0.01</td>
<td>1.99</td>
<td>1.59</td>
</tr>
<tr>
<td>2051 – 2061</td>
<td>1.75</td>
<td>-0.06</td>
<td>1.81</td>
<td>1.45</td>
</tr>
<tr>
<td>2061 onwards</td>
<td>2.00</td>
<td>0.00</td>
<td>2.00</td>
<td>1.60</td>
</tr>
</tbody>
</table>

1.2.22 In accordance with the Treasury’s Green Book, VOT growth rates in Table 3 above for a given year should be modified according to whether the discount rate for that year is different from the rate for the current year as follows:

\[
\text{VOTgrowth\_modified\_year} = \frac{\text{discount\_rate\_mod\_year}}{\text{discount\_rate\_current\_year}} \times \text{VOTgrowth\_original\_year}
\]

### Vehicle Occupancies

1.2.23 Car occupancy figures are shown in Table 4. These figures were derived from the 1999 - 2001 National Travel Survey and show the sum of driver occupancy (always 1) and passenger occupancy. Occupancies in the top half of Table 4 are expressed in per vehicle kilometre and those in the bottom half are per trip.

#### Table 4: Car Occupancies (2000)

<table>
<thead>
<tr>
<th>Journey Purpose</th>
<th>Weekday</th>
<th>Weekend</th>
<th>All Week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7am – 10am</td>
<td>10am – 4pm</td>
<td>4pm – 7pm</td>
</tr>
<tr>
<td></td>
<td>Occupancy Per Vehicle Kilometre Travelled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>1.23</td>
<td>1.19</td>
<td>1.17</td>
</tr>
<tr>
<td>Commuting</td>
<td>1.16</td>
<td>1.15</td>
<td>1.13</td>
</tr>
<tr>
<td>Other</td>
<td>1.71</td>
<td>1.78</td>
<td>1.82</td>
</tr>
<tr>
<td>Average Car</td>
<td>1.37</td>
<td>1.59</td>
<td>1.45</td>
</tr>
<tr>
<td></td>
<td>Occupancy Per Trip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>1.26</td>
<td>1.19</td>
<td>1.20</td>
</tr>
<tr>
<td>Commuting</td>
<td>1.16</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>Other</td>
<td>1.72</td>
<td>1.70</td>
<td>1.76</td>
</tr>
<tr>
<td>Average Car</td>
<td>1.46</td>
<td>1.59</td>
<td>1.53</td>
</tr>
</tbody>
</table>
1.2.24 Occupancies for all other vehicles are shown in Table 5. These figures also show the sum of driver and passenger occupancy. Occupancies for different times of the day are only available for cars. For LGVs, different occupancy figures are available for a weekday and the weekend. For all other vehicles, only all week average occupancy figures are available. These should be used for all time periods. Values for heavy and light rail are not included as it is assumed that, if a public transport project is being appraised, a project specific public transport model will be used which will give appropriate details of passenger occupancy. Average PSV occupancy figures are given, as these are required for highways scheme appraisal.

<table>
<thead>
<tr>
<th>Vehicle Type and Journey Purpose</th>
<th>Weekday Average</th>
<th>Weekend Average</th>
<th>All Week Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGV Work (freight)</td>
<td>1.20</td>
<td>1.26</td>
<td>1.20</td>
</tr>
<tr>
<td>LGV Non Work (commuting and other)</td>
<td>1.46</td>
<td>2.03</td>
<td>1.59</td>
</tr>
<tr>
<td>Average LGV</td>
<td>1.23</td>
<td>1.35</td>
<td>1.25</td>
</tr>
<tr>
<td>OGV1 Work only</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>OGV2 Work only</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>PSV Driver</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>PSV Passenger</td>
<td>12.20</td>
<td>12.20</td>
<td>12.20</td>
</tr>
</tbody>
</table>

1.2.25 Table 6 shows the predicted decline in car passenger occupancies as an annual percentage until 2036, after which car passengers are assumed to remain constant. The occupancy of all other vehicle types should be assumed to remain unchanged over time.

<table>
<thead>
<tr>
<th>Journey Purpose Splits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
</tr>
<tr>
<td>Weekday: 7am – 10am</td>
</tr>
<tr>
<td>Work</td>
</tr>
<tr>
<td>Non – Work (commuting and other)</td>
</tr>
</tbody>
</table>

1.2.26 Data from the National Travel Survey (1999 – 2001) has been used to produce journey purpose splits for work and non-work travel (commuting and other), based on distance travelled and trips made. These purpose splits are necessary in order to calculate values of time per vehicle for the average vehicle. Journey purpose splits are assumed to remain constant over time.
1.2.27 The purpose splits based on distance travelled in work and non-work time are given in Table 7.

<table>
<thead>
<tr>
<th>Mode /Vehicle Type &amp; Journey Purpose</th>
<th>Weekday</th>
<th>Weekend Average</th>
<th>All Week Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7am – 10am</td>
<td>10am – 4pm</td>
<td>4pm – 7pm</td>
</tr>
<tr>
<td>Percentage of Distance Traveled by Vehicles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>18.1</td>
<td>19.9</td>
<td>13.0</td>
</tr>
<tr>
<td>Commuting</td>
<td>46.0</td>
<td>11.4</td>
<td>40.8</td>
</tr>
<tr>
<td>Other</td>
<td>35.9</td>
<td>68.7</td>
<td>46.2</td>
</tr>
<tr>
<td>LGV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work (freight)</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
</tr>
<tr>
<td>Non – Work (Commuting and Other)</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>OGV1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>OGV2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Percentage of Distance Traveled by Occupants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>15.4</td>
<td>13.8</td>
<td>10.2</td>
</tr>
<tr>
<td>Commuting</td>
<td>38.3</td>
<td>8.1</td>
<td>32.2</td>
</tr>
<tr>
<td>Other</td>
<td>46.4</td>
<td>78.1</td>
<td>57.6</td>
</tr>
<tr>
<td>PSV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>3.9</td>
<td>2.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Commuting</td>
<td>30.0</td>
<td>11.1</td>
<td>36.6</td>
</tr>
<tr>
<td>Other</td>
<td>66.1</td>
<td>86.9</td>
<td>59.5</td>
</tr>
<tr>
<td>Heavy Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>14.1</td>
<td>22.4</td>
<td>16.4</td>
</tr>
<tr>
<td>Commuting</td>
<td>51.9</td>
<td>10.2</td>
<td>55.9</td>
</tr>
<tr>
<td>Other</td>
<td>34.1</td>
<td>67.4</td>
<td>27.7</td>
</tr>
<tr>
<td>Light Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>1.9</td>
<td>0.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Commuting</td>
<td>82.4</td>
<td>8.5</td>
<td>75.7</td>
</tr>
<tr>
<td>Other</td>
<td>15.7</td>
<td>91.3</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Note: The shaded areas in the table indicate a small sample, hence these figures should be treated with caution.
1.2.28 The purpose splits based on trips made in work and non-work time are given in Table 8.

### Table 8: Proportion of Trips Made in Work and Non-Work Time

<table>
<thead>
<tr>
<th>Mode /Vehicle Type and Journey Purpose</th>
<th>Weekday</th>
<th>Weekend</th>
<th>All Week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7am – 10am</td>
<td>10am – 4pm</td>
<td>4pm – 7pm</td>
</tr>
<tr>
<td><strong>Percentage of Vehicle Trips</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>6.8</td>
<td>8.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Commuting</td>
<td>40.6</td>
<td>11.6</td>
<td>32.3</td>
</tr>
<tr>
<td>Other</td>
<td>52.7</td>
<td>80.1</td>
<td>62.2</td>
</tr>
<tr>
<td>LGV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work (freight)</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
</tr>
<tr>
<td>Non – Work (Commuting and Other)</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>OGV1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>OGV2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Percentage of Person Trips</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>5.2</td>
<td>2.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Commuting</td>
<td>33.3</td>
<td>15.6</td>
<td>25.8</td>
</tr>
<tr>
<td>Other</td>
<td>61.5</td>
<td>82.2</td>
<td>70.1</td>
</tr>
<tr>
<td>PSV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>1.5</td>
<td>1.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Commuting</td>
<td>41.7</td>
<td>10.6</td>
<td>43.0</td>
</tr>
<tr>
<td>Other</td>
<td>56.8</td>
<td>88.2</td>
<td>55.2</td>
</tr>
<tr>
<td>Heavy Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>6.7</td>
<td>13.6</td>
<td>6.7</td>
</tr>
<tr>
<td>Commuting</td>
<td>71.7</td>
<td>14.9</td>
<td>68.0</td>
</tr>
<tr>
<td>Other</td>
<td>21.6</td>
<td>71.5</td>
<td>25.4</td>
</tr>
<tr>
<td>Light Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>2.8</td>
<td>0.7</td>
<td>3.3</td>
</tr>
<tr>
<td>Commuting</td>
<td>83.0</td>
<td>10.8</td>
<td>70.7</td>
</tr>
<tr>
<td>Other</td>
<td>14.2</td>
<td>88.5</td>
<td>26.0</td>
</tr>
</tbody>
</table>

Note: The shaded areas in the table indicate a small sample, hence these figures should be treated with caution.
Values of Time per Vehicle

1.2.29 The market price values of time per vehicle are given in Table 9. These values were calculated by multiplication of the appropriate figures from Tables 1, 2, 4, 5 and 6. Average car, average LGV and average PSV values also use the journey purpose split data from Table 7 as weights. The values are based on distance travelled.

<table>
<thead>
<tr>
<th>Vehicle Type and Journey Purpose</th>
<th>Weekday</th>
<th>Weekday</th>
<th>Weekend</th>
<th>All Week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7am – 10am</td>
<td>10am – 4pm</td>
<td>4pm – 7pm</td>
<td>7pm – 7am</td>
</tr>
<tr>
<td>Car Work</td>
<td>30.74</td>
<td>30.00</td>
<td>29.61</td>
<td>29.81</td>
</tr>
<tr>
<td>Commuting</td>
<td>5.84</td>
<td>5.79</td>
<td>5.69</td>
<td>5.69</td>
</tr>
<tr>
<td>Other</td>
<td>7.58</td>
<td>7.89</td>
<td>8.08</td>
<td>7.86</td>
</tr>
<tr>
<td>Average Car</td>
<td>10.97</td>
<td>12.05</td>
<td>9.90</td>
<td>9.77</td>
</tr>
<tr>
<td>Non – Work (Commuting and Other)</td>
<td>6.70</td>
<td>6.70</td>
<td>6.70</td>
<td>6.70</td>
</tr>
<tr>
<td>Average LGV</td>
<td>11.55</td>
<td>11.55</td>
<td>11.55</td>
<td>11.55</td>
</tr>
<tr>
<td>OGV1 Working</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
</tr>
<tr>
<td>OGV2 Working</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
<td>10.18</td>
</tr>
<tr>
<td>PSV (Occupants)</td>
<td>19.80</td>
<td>15.11</td>
<td>19.80</td>
<td>24.24</td>
</tr>
<tr>
<td>Work</td>
<td>18.45</td>
<td>6.83</td>
<td>22.50</td>
<td>23.43</td>
</tr>
<tr>
<td>Commuting</td>
<td>35.97</td>
<td>47.28</td>
<td>32.38</td>
<td>30.58</td>
</tr>
<tr>
<td>Other</td>
<td>74.21</td>
<td>69.22</td>
<td>74.68</td>
<td>78.25</td>
</tr>
</tbody>
</table>

1.2.30 From Table 9, using national average vehicle proportions for 2002, the market price value of an average vehicle is £11.28 per hour, 2002 prices and values.
1.3 Vehicle Operating Costs

1.3.1 The use of the road system by private cars and lorries gives rise to operating costs for the user. These include the obvious costs of fuel, oil and tyres, and an element of vehicle maintenance. The models for car and goods vehicle operating costs also include allowances for the purchase of new vehicles, as discussed below.

1.3.2 The distance-related costs to private households and business of car purchase are included in the car non-fuel operating costs by inclusion of an allowance for mileage related depreciation. In addition, for business cars, an allowance is also made for the decline in vehicle capital value (other than that accounted for by mileage related depreciation).

1.3.3 The costs to freight carriers of goods vehicle purchases are taken into account under goods vehicle non-fuel operating costs. As with private cars, it is assumed that the decision to purchase goods vehicles is independent of the transport policy option pursued. However, changes in congestion on the road system will influence the productivity with which any given fleet of goods vehicles can be used, and this element is taken into account in computing goods vehicle operating costs.

1.3.4 This section provides the latest vehicle operating cost (VOC) values recommended by the Department for use in economic appraisals of transport projects. VOCs are separated into fuel VOCs and non-fuel VOCs and are discussed separately within this section. All parameters are expressed in average 2002 values and prices.

Vehicle Operating Costs - Fuel

1.3.5 Fuel consumption is estimated using a function of the form:

\[ L = a + b \cdot v + c \cdot v^2 + d \cdot v^3 \]

Where:
L = consumption, expressed in litres per kilometre;
v = average speed in kilometres per hour; and
a, b, c, d are parameters defined for each vehicle category.

1.3.6 The parameters needed to calculate the fuel consumption element of VOCs are given in Table 103.

---

3 This has been derived from an equation given by AEA Technology’s National Environmental Technology Centre (NETCEN) which estimates carbon emissions in grams per kilometre travelled, based on laboratory testing of different vehicle types over different journey cycles (including varying degrees of accelerating, decelerating, idling and stop-starts, as well as travelling at constant speeds). The equations are consistent with those that are used to compile the National Atmospheric Emissions Inventory (NAEI). The NETCEN relationship has been adapted to reflect fuel consumption in litres per kilometre travelled by making use of the fact that carbon emissions and fuel consumption are directly proportional.
### Table 10: Fuel VOC Formulae Parameter Values (litres per km, 2002)

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol Car</td>
<td>0.18804764</td>
<td>-0.00437947</td>
<td>0.00005068</td>
<td>-0.0000001691</td>
</tr>
<tr>
<td>Diesel Car</td>
<td>0.14086613</td>
<td>-0.00285222</td>
<td>0.00002867</td>
<td>-0.0000000693</td>
</tr>
<tr>
<td>Average Car</td>
<td>0.17813952</td>
<td>-0.00405874</td>
<td>0.00004606</td>
<td>-0.0000001481</td>
</tr>
<tr>
<td>Petrol LGV</td>
<td>0.25246149</td>
<td>-0.00486999</td>
<td>0.00004424</td>
<td>-0.0000000753</td>
</tr>
<tr>
<td>Diesel LGV</td>
<td>0.18637593</td>
<td>-0.00268049</td>
<td>0.00001172</td>
<td>0.0000000823</td>
</tr>
<tr>
<td>Average LGV</td>
<td>0.19628876</td>
<td>-0.00300892</td>
<td>0.00001659</td>
<td>0.0000000587</td>
</tr>
<tr>
<td>OGV1</td>
<td>0.76833752</td>
<td>-0.02257303</td>
<td>0.00031766</td>
<td>-0.0000013544</td>
</tr>
<tr>
<td>OGV2</td>
<td>1.02443156</td>
<td>-0.03021812</td>
<td>0.00044285</td>
<td>-0.0000020059</td>
</tr>
<tr>
<td>PSV</td>
<td>0.63466867</td>
<td>-0.01898970</td>
<td>0.00027431</td>
<td>-0.0000012161</td>
</tr>
</tbody>
</table>

### Table 10a: Fuel VOC Formulae Parameter Values (pence per km, 2002)

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol Car</td>
<td>3.13851511</td>
<td>-0.07309335</td>
<td>0.00084585</td>
<td>-0.000000282</td>
</tr>
<tr>
<td>Diesel Car</td>
<td>2.59193679</td>
<td>-0.05248085</td>
<td>0.00052753</td>
<td>-0.00000128</td>
</tr>
<tr>
<td>Average Car</td>
<td>3.03711854</td>
<td>-0.06919799</td>
<td>0.00078525</td>
<td>-0.00000253</td>
</tr>
<tr>
<td>Petrol LGV</td>
<td>4.21358227</td>
<td>-0.08128013</td>
<td>0.00073837</td>
<td>-0.00000126</td>
</tr>
<tr>
<td>Diesel LGV</td>
<td>3.42931711</td>
<td>-0.04932102</td>
<td>0.00021565</td>
<td>0.000000151</td>
</tr>
<tr>
<td>Average LGV</td>
<td>3.56136519</td>
<td>-0.05459225</td>
<td>0.00030115</td>
<td>0.00000106</td>
</tr>
<tr>
<td>OGV1</td>
<td>14.13741037</td>
<td>-0.41534375</td>
<td>0.00584494</td>
<td>-0.00002492</td>
</tr>
<tr>
<td>OGV2</td>
<td>18.84954070</td>
<td>-0.55601341</td>
<td>0.00814844</td>
<td>-0.00003691</td>
</tr>
<tr>
<td>PSV</td>
<td>11.67790353</td>
<td>-0.34941048</td>
<td>0.00504730</td>
<td>-0.00002238</td>
</tr>
</tbody>
</table>
1.3.7 In Table 10a the VOC parameters have been converted into pence per kilometre by multiplying by the 2002 resource cost of fuel reported in Table 11. OGV1, OGV2 and PSV are assumed to be diesel driven and therefore parameters for these vehicles have been multiplied by the resource cost of diesel. The parameters for average car and average LGV are calculated as the average of the parameters for petrol and diesel cars and LGVs weighted according to the proportions of total traffic (vehicle kms) that are petrol and diesel. In the absence of more specific evidence it has been assumed that the proportions of traffic that are diesel and petrol are broadly equivalent to the proportions of diesel and petrol vehicles in the fleet. For the proportions of diesel and petrol cars in the fleet, see Table 12. The proportion of LGV traffic that is diesel is assumed to be constant through time, at 85%.

1.3.8 The cost of fuel is shown in Table 11. These figures are annual average observed values provided by Department of Energy and Climate Change (DECC). Figures for average cars and average LGVs represent the weighted averages of the corresponding petrol and diesel figures where the weights used are the proportions of total car / LGV fuel consumption that are forecast to be petrol and diesel in each year. In Table 11, ‘Petrol’ is a weighted average between Ultra Low Sulphur Petrol (standard unleaded) and Super Unleaded. Super Unleaded is assumed to constitute 10% of the petrol market by 2030. ‘Diesel’ comprises both Ultra Low Sulphur and Sulphur Free varieties.

1.3.9 The resource cost of fuel VOCs is net of indirect taxation. The market price is gross of indirect taxation and is therefore the sum of the resource cost and fuel duty, plus VAT (that is, market price = [resource cost + fuel duty] x [1 + VAT]). In work time the perceived cost of fuel VOCs is the cost perceived by businesses. Businesses are generally viewed as perceiving costs in the factor cost unit of account as most business costs are free of indirect taxation because they can claim it back. However, businesses cannot reclaim fuel duty and therefore the perceived value of fuel VOCs in work time is equal to the resource cost plus fuel duty. In non-work time, the perceived cost of fuel VOCs is the cost as perceived by the individual consumer. Consumers perceive costs in the market prices unit of account and therefore the perceived value of fuel VOCs in non-working time is equal to the market price.

1.3.10 The values for fuel duty take account of all increases announced in the 2008 Pre-Budget Report (HMT, 2008) – 2p increase on 1/12/2008, 1.8p increase on 1/4/2009 and 0.5p increase above indexation on 1/4/2010. From 1/4/2011 fuel duty is assumed to increase in line with the Retail Price Index (RPI) until 2030. Fuel duty is assumed to remain constant in real terms after 2030. Also, the VAT rate on road fuel was decreased from 17.5% to 15% from 1st December 2008 for 13 months. Because transport modelling software usually works in full calendar years, the VAT reduction is restricted to the year 2009.

1.3.10aThe values in Table 11 have been deflated to 2002 prices using HM Treasury’s GDP deflator. The GDP deflator is a much broader price index than the CPI, RPI or RPIX (which only measure consumer prices) as it reflects the prices of all domestically produced goods and services in the economy. Hence, the GDP deflator also includes the prices of investment goods, government services and exports, and subtracts the price of UK imports. The wider coverage of the GDP deflator makes it more appropriate for deflating public expenditure series.

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4 In earlier versions of this TAG Unit, this Table presented April observed values, taken from Transport Statistics Great Britain (DfT 2005). Annual averages are considered to be more appropriate than April values.
### Table 11 Fuel Costs, Fuel Duty and VAT Rates (in 2002 prices)

<table>
<thead>
<tr>
<th>Year</th>
<th>Resource Cost (pence per litre)</th>
<th>Duty (pence per litre)</th>
<th>VAT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Petrol</td>
<td>Diesel</td>
<td>Av. Car</td>
</tr>
<tr>
<td>2002(actual)</td>
<td>16.7</td>
<td>18.4</td>
<td>17.0</td>
</tr>
<tr>
<td>2003(actual)</td>
<td>18.2</td>
<td>19.6</td>
<td>18.5</td>
</tr>
<tr>
<td>2004(actual)</td>
<td>20.2</td>
<td>21.4</td>
<td>20.5</td>
</tr>
<tr>
<td>2005(actual)</td>
<td>25.0</td>
<td>28.0</td>
<td>25.7</td>
</tr>
<tr>
<td>2006(actual)</td>
<td>27.6</td>
<td>30.4</td>
<td>28.3</td>
</tr>
<tr>
<td>2007(actual)</td>
<td>27.7</td>
<td>29.5</td>
<td>28.2</td>
</tr>
<tr>
<td>2008</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>2009</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>2010</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>2011</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>2012</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>2013-17</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>2018-21</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>2022-26</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>2027-30</td>
<td>)</td>
<td>)</td>
<td>)</td>
</tr>
</tbody>
</table>

1.3.11 Table 12 provides forecasts of the proportions of diesel and petrol vehicles in the car fleet\(^5\). These forecasts are used in the COBA and TUBA software programs when subdividing the total number of cars into petrol or diesel.\(^6\)

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\(^5\) The figures for the proportion of car fleet using petrol or diesel in the previous version of this unit have been revised to reflect the use of a more reliable source of evidence.

\(^6\) Ideally we would use the proportions of total traffic (vehicle kms) that are petrol and diesel in COBA and TUBA. The car fleet split is used here in the absence of forecasts of the car traffic split.
Table 12: Proportion of Car Fleet Using Petrol or Diesel (%)

<table>
<thead>
<tr>
<th>Year</th>
<th>Petrol</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>79</td>
<td>21</td>
</tr>
<tr>
<td>2003</td>
<td>78</td>
<td>22</td>
</tr>
<tr>
<td>2004</td>
<td>77</td>
<td>23</td>
</tr>
<tr>
<td>2005</td>
<td>76</td>
<td>24</td>
</tr>
<tr>
<td>2006</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>2007</td>
<td>74</td>
<td>26</td>
</tr>
<tr>
<td>2008</td>
<td>72</td>
<td>28</td>
</tr>
<tr>
<td>2009</td>
<td>71</td>
<td>29</td>
</tr>
<tr>
<td>2010</td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>decreasing to</td>
<td>increasing to</td>
</tr>
<tr>
<td>2025</td>
<td>57</td>
<td>43</td>
</tr>
<tr>
<td>2026 onwards</td>
<td>57</td>
<td>43</td>
</tr>
</tbody>
</table>

Rates of Change in Fuel VOCs

1.3.12 There are two causes of changes in fuel VOC over time: improvements in vehicle efficiency; and changes in the cost of fuel. For cars, changes in fuel VOCs also reflect changes in the proportion of traffic using either petrol or diesel (see Table 12).

1.3.13 Vehicle efficiency assumptions are shown in Table 13. These figures show changes in fuel consumption and therefore negative figures indicate an improvement in vehicle efficiency. It should be noted that the figures for average car and average LGV represent the change in the fuel consumption of the petrol and diesel cars / LGVs weighted according to the proportion of car / LGV traffic driven by vehicles of each fuel type. The changes in average car fuel efficiency also reflect the increasing proportion of traffic that is diesel over time, and that diesel cars are expected to remain more fuel efficient than petrol cars.

1.3.14 The forecast changes in the cost of fuel are shown in Table 14. Changes in the resource cost of petrol and diesel are based on the Updated Energy Projections (UEP) published in November 2008 by the Department of Energy and Climate Change (DECC). The figures represent the central oil price scenario. The figures for average car and average LGV represent the change in resource cost per litre for the average car and LGV. The changes in each year for the average car reflect changes in the resource costs of petrol and diesel, the forecast increase in the proportion of traffic that are diesel cars, and that the resource cost of diesel is forecast to remain above the resource cost of petrol.
### Table 13: Assumed Vehicle Fuel Efficiency Improvements

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Change in Vehicle Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol Car</td>
<td>(%)</td>
</tr>
<tr>
<td>Diesel Car</td>
<td>-0.74</td>
</tr>
<tr>
<td>Average Car</td>
<td>-1.18</td>
</tr>
<tr>
<td>Petrol LGV</td>
<td>-1.22</td>
</tr>
<tr>
<td>Diesel LGV</td>
<td>0.97</td>
</tr>
<tr>
<td>Average LGV</td>
<td>0.64</td>
</tr>
<tr>
<td>OGV1</td>
<td>0.46</td>
</tr>
<tr>
<td>OGV2</td>
<td>-0.17</td>
</tr>
<tr>
<td>PSV</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 14: Forecast Growth in the Resource Cost of Fuel

<table>
<thead>
<tr>
<th>Range of Years</th>
<th>Petrol (% pa)</th>
<th>Diesel (% pa)</th>
<th>Average Car (% pa)</th>
<th>Average LGV (% pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007 – 2008</td>
<td>1.88</td>
<td>4.38</td>
<td>2.58</td>
<td>4.00</td>
</tr>
<tr>
<td>2009 – 2010</td>
<td>-2.64</td>
<td>-2.75</td>
<td>-2.67</td>
<td>-2.73</td>
</tr>
<tr>
<td>2010 – 2015</td>
<td>0.58</td>
<td>0.56</td>
<td>0.57</td>
<td>0.56</td>
</tr>
<tr>
<td>2015 – 2020</td>
<td>0.57</td>
<td>0.55</td>
<td>0.56</td>
<td>0.55</td>
</tr>
<tr>
<td>2020 – 2025</td>
<td>0.55</td>
<td>0.54</td>
<td>0.54</td>
<td>0.54</td>
</tr>
<tr>
<td>2025 – 2030</td>
<td>0.54</td>
<td>0.52</td>
<td>0.53</td>
<td>0.52</td>
</tr>
<tr>
<td>2030 +</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1.3.15 The Department is aware that the accuracy of the cubic equation in representing the relationship between speed and fuel consumption (shown in paragraph 1.3.5 above), lessens at low speeds. The Department is engaged in research to further improve the robustness of this relationship at low speeds.
Vehicle Operating Costs – Non-Fuel

1.3.16 The elements making up non-fuel vehicle operating costs include oil, tyres, maintenance, depreciation and vehicle capital saving (only for vehicles in working time). The non-fuel elements of VOC are combined in a formula of the form:

\[ C = a_1 + \frac{b_1}{V} \]

where:

- \( C \) = cost in pence per kilometre travelled,
- \( V \) = average link speed in kilometres per hour,
- \( a_1 \) is a parameter for distance related costs defined for each vehicle category,
- \( b_1 \) is a parameter for vehicle capital saving defined for each vehicle category (this parameter is only relevant to working vehicles).

1.3.17 The parameters needed to calculate the non-fuel vehicle operating resource costs are given in Table 15. These parameters are in 2002 prices and exclude indirect taxation.

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Parameter Values</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Values</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( a_1 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pence/km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( b_1 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pence/hr</td>
<td></td>
</tr>
<tr>
<td><strong>Car</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>4.069</td>
<td>111.391</td>
</tr>
<tr>
<td>Non-Work Car (commuting and other)</td>
<td>3.151</td>
<td>-</td>
</tr>
<tr>
<td>Average Car</td>
<td>3.308</td>
<td>19.048</td>
</tr>
<tr>
<td><strong>LGV</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>5.910</td>
<td>38.603</td>
</tr>
<tr>
<td>Non-Work (commuting and other)</td>
<td>5.910</td>
<td>-</td>
</tr>
<tr>
<td>Average LGV</td>
<td>5.910</td>
<td>33.970</td>
</tr>
<tr>
<td><strong>OGV1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.501</td>
<td>216.165</td>
</tr>
<tr>
<td><strong>OGV2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.702</td>
<td>416.672</td>
</tr>
<tr>
<td><strong>PSV</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24.959</td>
<td>569.094</td>
</tr>
</tbody>
</table>

1.3.18 Non-fuel VOC parameters for work and non-work cars (commuting and other) and private LGVs have been derived in accordance with previous methods outlined in *Review of Vehicle Operating Costs in COBA* (EEA Division, DoT 1990-91). Non-fuel parameters for all other vehicles have been updated from the *Transport Economics Note* (DfT 2001) by the ratio of average 1998 and 2002 Retail Price Indices.
1.3.19 The marginal resource costs of oil, tyres, mileage and maintenance related depreciation, are assumed to be fixed costs per kilometre and appear in the ‘a1’ term. The difference between the ‘a1’ term for work and non-work time non-fuel car operating costs reflects the difference in the composition of the vehicle fleet in work and non-work time. In work time, a large proportion of total mileage is by cars with large engine sizes and these cars have higher non-fuel VOCs. The ‘b1’ term in the non-fuel costs represents changes in the productivity of commercial vehicles and cars in working time, all goods vehicles and PSVs.

1.3.20 The time component of depreciation is excluded since it does not vary with distance or speed. For OGVs and PSVs depreciation is assumed to be totally time related; this is based on evidence from trade sources which suggest that factors such as obsolescence and condition are more important determinants of vehicle value than mileage per se. For cars and LGVs evidence from second hand prices indicates that part of their depreciation is related to mileage; and therefore this element is recorded as a marginal resource cost.

1.3.21 For demand modelling and the calculation of consumer surplus, costs must be expressed in perceived cost terms. The perceived cost of non-fuel VOCs differs for work and non-work time. In work time, the perceived cost is the cost perceived by businesses and is therefore equal to the resource cost. In non-work time, it is assumed that travellers do not perceive non-fuel VOCs, so the perceived cost is zero.

1.3.22 The assumption that those making non-work car trips do not perceive their non-fuel vehicle operating costs means that estimates of consumer surplus for non-work purposes, which are based on perceived costs, do not reflect changes in non-fuel vehicle operating costs.

1.3.23 However, changes in users’ expenditure on non-fuel VOCs are included in the calculation of user benefits for non-work purposes - see TAG Unit 3.5.3, Transport User Benefit Calculation for details. These calculations use non-fuel VOCs expressed in market prices. Non-fuel VOCs in market prices for non-work purposes may be estimated from the formula given above, using the parameters given in Table 15 plus VAT (that is, market price = resource cost x (1+VAT)).

Rates of Change in Non-Fuel VOCs

1.3.24 Non-fuel VOCs are assumed to remain constant in real terms over the forecast period. This assumption is made because the main elements which make up non-fuel VOCs are subject to less volatility than fuel VOCs.

Bus Operating Costs

1.3.25 In a simple highway appraisal, buses are treated as part of the traffic flow, and the operating cost formulae described above are applied, using the appropriate parameter values for PSVs. In a multi-modal study, however, different options may result not only in faster or slower running times for existing bus services, but in the need for more or different levels and patterns of bus service provision. In these cases, the impact of options on the costs of bus service provision have to be considered in more detail.

1.3.26 The bus operating model requires assumptions to be input on various operational characteristics, such as sickness rates, working days per week, holiday allowances, employers’ costs, engineering spares etc and also unit cost rates for each grade of staff, fuel and tyres etc. Vehicle fleet requirements and costs are considered as capital expenditure outside the model and are included in option costs. The Overall Approach: The Steps in the Process (TAG Unit 2.1) gives an overview of how costs are covered in the appraisal process. The Estimation and Treatment of scheme costs (TAG Unit 3.5.9) provides further detail on estimating and treating costs for use in the appraisal process.
1.3.27 Bus operating costs vary by region and by service type. Information on the operating cost of local bus services, by area, can be found in *Focus on Public Transport* and in *The Passenger Transport Industry in Great Britain Facts* (Confederation of Passenger Transport 1999-2000). Where no other information is available, these costs should be used as default indicators of the operating cost of bus services. However, more detailed information on bus costs should be sought where bus based measures are likely to play a significant part in a strategy. Study consultants may be able to provide more detailed cost estimates using bus operating cost models. The validity of such costs should be cross-checked with other data sources, including the range of values given in the national statistics. Where possible, the co-operation and views of local bus operators should be sought. The Confederation of Passenger Transport (CTP) may also be able to provide assistance in estimating the costs of bus operation.

**Rail Operating Costs**

1.3.28 Information on rail operating cost assumptions can be obtained by discussion with the Department.

### 2 Further Information

The following documents provide information that follows on directly from the key topics covered in this Unit.

<table>
<thead>
<tr>
<th>For information on:</th>
<th>See:</th>
<th>TAG Unit number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Appraisal Process</td>
<td><em>The Overall Approach: The Steps in the Process</em></td>
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</tr>
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<td><em>The Appraisal Process</em></td>
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</tr>
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<td><em>Modelling</em></td>
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<tr>
<td>Estimating and Treating Scheme Costs</td>
<td><em>The Estimation and Treatment of Scheme Costs</em></td>
<td>TAG Unit 3.5.9</td>
</tr>
</tbody>
</table>

### 3 References


Confederation of Passenger Transport (1999-2000), *Focus on Public Transport*


ITEA Division, Department for Transport (2001), Transport Economics Note

EEA Division, Department of Transport (1990-91), Review of Vehicle Operating Costs in COBA

Department for Transport (2005), Transport Statistics Great Britain.

4 Document provenance

1. This Transport Analysis Guidance (TAG) Unit is based on Appendix H of Guidance on the Methodology for Multi-Modal Studies Volume 2 (DETR, 2000), the Transport Economics Note (DfT, 2001) and Netcen’s Carbon Emission and Fuel Consumption Parameters for the National Transport Model (NETCEN, 2005).

2. February 2007:
   (i) Parameters in Table 10 rounded.
   (ii) Corrections to Table 15.

   (i) Values in Tables 10a and 11 revised to include BERR actual annual average fuel prices.
   (ii) Table 14 fuel price forecasts updated to include BERR central oil price forecast.
   (iii) Table 15 and following text redrafted to clarify treatment in modelling and appraisal of non-fuel vehicle operating costs for non-work purposes.

   (i) Table 4. Errors in Average Car values corrected.
   (ii) Table 11 revised to reflect latest DECC fuel prices, Fuel Duty and VAT rate changes.
   (iii) Table 14 fuel price forecasts updated to include DECC central oil price forecasts.
   (iv) Table 15 headings clarified.

Technical queries and comments on this Unit should be referred to:

Integrated Transport Economic Appraisal (ITEA) Division
Department for Transport
Zone 3/08 Great Minster House
76 Marsham Street
London SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
Variable Demand Modelling – Preliminary Assessment Procedures

TAG Unit 3.10.1

June 2006

Department for Transport

Transport Analysis Guidance (TAG)
1 Variable Demand Modelling – Preliminary Assessment Procedures

1.1 Background

1.1.1 TAG units 2.9 and 3.10 explain why variable demand modelling needs to be considered and provide guidance on how to carry out such modelling. This unit forms the first stage in the process and explains how to establish whether there is a need for variable demand modelling in a particular application.

1.2 The Importance of Variable Demand Modelling

1.2.1 Any change to transport conditions will, in principle, cause a change in demand. The purpose of variable demand modelling is to predict and quantify these changes.

1.2.2 The Standing Advisory Committee on Trunk Road Appraisal (SACTRA) considered all these effects in 1994 and emphasised the importance of establishing a realistic scenario in the absence of the scheme or strategy, the extent of travel suppression in the "without-scheme" case, and the extra traffic induced in the "with-scheme" case.

1.2.3 Although the modelling effort needs to be proportionate to the scale of the scheme, the need to consider variable demand is not simply a question of the size of the scheme. Since both demand changes and benefits tend to scale with the size of the scheme, changes in demand can have similar proportionate effects on benefits for both large and small schemes. Thus changes in demand can seriously undermine the economic efficiency justification for schemes of any size.

1.2.4 There may be wider effects of the scheme, on the environment, accessibility or safety, for example, which will also be affected by changes in demand: these must be judged separately from the economic efficiency of the scheme. Any reduction in any type of benefit can undermine the justification for the scheme, since this depends on the balance between the benefits and the costs of the scheme.

1.2.5 Detailed responses in the demand for transport of freight are not considered here. It is usually sufficient to assume that freight traffic is growthed up from the base using NRTF factors and is susceptible to re-routeing.

1.3 Assessment of the Need for Variable Demand Modelling

1.3.1 It may be acceptable to limit the assessment of a scheme to a fixed demand assessment if the scheme is quite modest both spatially and in terms of its effect on travel costs. Schemes with a capital cost of less than £5 million can generally be considered as modest.

1.3.2 When carrying out the assessment of the need for variable demand, it is important that a reference case forecast is defined. This captures the background growth as a result of demographic changes and growth in car ownership. The reference case forecast expresses forecast demand at the base year generalised cost and value of time. Under congested conditions, the reference case forecasts may be affected by diverted or suppressed traffic. Hence, construction of the correct do minimum could have a considerable impact on the scheme benefits. It is therefore important that the do-minimum forecasts as a result of assigning the reference case forecast to the “without scheme” network model explicitly the effect of congestion on demand before modelling the effect of the transport scheme.
1.3.3 It is expected that where a variable demand model is used for forecasting, then that model will be used to derive forecasts for all scenarios, both with and without the scheme.

1.3.4 It should be remembered that the benefit from schemes can be substantially reduced by changes in demand arising from the scheme, and that any scheme potentially encourages more trips and affects congestion levels over the entire journey distances travelled by the traffic through it. Indeed, where the link speed-flow relationship of the scheme itself is nearly flat under the expected operating conditions, induced traffic may have little effect on speeds on the scheme, but there may still be substantial reductions in speeds on roads leading to and from it due to induced traffic. Those extra induced trips and longer trips are the key components of induced traffic.

1.3.5 In order to establish a case for omitting fully specified variable demand modelling for schemes above £5 million, it is strongly recommended that preliminary quantitative estimates of the potential effects of variable demand on both traffic levels and benefit are made. An elastic assignment procedure can give an initial indication of the effects. This procedure should only be used to ascertain whether variable demand modelling is required and for nothing else.

1.3.6 In order to make any benefit assessment, the same model must be used in both the do-minimum and the do-something.

1.3.7 In assessing whether variable demand modelling is required, the procedures required are:
   1. A fixed trip matrix approach – i.e., simple TEMPRO growth but no suppression or induction

Note that the do-minimum and do-something matrices in 1 are identical to each other. Also note that the do-minimum for 2 is different from the do-minimum for 1. A robust case for carrying out a fixed-demand assessment is if the difference in scheme benefits between 1 and 2 is less than 10% in the opening year, or 15% in the forecast year (10 to 15 years later).

1.3.8 These calculations may convince you that it is safe not to model variable demand and thus provide a useful justification for restricting the assessment to fixed trip matrix.

1.3.9 The environmental and other wider effects, and the possible superiority of alternative schemes, including improvements to public transport, also need to be considered.

1.3.10 Taking into account the qualitative aspects discussed above, if you decide that variable demand modelling is required then you need to establish the scope of the variable demand model, see VDM Scope of the Model (TAG Unit 3.10.2) and build one, see VDM Key Processes (TAG Unit 3.10.3).

1.4 Reporting

1.4.1 It is expected that the outcome of the above assessment will be reported in the model or appraisal documentation. Details of how each criterion has been considered and all the evidence that has been compiled should be fully documented.
2 Further Information

The following documents provide information that follows on directly from the key topics covered in this TAG Unit.

<table>
<thead>
<tr>
<th>For information on:</th>
<th>See:</th>
<th>Link:</th>
</tr>
</thead>
<tbody>
<tr>
<td>An overview of modelling issues</td>
<td>Summary Advice on Modelling</td>
<td>TAG Unit 2.4</td>
</tr>
<tr>
<td>An overview of variable demand modelling</td>
<td>Variable Demand Modelling</td>
<td>TAG Unit 2.9</td>
</tr>
<tr>
<td>Detailed advice on transport modelling</td>
<td>Modelling</td>
<td>TAG Unit 3.1</td>
</tr>
</tbody>
</table>

3 References

DETR (July 1998) A New Deal for Transport: Better for Everyone

4 Document Provenance

This Transport Analysis Guidance (TAG) Unit reflects the consultation comments received on Steps 1 to 4 of the draft Variable Demand Modelling Advice produced by TRL in June 2003.

Technical queries and comments on this TAG Unit should be referred to:

Integrated Transport Economics and Appraisal (ITEA) Division
Department for Transport
Zone 3/06 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
Variable Demand Modelling – Scope of the Model

TAG Unit 3.10.2

June 2006

Department for Transport

Transport Analysis Guidance (TAG)
## Contents

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   1.4 Forms of Trip Matrices: Vehicle Occupancy
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2 **Further Information**

3 **References**

4 **Document Provenance**
1 Variable Demand Modelling - Scope of the Model

1.1 Background

1.1.1 TAG units 2.9 and 3.10 explain why variable demand modelling needs to be considered and provide guidance on how to carry out such modelling for highway schemes. This unit forms the second stage of the process, TAG Units 3.10.3 and 3.10.4 detail subsequent stages, and explains how to establish the scope and coverage of the model for the particular application.

1.1.2 Important recommendations are shown highlighted and in bold. If those actions are not followed analysts will need to provide rigorous justification for the course of action taken.

1.1.3 A summary of the advice in this TAG unit is as follows:-

- The demand and supply processes need to allow for trip redistribution when designing the zone system and provide a fine enough level of detail for the scheme and strategies being assessed. This is discussed in Section 1.2.

- Various stages of the demand modelling and forecasting process require travel movements to be described in terms of the factors that generate or attract trips – i.e. by productions and attractions (P/A). The guidance discusses the conversion between P/A and origin/destination (O/D) form for use in the multi-stage modelling process.

- Modelling variable demand uses reference case growth forecasts and socio-economic data that influence the travel of individuals. The need for these data and possible sources are discussed in Section 1.6.

- The impacts of different policy measures on particular groups of people can only be represented realistically and forecast satisfactorily if the demand modelling process is suitably segmented. Modelling should use groups of travellers (segments) which it is expected will continue to behave in similar fashion over time.

- A variable demand model will need to include a highway assignment stage to provide cost information to the demand model.

- Travel demand and traffic levels vary throughout the day and this usually requires the modelling of different time periods. The need to divide the day into different periods related to the daily profiles of road traffic, is no more onerous than is normally needed in assignment modelling itself, unless it is intended to model peak spreading, as described in VDM Key Processes (Unit 3.10.3).

- All transport models depend upon relating people’s travel choices to estimates of their generalised cost of travel – a weighted sum of time and other costs of travel which can be measured in units of money or (preferably) time.

1.2 Model Area and Zone Size

1.2.1 Traffic assignment modelling connects the underlying zones which contain the demand to a network of links using “zone centroid connectors” serving the entire zone. For this reason it is generally desirable to have both zones and network at as fine a level of detail as possible within a ‘fully modelled area’ – the area in which both routeing and demand responses to the scheme being assessed are expected to occur. That may be larger than the area necessary for assignment modelling alone.

1.2.2 It is usually unnecessary to extend this level of detail beyond the ‘fully modelled area’ though there need to be ‘intermediate’ regions around the fully modelled area to provide realistic demand into the area. Zones just
outside the fully modelled area should be of intermediate size enough to provide realistic demand. Anything outside the intermediate zones should be at the coarsest acceptable level for the schemes and policies being assessed. In general, the smaller the fully modelled area relative to the scheme, the more important is the accuracy of the external connectors. However, it is important to represent in a realistic fashion:

- travel to and from external zones beyond the boundary of the fully modelled area,
- congestion on centroid connectors within a zone, and
- mechanisms which allow trips to interchange between intrazonal and interzonal trips

1.2.3 Other considerations in determining zone size relate to the need to forecast the numbers of intra-zonal trips, and the mix of modes being considered. Further advice on zone sizes for public transport modelling is given in TAG Units 2.10 and 3.11.

1.2.4 More detail is given below of how the fully modelled area and its hinterland should be defined and how the inclusion of demand modelling involves extra considerations about the realistic representation of competing destinations.

1.2.5 Guidance is available as to the level of network detail required for congested assignment models. For example, the IHT’s Guidelines on Developing Urban Transport Strategies suggests that "all roads that carry significant volumes of traffic" should be included and, more generally, that the network "should be of sufficient extent to include all realistic choices of route available to drivers". When considering zone size, the integrating characteristic is that the entire zone is assumed to act as if concentrated at the centroid connectors. Consequently, if a zone contains distinctly different types of population or activity in different areas which are likely to access different points on the network, consideration should be given to sub-dividing it.

1.2.6 However, a balance has to be struck between detail and simplicity of representation, and the guiding principle should be to judge whether combining travellers and activities into a single zone is likely to make the conclusions of the assessment less reliable, or make it impossible to answer some questions of relevance to the assessment. Since the finest level of disaggregation of data is generally at the level of Census Output Areas for the 2001 Census, the model zones will generally be built up from aggregations of these or earlier equivalent areas.

1.2.7 If the fully modelled area is well-defined, then the boundary for both the demand and supply systems will coincide: i.e. inside the boundary both zones and network will be detailed, and outside they will be coarse (though there may also be an 'intermediate' region around the fully modelled area). In the assignment, the fully modelled area may use delay calculations from junction simulation, while the intermediate and external areas may be modelled in link-based representation only. Zone size is likely to increase from core to intermediate to external.

1.2.8 Movements between the internal and external areas need to be represented at an appropriate level of detail, for four reasons:

- On the demand side if only internal movements are properly represented as trips, then zones near the border will have (apparently) lower levels of trip-making.
- Secondly on the demand side, when modelling destination choice, travel opportunities to both internal and external zones need to be represented. Thus although the external area can be represented at a coarse geographical level, it is important that it should contain sufficient close
destinations, and appropriately attractive ones, to take a realistic share of demand from within the modelled area.

- Similarly, zones just outside the fully modelled area need to provide a realistic demand into the area. Hence, the fully modelled area should be surrounded by a ring of zones with a dimension a little larger than the internal zones, and outside these will be very large zones representing the rest of the external area.

- On the supply side (network), movements from one external zone to another external zone may form ‘through traffic’ in the modelled area and this may respond to factors beyond the scope of the model. It is usually satisfactory to treat through-traffic as fixed in volume, but free to choose its routing within the modelled area.

1.2.9 The size of internal zones will need to be carefully considered in relation to intrazonal trips: the larger they are, the larger will be the proportion of trips originating in them which remain intrazonal, i.e. their destination is also within the origin zone itself. It is important to represent the costs of such trips realistically, otherwise there may be biases in the demand model. At the distribution stage it is important to be able to redistribute intrazonals to become interzonals, and interzonals to become intrazonals, if relative costs change. If the zone sizes are small this is less of a problem, but for large zones it is important that the average intrazonal costs are as realistic as possible.

1.2.10 Various approaches may be used to derive intrazonal costs:

- assume the average cost of an intrazonal trip is a fixed proportion of the costs of interzonal trips to the neighbouring zones, or
- assume the mean distance of an intrazonal trip is a proportion of distance to the neighbours and costed accordingly.

Intrazonal costs should reflect the prevailing level of congestion via the mean journey speeds, and preferably its response to changing demand: basing costs on those of trips to the neighbouring zones will generally be sufficient.

1.2.11 The key considerations are that:

- It is desirable to have both zones and network at as fine a level of detail as possible within the ‘fully modelled area’ – i.e. the area in which both routeing and demand responses are expected to occur. This requires a judgement about the general level of detail appropriate to the assessment, i.e. its likely consequences for the accuracy of assessment or for policy.

- Zone size outside this area can be much coarser, but the size of external zones, and the distance of the boundary between the internal and external areas from the scheme itself, has implications for the appropriate length of the external zonal connectors and external network links. Generally, the smaller the fully modelled area relative to the scheme, the more important are zones just outside the fully modelled area and the accuracy of their external connectors.

- Average intrazonal trip costs should be calculated as accurately as possible to remove bias in the distribution model.

1.3 Forms of Trip Matrices: Production/Attraction or Origin/Destination

1.3.1 There are two alternative ways of describing the travel pattern:

- When travel patterns are constructed from roadside surveys the trips are logically described by the place the trip started and the place the trip finished, and the trip purpose of each end. This is usually known as an Origin-
Destination (O/D) based trip pattern. Assignment models use this definition of the trip matrix.

- An alternative way of looking at the trip pattern is from the viewpoint of the factors that produce or attract trips, i.e. on a Production-Attraction (P/A) basis, with home generally being treated as the “producing” end, and work, retail etc as the “attracting” end. To properly define trip production and attraction, it is important to understand what home based and non home based trips are. Home based trips are trips where the home of the trip maker is either the origin or the destination of the trip. Non home based trips on the other hand are trips where neither end of the trip is the home of the trip maker. Trip production is usually defined as the home end of a home based trip or the origin of a non home based trip. Trip attraction on the other hand is defined as the non-home based end of a home based trip or the destination of a non home based trip. Changes in these P/A trip end forecasts over time or by scenario will lead to changes in the trip pattern. This definition of the trip matrix has normally been used in modelling travel demand.

1.3.2 The distinction between production/attraction and origin/destination matrices is most easily explained by the example of commuting trips from home. On an O/D basis a commuter from the suburbs with a workplace in the city-centre completes one trip from suburb to centre in the morning and one trip from centre to suburb in the evening, say. On a P/A basis, the suburb ‘generates’ two commuter trips¹ (there and back) and the centre ‘attracts’ two commuter trips. This distinction is most important when forecasting travel patterns in the future since, for instance, changes in workplace distribution may well be different from those in employee’s residences. This can, in most circumstances, lead to different forecasts of trips depending on which of the two trip matrix definitions is used.

1.3.3 In current modelling practice, trip end modelling is usually done on a P/A basis, as with the TEMPRO forecasts, but assignment is always done on an O/D basis since the actual direction of travel at a particular point in time is important. Somewhere during a multi-stage modelling process trip matrices must be converted from a P/A basis to an O/D basis.

1.3.4 The conversion is usually done after time of day choice, distribution and mode choice and before assignment. P/A based trips are converted into O/D based trips by using conversion factors disaggregated by time of day and trip purpose (distinguishing between inbound and outbound home-based trips). Although these factors may change over time in reality, it is usually acceptable practice to assume constancy before any time-period choice is applied. Such factors can be obtained locally or by using NTS data tables (this is how the DfT’s TEMPRO produces O/D based forecasts from P/A forecasts).

1.3.5 Figure 1 below indicates what might be described as the “traditional” form of the model, in which an “absolute” demand model is used, in PA form, to estimate the matrices. It is then converted to O-D format, and assigned to the network, and the costs are then taken from the network, converted back to P/A format where required, and the demand model is updated. The dark black arrows apply in all cases, but the dashed arrows apply only when the “traditional” approach is being used.

¹ In a number of transport models the modelling is not based on trips but on tours. A “tour” is applied to any round trip, starting and finishing at home, and may contain stops at several different destinations, but few models handle multi-destination tours. Journeys between non-home destinations are handled automatically in models which represent tours, but most demand models treat them as Non-Home Based trips.
1.3.6 In practice, as we discuss in section 1.5, it is often necessary to take an incremental modelling approach. This introduces further considerations into the conversion between PA and OD.

1.3.7 Where a non-uniform growth is forecast at either the production (home) end or the attraction end, forecasts produced using O/D matrices will be less accurate than those produced using P/A based matrices. For this reason P/A matrices should be used, even if no explicit trip distribution modelling is performed.

1.3.8 Although P/A based matrices are strongly recommended in demand modelling, there are a number of circumstances where it may be satisfactory to use O/D based matrices for forecasting:

1. Where forecasts are based on a simple overall growth rate, by purpose. In this case the forecast will not be biased.

2. For peak period modelling only. For this time-period it can reasonably be assumed that the vast majority of trips are starting from home so an O-D based trip matrix is the same as a P/A based matrix. For other time periods the only way to keep consistency would be to base the modelling on the basis of purpose and direction, for instance to model Home to Work separately from Work to Home.

3. Where the demand responses are estimated in conjunction with the assignment process in some simplified elasticity calculation, see VDM Key Processes (TAG Unit 3.10.3), there must be common definitions, and these are perforce those of O/D since that is the basis of the assignment process. The preceding arguments suggest that using this method would be a better approximation for forecasting if undertaken in the morning-peak and/or with direction based purposes.
4. There will be many circumstances when the original roadside or household survey data has been lost, and the only trip data available are O/D matrices, by time-period, and perhaps purpose, for use in assignment. This should only be used where new surveys are impractical.

1.4 Forms of Trip Matrices: Vehicle Occupancy

1.4.1 Whilst assignment modelling is concerned with vehicle movement, demand modelling is concerned with individual traveller decisions. Before the assignment stage is reached car occupancy factors need to be applied to the private travel demand matrices to convert them to vehicles. *Values of Time and Operating Costs* (TAG Unit 3.5.6) give default values by trip purpose and time period, as well as assumptions about how these factors are expected to change through time. Local factors can be calculated from RSI data to see if there are other local factors affecting car occupancy, such as direction of travel or type of flow. These local factors should be used if there are significant differences from the national ones and if there is confidence that the RSI-based factors are an unbiased estimate of all vehicle travel in the area.

1.5 Aspects of Incremental Modelling

1.5.1 As is discussed in (TAG Unit 3.10.3), demand models may be either absolute or incremental: in the latter case, this means that they "pivot" off a base matrix, and only model the changes to the matrix brought about by changes in (generalised) cost. However, the implications of section 1.3 are that this base matrix needs to be in P/A format. In section 1.5 some guidance is given as to how this base matrix can be obtained.

1.5.2 Whether the demand model is absolute or incremental in form, there will be a need to validate the base matrix at the network level. In practice, this means that the conversion from P/A to O-D is carried out, and the resulting matrix assigned. Then the assignment process is validated according to the procedures given in (DMRB.12.2.1).

1.5.3 Problems may be incurred when, after reasonable adjustments to the network, it is concluded that significant errors remain which are essentially attributable to the matrix. Ideally, further data should be introduced to the whole modelling procedure in such a way that the base P/A matrix is modified. Unfortunately, there is very little experience of how to do this, and conventional methods of "matrix estimation" (using, in particular, link counts as a source of information) only operate at an O-D level. If the O-D matrix is adjusted in this way, in order to improve the quality of the assignment, there is no direct way in which these adjustments can be conveyed to the P/A-based demand model. The result is that there will be a discrepancy between the demand model and the assignment model.

1.5.4 With the current state of knowledge, if this position is encountered, the best approach is to use an incremental version of the assignment model. Essentially, after converting the output of the demand model from P/A to O-D, the resulting matrix is not directly assigned, but is compared with a base case, and the implied changes are used to adjust an independently validated "assignment matrix". This adjustment could be done in a number of ways, proportionally, additively, or by a mixture of the two².

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² Note, although for the greater part of the matrix, no problems will be incurred by either an additive or a proportional approach, both these methods can give rise to problems in specific cases. It is possible that the demand model could imply a decrease in demand for a particular ij cell which causes the adjusted assignment matrix to go negative. Alternatively, a large proportionate effect predicted by the demand matrix in the case of a low base demand could correspond with a much larger cell in the assignment matrix. Some care is therefore required in
1.5.5 There are thus two types of incremental modelling, a) on the demand side, on a P/A basis, and b) on the assignment side, on an O-D basis. These two incremental variants are entirely independent of each other, so that there are four possible combinations, which can be written according to the following matrix:

<table>
<thead>
<tr>
<th>Demand</th>
<th>Assignment</th>
<th>Direct from P/A</th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Pivot</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

1.5.6 These alternatives are illustrated in figure 2 below, where the red text and arrows indicate an incremental or marginal demand model where the model “pivots” off a base matrix (in PA form) and is driven by the change between the scheme costs and the base costs. The blue text and arrows indicate an incremental or adjusted assignment process, in which the demand matrix, after conversion to OD format, is compared with a base case, and the implied (OD) changes are used to adjust an independently validated “assignment matrix”.

1.5.7 Type 2, with an absolute demand model and an adjusted assignment, is used by a number of models (for example, the LTS model). Type 3, with an incremental demand model and a direct P/A to O-D conversion, is essentially what is done in the START model (although it does not strictly carry out an assignment). Type 1 is the “conventional” approach illustrated in Figure 1 in Section 1.3 applying the method, and a small amount of re-allocation between cells may be necessary, with the aim of ensuring that the total change predicted by the demand procedure is maintained.
1.6 General Data Requirements and the Reference Case

1.6.1 The detailed advice below lists the type and sources of data required for variable demand modelling, beyond the data used for assignment modelling. In most cases only a sub-set of these data sources will be needed for a given model; less detailed models will require less data, and may base some of their categorisation on assumptions or transfer of appropriate data from other models. As a minimum, however, any multi-stage demand model will require a database which provides, in the base year for each origin zone:

- the total number of “car-available” trips
- to each destination zone
- for each of several purposes
- by each of the modes modelled, and
- within each modelled time period.

<table>
<thead>
<tr>
<th>Data required</th>
<th>For use in</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Trip generation</td>
<td>TEMPRO, Census</td>
<td>From wards or Census Output Areas amalgamated to zones: advisable to categorise by sex and adult/child</td>
</tr>
<tr>
<td>Households</td>
<td>Trip generation</td>
<td>TEMPRO, Census</td>
<td>From wards or Census Output Areas amalgamated to zones</td>
</tr>
<tr>
<td>Car ownership</td>
<td>Trip generation</td>
<td>TEMPRO, Census, Local Household Travel Survey, Household Expenditure Survey, NTEM/NCOP</td>
<td>Averaged across zones, or might be estimated from other socio-economic data</td>
</tr>
<tr>
<td>Socio-Economic Group</td>
<td>Trip generation</td>
<td>Census, Local Household Travel Survey, Household Expenditure Survey</td>
<td>Not often used except in distinguishing workers from unemployed and retired, but some models categorise work travel by broad SEG groups (e.g. blue/white collar) and land-use models also require considerable SEG data.</td>
</tr>
<tr>
<td>Land-use data</td>
<td>Trip generation, distribution</td>
<td>Census and Special Workplace Statistics, TEMPRO for trip ends by purpose, Local Authority planning data for employees, retail and commercial floorspace by zone.</td>
<td>Employees and retail space by zone enable calculation of zonal trip totals for doubly-constrained (to/from work) trip distribution, and attractiveness for optional trips. Some land-use/transport models need considerable detail for SEG, employment and floorspace data.</td>
</tr>
<tr>
<td>Car availability</td>
<td>Modal split Distribution</td>
<td>Local Household Travel Survey, National Travel Survey (NTS)</td>
<td>Can be estimated from household composition and license holding</td>
</tr>
<tr>
<td>License holding</td>
<td>Trip generation, modal split</td>
<td>Local Household Travel Survey, Household Expenditure Survey, National Travel Survey</td>
<td>Categorisation by number of licenses and number of household cars indicates level of car availability</td>
</tr>
<tr>
<td>Travel to zonal destinations by:</td>
<td>Trip distribution, modal split, time-period choice</td>
<td>Roadside Interviews (RSIs), local Household Travel Survey, journey to work from Census, TEMPRO, National Travel Survey,</td>
<td>Full detail only available from specialised local surveys, by interview or questionnaire. NTS local samples are small, but values might be adjusted from wider NTS (e.g. split of purpose by time of day). Census work journey may be extrapolated to other purposes</td>
</tr>
<tr>
<td>purpose mode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>time of day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(period)</td>
<td>Trip lengths</td>
<td>Car operating costs</td>
<td>Vehicle occupancies</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td></td>
<td>Trip distribution, Modal split</td>
<td>All responses</td>
<td>Values from <em>Values of Time and Operating Costs</em> (TAG Unit 3.5.6)</td>
</tr>
<tr>
<td></td>
<td>Local Household Travel Survey, National Travel Survey, journey to work Census</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not used directly since distance is specified by zonal structure, but should be used in validation</td>
<td></td>
<td>Perceived money costs of a car journey are less than true average cost, and are assumed to be different for business and private travel.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 1.6.2   | If a model is being built to describe and validate the base year as well as the forecast years, this information can be obtained from a variety of sources as summarised in the Table above. These sources are not independent. TEMPRO offers a valuable source of most of the data required to predict trip ends, both trip productions based on household characteristics and trip attractions based on employment etc, as well as car availability forecasts.
For further information on TEMPRO and the data used see www.tempro.org.uk.

1.6.3 In many cases TEMPRO may be sufficient, and there will be no need to go back to the original sources. In other cases the TEMPRO zones may be too large, so that the TEMPRO data may have to be adjusted in the light of local knowledge or data specific to the study zones obtained from more original sources. Effort can be saved if there has been a suitable local transport survey, or if there is a local transport model from which the required data can be extracted. If the base data contains all the necessary detail but refers to a date which is considered too early for reliable prediction, then the data can sometimes be updated on the basis of more recent global indicators and good judgement.

1.6.4 There are two separate processes that need to be considered when developing forecast models:

- the production of a base year travel pattern, and
- the production of reference forecasts for future years.

1.6.5 The base P/A matrix can be constructed from observed travel movements based on road-side and passenger surveys, as well as household survey data. Although in theory it should also be possible to make use of traffic counts, the fact that these contain no directional information (ie, we do not know which the journey is from home, or to home, or, for that matter, non-home-based) means that there is no current methodology for doing this.

1.6.6 The detail available in these travel patterns is largely dictated by the richness of the survey data, and in reality the procedure to provide the “best” base matrices will always involve some synthesis as it is rare that all movements are surveyed. In carrying out a synthesis of a P/A matrix, it will generally be desirable to enforce the productions to agree with some reputable “trip end model”, and TEMPRO should be treated as the default in this respect. TEMPRO provides forecasts of trip ends which have been derived by feeding TEMPRO planning data into the National Car Ownership and National Trip End Models at the TEMPRO or NTEM level of zoning. These models may also be applied at a local model level of zoning by feeding in appropriate planning data at the local model zone level. Alternatively, more detailed local data may be available to use with the model, but it will be necessary to ensure that at a broad level it is consistent with the assumptions of the National Trip End Model (NTEM) within the TEMPRO program.

1.6.7 If an absolute demand model is being created, then a theoretical structure representing mode and distribution will be chosen for each purpose, together with estimates of trip ends, and the mathematical functions will be calibrated to reproduce as much of the “observed” data as is possible (some guidance on the general calibration of such models is given in TAG Unit 3.10.3).

1.6.8 However, for many reasons, this is not always the appropriate approach. This may be because of lack of calibration expertise, or it may be that even after considerable effort, the theoretical structure is still unable to accommodate the essential pattern of the observed data. In this case, the following approach may be helpful.

1.6.9 The essence of the approach is to begin with a wholly synthetic model which makes minimal, but reasonable, assumptions. In this way, initial P/A matrices at the required level of detail are developed. These are then treated as a “prior” which is then modified in the light of observed data, and the reliability thereof, leading to an improved version of the base matrix.

1.6.10 The initial synthetic model would start off with the all-day productions and attractions implied by TEMPRO for each purpose (or, better, make use of the underlying car ownership and trip end functions applied to local data on
population, households and employment). The matrix cells would then be filled by means of a standard gravity model which should be constrained to reproduce (at least) average trip length for the purpose (taken either from local sources or national sources such as NTS). Next, factors giving modal choice and time of day (again, available as part of the NTEM database) can be applied. In this way the complete prior matrix is built up by mode and time period, distinguishing the outbound and return portions of home-based purposes.

1.6.11 The process of “introducing observed data” must then make allowance for the statistical accuracy of that data, based essentially on sampling theory (see guidance in DMRB 12.1). This could be done along the following lines. For each observed cell of the matrix (ie production zone, attraction zone, purpose, mode, time period as well as possibly some segmentation data relating to car availability etc), the “prior” value would be tested as to whether it lay outside of the confidence region of the observed data: if so, the prior data will need to be modified.

1.6.12 In the course of such modification, certain key features of the prior matrix may be lost: for example, the modifications may change the total productions, or the average trip length. There will therefore be a need for an iterative process which attempts to re-impose some features as “constraints”. The modification can typically be done by means of a “proportionate fitting method”. Note that, provided that purpose is available in all the observed data, this adjustment process can be carried out independently for each purpose.

1.6.13 When the adjustments have converged to a satisfactory degree, the resulting matrices can be taken as an acceptable P/A basis, and used as the pivot for an incremental demand model.

1.6.14 If a modified (O-D) matrix for assignment purposes has already been validated, then this matrix should be used as the basis for assignment, and predicted changes in demand (after conversion from P/A to O-D) will be used to adjust this matrix. Thus this corresponds to type 4 in figure 2 above.

1.6.15 If no assignment matrix is in existence, then the first step should be to see whether the derived base P/A matrix can, when converted to O-D form, be satisfactorily validated at the assignment level. If this turns out to be the case, then the form of the overall model will correspond to type 3 in figure 2. If the base P/A matrix cannot produce a satisfactory matrix for assignment, then it will be acceptable to carry out further “matrix estimation” work on the resulting O-D matrix, to produce an “assignment matrix” which is not compatible with the base P/A matrix: in this case the overall model will again be of type 4 form.

1.6.16 We now go on to consider the forecasting of the reference case, which is required when the demand model is of incremental form.

1.6.17 The reference case is a forecast at constant generalised cost and constant value of time. It is based on the assumption of no change in travel costs from the base year. It is not intended to be a realistic forecast, but is essentially a way of “locating” the demand curve for the future scenario.

1.6.18 The construction of the reference forecast requires the “reference case” growth factors and will involve the adjustment of the row and column of the base P/A matrix at an all-day all-modes level to reflect expected land-use and car ownership changes. Since by assumption the travel costs do not change, it is appropriate to assume that mode and time of day proportions, for each segment distinguished in the base matrices, are unchanged. These proportions therefore need to be derived from the base matrices, and re-applied after the rows and columns have been adjusted. As a default, the growth factors for both productions and attractions should be based on TEMPRO (or, as noted earlier, by making use of the underlying car
ownership and trip end functions applied to local data on population, households and employment for both base and future scenarios).

1.6.19 The prediction of responses to different schemes can be obtained using an incremental demand or absolute modelling approach which pivots off the reference matrices (see VDM Key Processes (TAG Unit 3.10.3)). When the demand model is non-incremental, the reference matrices are not strictly required, though the expected land-use and car ownership changes need to be reflected, again using TEMPRO as a default.

1.6.20 Modelling of incremental changes from the base matrix is likely to be adequate for most assessments. For very large schemes or situations where there will be substantial land-use and demographic changes within the timescale of the assessment, however, it may be necessary to make a detailed absolute forecast (i.e. with absolute values predicted by the demand model) of at least part of the future reference case.

1.6.21 The data required for the demand calculations depend upon the chosen level of segmentation (or disaggregation) of travellers and travel characteristics, as discussed in Section 1.3 of this Unit. The level and details of the segmentation should depend on the planned policy tests and on those differences which are considered to be important to people’s travel behaviour. However, it is as well to be aware what data are available before deciding on the appropriate segmentation, since it may be necessary to modify the preferred segmentation according to the availability or lack of existing data.

1.6.22 For demand modelling the required matrices should be in production-attraction format as discussed in Section 1.3. This will then need to be converted to origin-destination format before the assignment stage of the modelling process. For trip ends (productions and attractions), much of the spadework has already been done for the National Transport Model, and the underlying data for this is available from the TEMPRO Trip End Model Program.

1.6.23 Trip distribution requires some measure of the attraction of each zone for different trip purposes, and the necessary data can be obtained from TEMPRO and more detailed data from the Census Special Workplace Statistics, Local Authority planning data, and local travel surveys. If there is a relevant local transport model then both data and appropriate parameter values may also be mined from the model. Such a local model could of course be used as the basis for building the new model. Modal split modelling requires the categorisation of travellers according to whether they have a car available for their journey. True car availability is difficult to model, and most models settle for categorisation of travellers according to whether they come from a household with no car, one car, or more than one car. This can be obtained from TEMPRO or local travel surveys if mode choice is to be explicitly modelled. It will also be necessary to obtain data on the alternative public transport options. The extent to which this is needed will depend upon how important competition between car and public transport is judged to be. If it is of fairly peripheral interest, limited ad hoc surveys may be sufficient, but if it is thought important for reasons such as the consideration of alternative public transport schemes then detailed modelling of public transport network will be necessary, and the reader is referred to the guidance on Public Transport Modelling and Forecasting for further advice. Again, a relevant local travel survey may provide relevant information on both public transport services and use. If slow modes are to be modelled, travel costs for walking and cycling can be derived satisfactorily on the basis of mean speeds by type of path with an allowance for street-crossing delays.

1.6.24 Good local data is preferable, but collection of detailed data from household surveys is expensive. As with all the modelling, the degree of effort to
be applied to data collection depends upon the complexity and detail that can be justified by the particular application. Where a comprehensive demand model is to be built for general policy analysis and assessment work across a wide network it is obviously sensible to spend considerable resource in data collection for both calibration and validation.

1.6.25 Where, however, the intention is to test a smaller scheme against variable demand there may be insufficient data to calibrate a satisfactory mode choice or distribution model and illustrative parameter values should be used (see VDM Key Processes TAG Unit 3.10.3). Inevitably, this approach will introduce uncertainties, and the modeller will have to judge their importance, but sensitivity testing against variation in the more important and uncertain parameters will demonstrate the robustness or otherwise of the conclusions.

1.6.26 In this more limited application of variable demand modelling, it will generally be sensible to use the demand model incrementally rather than absolutely, see VDM Key Processes (TAG Unit 3.10.3). In that case the model merely predicts changes from the known base situation as travel speeds and costs change, rather than trying to predict the details of the base situation. When used incrementally, the variable demand model does not need to generate trips on the basis of detailed household socio-economic data: it needs a reference case incorporating those factors, but the variable demand model itself merely predicts how these reference case trips will be affected by changing costs. Similarly, it does not need to contain detailed zone attraction parameters for distribution, since these will be incorporated in the reference case, but merely needs to adjust scaled versions of the observed trip matrix as costs change. Such simplifications do not hold for those models which incorporate incremental modelling by forecasting the differences between two absolute models. See VDM Key Processes (TAG Unit 3.10.3).

1.6.27 The validity of the base year matrix and the derivation of the parameters on which the demand model is based should be reported in an extended version of the validation report required by DMRB 12.2.1. That should report the assignment validation, identify which of the sensitivity parameters have been imported from elsewhere and report the standard errors and other confidence attributes of new data and new sources. Although some of those parameters may remain substantially untested, provided the model’s responses to changing costs accord with what is known, see VDM Convergence, Realism and Sensitivity (TAG Unit 3.10.4) it is likely to be adequate for its limited purposes.

1.7 Segmentation: Trip and Person Types

1.7.1 “Segmentation” is the dividing of travel, traveller and transport attributes into different categories so that all travellers in the same category can be treated in the same way. In the extreme, every link of the road and public transport network would be represented in the model, and zones would be small enough to allow identification of every trip. The trip matrix would be segmented by purpose and person/commodity type, and into time periods, so that every segment is completely homogeneous. All possible responses to changes in trip costs would be included. Such an all-embracing model is clearly impractical, and compromises have to be made. In general assignment and demand models require different forms of segmentation:

- In assignment models different categories of road and vehicle are identified because they require different parameter values in relation to traffic flow and speed. Some assignment models may categorise by broad trip purpose because these may grow at different rates over time, or be present in different proportions in different time periods. More
segmentation may be required when testing policy options that may affect different groups of road users in different ways (for example charging for road use may require segmentation to reflect ‘willingness-to-pay’). Otherwise, segmentation by time of day (see Section 1.8) is the most important issue for assignment modelling.

- Demand modelling generally requires more categorisation, both in order to estimate how much demand, and of what type, a particular zone may produce or attract, and because different types of traveller respond differently to changes in travel conditions and costs.

1.7.2 To be accepted by the policy-makers, forecasting and assessment must be seen to deal realistically with the variety of external factors which will contribute to changes in travel demand in the coming years. Moreover, policy makers may wish to know whether policies impact differently on different types of traveller, and if so, how. However, segmentation increases the size, complexity and run times of models, as does a more detailed spatial description using smaller zones and judgements have to be made about how much detail is necessary in a particular application. The same degree of segmentation may not be necessary at all stages of the model, and each of the stages of the demand model is considered in turn in the detailed discussion below.

1.7.3 Ultimately the segmentation adopted in the modelling process must depend on the nature of the study area, the objectives of the study, the data available, the outputs required and the intended model structure. The Table below suggests the minimum levels of segmentation for demand modelling. Note that these are guidelines on minimum segmentation, they are not necessarily adequate, and the degree of segmentation used should depend upon the particular application and the resources available.

### Minimum segmentations for a multi-stage demand model

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Segmentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household type and traveller type</td>
<td>Normally 2 categories: travellers categorised into car-available/no-car-available (or by household car ownership of 0, 1 or 2+ cars). Models that only need to deal with road traffic will include only those travellers who have a car available. If a local trip generation model is being developed, a more detailed segmentation into household structure, employed members, etc is very desirable and used in TEMPRO, but this finer level of segmentation need not be carried through to the subsequent stages.</td>
</tr>
<tr>
<td>Value of time</td>
<td>Variation of VOT across the population is important but can usually be addressed sufficiently through the trip purpose split. However, for schemes specifically involving charging, some additional segmentation by willingness-to-pay or income, and possibly also by trip distance, may be required. In this case 3 categories (tercile distributions of VOT pro-rata with income) will be adequate. Where there is a large range of trip distance, it may be desirable to allow VOT to vary with trip distance.</td>
</tr>
<tr>
<td>Trip purpose</td>
<td>3 categories: Work/ Employer’s business/ Other: These categories are likely to have different elasticities and different distributions in both time and space, and substantially different values of time.</td>
</tr>
<tr>
<td>Modes</td>
<td>2 categories: Car/public transport. It is essential to have a base of trips that can transfer to and from car. If slow modes are not represented then trip frequency change, which is sensitive to changes in generalised cost, should be modelled.</td>
</tr>
<tr>
<td>Road vehicle types</td>
<td>2 categories: Car/other, where the “other” may include freight and bus/coach as a fixed-flow matrix for assignment.</td>
</tr>
</tbody>
</table>
1.7.4 While it is undoubtedly useful to use a more elaborate segmentation of the population at the trip generation stage in order to facilitate forecasting, there is generally less requirement to carry such segmentation forward into subsequent stages of the model. A distinction between purposes is however essential; a suitable starting point would be – Work, employers business and others. Currently values of time used in appraisal are considered different for these purposes see Values of Time and Operating Costs (TAG Unit 3.5.6). Where modal choice is modelled, it will also be important to make a distinction between travellers who have a car available for a trip and those who do not and are therefore limited in their choice of modes.

1.7.5 Not all stages of the demand model require the same degree of segmentation. The paragraphs below give more detail on what is needed for each stage, and consider value of time issues.

1.7.6 Currently illustrative values are only available split by trip purpose (see VDM Key Processes (TAG Unit 3.10.3)). If the policies to be tested require more detailed segmentation, then the decision to use a simplified variable demand modelling approach should be reconsidered.

Trip Frequency

1.7.7 For most purposes it will be satisfactory to take the observed trip pattern and modify this pattern incrementally by making it respond to changes in travel times and costs. Estimation of base year or reference case trip-rates often involves a relatively high level of disaggregation. Some of these categories can then be aggregated in later stages of the modelling process. The main socio-economic variables leading to household trip generation are now reasonably well understood. They are:

- size of the household
- age structure
- numbers of employed members, students, retired members
- level of car ownership/availability
- number of driving licence holders
- income or socio-economic group (SEG)
- other area attributes (for example, population density)
- accessibility/ level of service

DfT’s TEMPRO program forecasts trip ends based on those factors.

1.7.8 Separate trip generation models based on that level of detail may be required where there are significant new development areas, to estimate the number of trips generated by a household (or person) with specified characteristics, for every purpose distinguished.

1.7.9 In other cases, the detailed local trip generation modelling is irrelevant and trip end growth commonly obtained through the application of TEMPRO is likely to be sufficient. TEMPRO aggregates over car availability categories and its outputs in Version 4 splits travel into:

- Home based (HB) shopping
- HB work
- HB visit friends and relatives
- HB recreation
- HB personal business
- HB education
- HB employers’ business
- HB holiday
with a similar split, excluding visit friends and relatives, for non-home-based trips. Again, these categories are generally aggregated into a smaller set for later stages of the modelling process.

1.7.10 Whilst TEMPRO gives some details of how traffic veh-kms could change in the light of changes in the Value of Time over time, evidence of the impact of changing travel costs on traffic veh-kms is not available for highly segmented categories, and in reality is not that well understood even for simple categorisations. Thus a categorisation by trip purpose (where the Values of Time are assumed to differ) is more than sufficient. It is also possible to assume that only certain trip purposes will change their frequency in response to changing travel costs, for instance trip frequency changes may be modelled for leisure trips but not for commuting trips.

**Trip Distribution**

1.7.11 The distribution model estimates the number of trips between each pair of zones, and ideally includes intrazonal trips which begin and end in the same zone, as well as the interzonal trips. It should be noted that it may be necessary to apply area-specific constants or movement specific deterrence functions within the distribution model to reflect the difference in the nature of travel to certain areas (e.g. longer distance trips to city centres). If this particular problem arises for the application being considered, some form of income or SEG segmentation may be appropriate to reflect how, for example, jobs in city-centres may have a high component of ‘high social economic groups (SEGs)’ such as professional and managerial posts in finance, banking and other business services, where workers may be drawn from further away producing higher average trip distances. A similar pattern may emerge for shopping trips to the city centre and both may require a ‘white collar /blue collar’ distinction, for example at a zonal trip attraction level. However, for most applications such a complication will be unnecessary.

**Mode choice**

1.7.12 Since the choice of mode depends on whether a traveller has a car available for the journey it is desirable to categorise travellers according to car availability for the trip, but since this is hard to identify in practice the segmentation is often merely by the level of household car ownership - 0, 1 or 2+ cars - rather then true availability. Variable demand models allocate trips to different modes according to the mean generalised cost of travel between the zonal origin and destination, in the relevant time period. There may be several modes to choose from: car, various forms of public transport, and possibly walk and cycle, though many models omit the ‘slow’ modes of walk and cycle. These issues are discussed in VDM Key Processes (TAG Unit 3.10.3). It is standard practice to develop models with different parameter values for different purposes and different categories of car availability (car-owners and non-car-owners, or the distinction may be based on a more elaborate indicator of car availability), since this obviously influences mode choice. These values may be estimated during calibration of the model to the observed travel patterns, but Stated Preference surveys may also be helpful in distinguishing between the travel sensitivities of the different groups. VDM Key Processes (TAG Unit 3.10.3) provides illustrative values for the sensitivity parameters of the various demand mechanisms, based on a review of existing models.

**Time of day choice**

1.7.13 Where time of day choice is modelled explicitly this choice mechanism can represent either **Macro time period choice** (the broad choice between time periods, e.g. 2 to 3 hours in length) or **Micro time period choice** (which uses fine periods e.g. 15 minutes). Obviously, the definition of the modelled time periods should be consistent with the choices to be made, as described
in Section 1.8 in this Unit, and the necessary segmentation by trip purpose, since obligatory travel such as work and education is likely to have less flexibility in adjusting its time of travel than are more optional purposes such as shopping or leisure.

Value of Time

1.7.14 The various demand mechanisms depend upon the “generalised cost” of travel, which combines the time and money costs of travel into a single quantity by using a “Value of Time” or VOT (see Section 1.9 in this Unit). This quantity is also used in assessing the costs and benefits of a scheme, but there is an important distinction to be made between appraisal values, which are standardised for equity reasons, and the behavioural values appropriate to modelling demand. In the demand models VOT represents the travellers’ perceptions of the time they have to spend travelling, and their willingness to trade money for time in order to visit their destinations. For some applications, differential responses or different willingness-to-pay, as represented by different values of time, will be important. This is particularly true for policy interventions such as road user charging, or where mode choice is likely to be more attractive to particular income groups, or where the impact on different segments of the population is an issue. In principle there should be different VOT distributions for each type of user class – for different journey purposes, for cars and goods vehicles, for travellers in different SEG or income groups, and for peak and off-peak travel. VOT has also been found to increase with trip distance, and the inclusion of this relationship may need to be considered where there is a wide distribution of trip lengths within (say) a corridor.

1.7.15 The effect of distributing VOT (or willingness-to-pay) according to the various types of traveller may be picked up sufficiently by using a different mean VOT for different trip purposes. However, where some form of charging is central to the scenarios being tested, it will probably be important to include this type of variation explicitly, since the effect of having some drivers with high VOTs, who are more willing to pay a modelled toll, is more than offset by those with low VOTs who elect to divert. The net effect depends upon the number of willingness-to-pay (WTP) bands into which the travellers are divided, but three or four seem to be adequate. The available evidence suggests that VOT should increase with an elasticity of 1.0 relative to income for employer’s business trips and 0.8 for other trip purposes (see Values of Time and Operating Costs (TAG Unit 3.5.6)).

1.7.16 A smaller number of user classes are likely to be required for Goods Vehicle and Employer Business trips. As a minimum, car travel for commuting, "other" purposes, and business, and ideally also light and heavy goods trips, should be distinguished.

1.8 Assignment Modelling

1.8.1 A variable demand model must include a highway assignment stage to provide travel cost information to the demand model. That assignment stage must include speed flow responses and must be adequately converged. Assignment can be considered separately from the other mechanisms, but it is essential that an equilibrium solution between demand and supply is obtained.

1.8.2 Assignment modelling that includes predicting traffic paths, loading traffic onto chosen paths, calculating speed changes, and iteration to convergence is a long established basis for estimating link flows and costs for input to economic appraisal procedures. Assignment has commonly been used on its own to appraise highway infrastructure improvements using one of a number of proprietary software packages. This advice assumes that the reader is already familiar with assignment, and has probably used it for fixed
demand appraisals with COBA, but it is discussed here in relation to demand modelling.

1.8.3 If an adequate assignment model already exists, then this model can be used to supply the travel times and costs necessary for generalised costs, see Section 1.9, which are a central input to the demand calculations. Care should however be taken to ensure that the existing model is suitable for this purpose, particularly in the geographical (spatial) representation and the generalised cost formulations.

1.8.4 To ensure true converged solutions, unless there are good reasons for not doing so, the ratio of journey time to journey distance should reflect the generalised cost formulations set out in Section 1.9 below. This requirement does not preclude the use of time-only assignments where they have been clearly shown to validate better than time plus cost, but where this is true a check should be made to see why this is so. It may be due to other factors affecting route-choice or that demand modelling requires the consideration of other elements of travel costs, for instance parking costs and access times are more likely to be needed in such models’ generalised cost formulations than if the transport model consisted of only an assignment model.

1.8.5 An important issue is that ‘good’ assignment convergence is necessary for ‘good’ convergence in the iterations between supply (assignment) and demand. Convergence criteria for assignment are discussed in DMRB 12.2.1. The issue of convergence between supply and demand is considered further in VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4).

1.8.6 There exists a substantial volume of comprehensive and satisfactory advice and information to guide the model development of an assignment model. Modelling (TAG Unit 3.1) discusses some of the issues and further DfT advice can be found in:

- DMRB 12.1.1, especially Chapter 9
- DMRB 12.2.1 (“Traffic Appraisal in Urban Areas”), especially Chapter 4.

Useful guidance can also be found in:

- “Guidelines on Developing Urban Transport Strategies” (IHT), Section 6.10.

1.8.7 The user is recommended to consult these documents and the user manuals of proprietary traffic assignment suites.

Is Dynamic Assignment Required?

1.8.8 Dynamic assignment can replicate the variation of demand within each time period modelled and this may be carried forward to micro time period choice models (see VDM Key Processes (TAG Unit 3.10.3)), but other variable demand model mechanisms only need average costs. Both needs can be met using dynamic assignment packages that represent explicitly variation of demand with time.

1.8.9 In demand modelling, a judgement must be made as to how best to define the time periods so that, within each, travel conditions are sufficiently constant to provide a realistic mean cost for the modelling purposes, this is further discussed in Section 1.8 below. A balance needs to be struck between the level of detail in the assignment step of the multi-stage model and the need for detail elsewhere in the modelling process (the number of time periods, the level of detail in the various segmentations, the stages included in the demand model etc).

1.8.10 Assignment models typically use a matrix of demand flows for the whole modelled time period, though it is common practice to use separate matrices representing the morning peak and inter-peak periods, or the peak hours. But once the modelling is broadened to examine how demand might respond
to changes in travel conditions there will be a need to re-examine the adequacy of the modelled time periods.

1.8.11 In general, demand modelling uses relatively broad time periods. When examining times and places of high congestion, it may be desirable to introduce a higher level of time-dependent responsiveness into assignment, either by modelling a series of short time-periods, or by dynamic assignment which represents explicitly the variation of demand over time, in order to obtain a better estimate of these average costs. This may be appropriate because:

- levels of demand change substantially during the assignment period (either across the whole matrix or in individual cells), so that travel times also vary substantially, or
- traffic demand exceeds capacity at some points on the network for some periods of time, so that not all demand can be satisfied.

1.8.12 The use of short time periods in a dynamic assignment will be valuable in modelling micro time period choice as part of the assignment stage (see below). In other aspects of demand modelling, the short assignment periods should be aggregated to provide costs consistent with the longer time periods used in the demand model.

1.8.13 All congested assignment suites can allow for journeys taking longer as congestion increases. Several can also model the formation of over-capacity queues and flow metering effects. These effects may imply that, in a given time period, fewer trips arrive at their destination than depart. This broadens the peak in the trip profile and is known as passive peak spreading. A different form of peak spreading arises from travellers actively choosing a different departure time to allow for congestion or to avoid it. Passive peak spreading, and travellers’ decisions to change their departure times by small amounts within the peak period (micro time period choice as discussed in VDM Key Processes (TAG Unit 3.10.3)), sometimes referred to as active peak spreading, are best addressed by the use of dynamic assignment models, or by “quasi-dynamic” modelling in which equilibrium assignment models are used to represent short time periods and queues remaining at the end of one period are handed on correctly to the start of the next period.

1.8.14 As with all decisions about detail in a multi-stage model, the choice of whether to use dynamic assignment must be driven by the added value of the extra complexity, or the error or deficiency introduced into the model by ignoring these dynamics. If the system is strongly peaked, the assumption of a flat profile in the corresponding time period will underestimate average delays and also calculate an incorrect spread over routes. These effects can be quite serious.

1.8.15 If a case is made for dynamic assignment modelling, travel conditions are likely to differ significantly over the model period and modellers should generally also assume that travellers may change their departure times. This is discussed in VDM Key Processes (TAG Unit 3.10.3). Fully-specified dynamic assignment offers an opportunity to model both passive peak spreading because of increasing journey times as congestion increases, and a behaviourally-based choice of travel departure times on a much finer timescale than is possible in the higher-level demand mechanisms.

1.8.16 Dynamic or quasi-dynamic assignment packages also have the potentially important benefit of providing properly flow-weighted travel costs to the variable demand model. This approach can provide a more representative average across the broader time period than can be obtained by simply assuming a constant level of traffic flow throughout the period.

1.8.17 **Overall, the guiding principles are that your model should be:**
justified by the situation it is applied to and the policy requirements of the assessment;

- supported by the available data and by appropriate calibration or the plausible importation of the relevant model parameters;

- supported by the expertise available: if you are unsure of the understanding required, but see the need for elaboration, get expert advice.

1.9 Division into Time Periods

1.9.1 Travel conditions vary considerably across the day, and across the days of the week and time of year. Models usually represent a weekday during a ‘neutral’ or representative month. In order to capture the variation in conditions within the modelled day, and especially the fact that many schemes are aimed primarily at times of maximum travel demand and highway congestion, it is conventional practice to divide the day into different periods for modelling purposes.

1.9.2 Demand modelling depends upon the time-divisions of the traffic assignment because the relevant travel costs and journey times which are extracted from the assignment are averages across the assignment periods. Hence, it is important to ensure consistency between the time-periods used in the calculation of these averages and the key time periods for the main demand segments.

1.9.3 However, the demand modelling can be assumed to take place over different time-periods, such as 24 hour weekday, 16 Hours or just a peak period. In theory, different demand responses can be modelled over different time-scales. A good deal of the survey data will be collected over a 12 hour or 16 hour period, and the background changes in trips estimated from TEMPRO data is on a 24 hour basis. Many of the current large regional models estimate trip frequency, mode choice and distribution over a 24 hour time period. However, procedures need to be adopted to convert such 24 hour trip patterns to be compatible with the shorter time-scales generally required for assignment modelling (a peak hour or an average inter-peak period, for instance). Paragraph 1.8.9 below explains how this can be done.

1.9.4 Guidance on division of the modelled period into time periods and time slices is given in Traffic Appraisal in Urban Areas DMRB 12.2.1. It recommends that automated traffic counts should be used to establish a daily profile across at least a week’s traffic data, and that subdivision should only be made where there is a clear difference in traffic congestion and/or travel patterns, or where there is an intention to model time of day choice. However, if modal transfer between private and public transport is important, and public transport offers different fares or frequencies at different times of day, it is advisable to choose time periods to reflect their different costs.

1.9.5 In general, it will be necessary to distinguish at least between peak and non-peak travel. Where the traffic profile is very variable leading to significantly different conditions at different times of the day, it may be desirable to sub-divide the peak period into a fairly narrow “peak of the peak”, say the peak hour, with shoulder periods on either side. This requires a judgement of the extent to which some form of average flow and speed across the modelled period can be taken as representative of the whole period and whether any off-peak model should represent a “typical” inter-peak hour, or a more extended “off-peak” encompassing early morning and evening travel in addition to the inter-peak.

1.9.6 It is unlikely that inclusion of variable demand modelling will require any greater segmentation of time periods than is satisfactory for assignment,
except where there is an interest in modelling time of day choice, as discussed in VDM Key Processes (TAG Unit 3.10.3).

**Feeding back costs from assignment to demand model**

1.9.7 The assignment model provides the travel times and costs required by the demand model, and generally both assignment and demand models will use costs averaged across the defined time periods into which the model has been divided. Many models relate all demand in a given purpose category to the costs in the period where most of these trips are made. Depending on which trip purposes are categorised in the model, the cost bases may be approximated as follows:

<table>
<thead>
<tr>
<th>trip purpose</th>
<th>cost base</th>
</tr>
</thead>
<tbody>
<tr>
<td>home-based journey to/from work</td>
<td>peak period costs</td>
</tr>
<tr>
<td>home-based education</td>
<td>peak period costs</td>
</tr>
<tr>
<td>home-based shopping</td>
<td>off-peak or interpeak period costs</td>
</tr>
<tr>
<td>home-based leisure/recreation</td>
<td>off-peak or interpeak period costs</td>
</tr>
<tr>
<td>home-based employer’s business</td>
<td>peak period costs</td>
</tr>
<tr>
<td>home-based “other”</td>
<td>off-peak or interpeak period costs</td>
</tr>
<tr>
<td>non-home-based employer’s business</td>
<td>off-peak or interpeak period costs</td>
</tr>
<tr>
<td>non-home-based “other”</td>
<td>off-peak or interpeak period costs</td>
</tr>
</tbody>
</table>

1.9.8 Obviously, this is not strictly correct, and more detailed models should ideally calculate the costs as weighted means across the periods according to the proportions of trips of each type in each period. Note that in the demand model these average costs for particular types of trips may be averaged again across different modes, or different destinations, to obtain the “composite” costs on which the demand mechanisms operate, as described in VDM Key Processes (TAG Unit 3.10.3).

1.9.9 Few models have as detailed a disaggregation of trip purposes as listed in paragraph 1.8.8 and it is usual to aggregate them into fewer categories (home-based shopping, leisure and social are often combined into “other” category, for example). For each category, the mean generalised costs of travel in the appropriate period, or in a combination of periods (or sub-periods) weighted according to the proportions of trips in each, are calculated and fed back to the demand model. Where the assignment model used is dynamic, or quasi-dynamic, (see below) mean costs can be obtained on a flow-weighted basis taking proper account of the variation over time, but the mean across the broader time periods should still form the basis of the demand modelling.

1.10 **Generalised Cost Formulation**

1.10.1 All transport modelling should recognise that people’s travel choices depend upon the cost, in both time and money. It is important to combine time and money into a single disincentive to travel, so that demand can be assumed to rise or fall with reductions or increases in either. To do so it is necessary to apply appropriate weights to the time and money components of this combined cost so that travellers can trade money for time, as in choosing between a faster but more expensive mode or a slower but cheaper mode. This combination of time and money costs is termed the “generalised cost” of a trip. Generalised costs are intrinsic to assignment modelling too, but for most applications car travel times and operating costs are highly correlated with journey distance and the modelling sometimes uses travel time alone as the cost basis, rather than the combination of time and money used in demand response modelling (see below and VDM Key Processes (TAG Unit 3.10.3)).
1.10.2 The term “disutility” of travel is sometimes used to refer to this combination of time and money, and for many purposes the distinction between the terms has been lost. In principle, however, disutility encompasses more than the travel times and costs, including aspects of travel which cannot be quantified in the generalised cost, such as general convenience or unknown local factors. Conversely, the term “utility” of travel may be used to denote the value of activities at the destination less the cost of getting there. The “disutility” is then the negative component (i.e. disincentive to travel) of the larger positive “utility”, i.e. the overall value of travelling. In this advice we will use “generalised cost” to refer to the weighted sum of time and money costs, and “disutility” to refer to the sum of generalised cost with any additional components, such as mode or area specific constants, which stand proxy for other local and unknown aspects of travel.

1.10.3 Note that, although it is referred to as generalised “cost”, it can be measured in terms of either money or time, and the parameter values suggested in VDM Key Processes (TAG Unit 3.10.3) use units of time based implicitly on the value of in-vehicle car time.

Components of generalised cost

1.10.4 Two kinds of variable can enter into the function of generalised cost:

- variables which relate to the trip under consideration, and
- variables which relate to the individual making the choice.

1.10.5 Taking mode choice as an example, the cost function developed for the choice of, say, rail by an individual can be influenced both by variables relating to rail (e.g. travel time, fare) and by variables relating to the individual (e.g. income, gender, journey purpose). In principle the generalised cost structure permits a considerable level of variation in behaviour to be examined and allowed for in the forecasting process.

1.10.6 Different groups of people will trade off time and money in different ways: for example, company car owners may be less affected by rises in fuel prices, and holders of certain kinds of public transport tickets may receive free marginal travel. There is likely to be further variation by trip purpose and time of day, which can be modelled using segmentation or disaggregation.

1.10.7 As Section 1.7 of this Unit noted, each segment considered will have, in principle, different parameters in the generalised cost function. Central to this is the concept of value of time, whereby money costs are converted into time units or vice-versa. Different values of time are appropriate to different segments of the travel market, particularly according to different journey purposes. Further information on values of time can be found in Values of Time and Operating Costs (TAG Unit 3.5.6).

1.10.8 Generalised cost normally includes elements relating to, for private car:

- fuel cost
- in-vehicle time
- parking costs
- access time

3 Units of disutility. In this TAG Unit it has been assumed that generalised cost and disutility are measured in units of generalised time based on 1 minute of in-vehicle car time being valued as 1 minute. In some demand model formulations the relative value of in-vehicle time is not assumed to be unity, but it will normally be possible to translate the formulations so that the equivalent assumptions to those in this Unit holds.
• tolls or user charges
so that, for example, measured in units of time:
\[ G_{\text{car}} = v_{wk}A + v_{wk}D + D\times VOC/(occ\times VOT) + PC/(occ\times VOT) \]
where A is the total walk time to and from the car, T is the journey time spent in the car, VOC is the vehicle operating cost per km, (note the advice in Values of Time and Operating Costs (TAG Unit 3.5.6) is to assume that travellers in course of work (Employer’s Business) take into account fuel cost and other operating costs of travel, whilst private travel only takes into account the cost of fuel) for a journey of D km, occ is the number of people in the car (who are assumed to share the cost), VOT is the appropriate Value of Time, and PC is the parking cost.  \( v_{wk} \) is the weight to be applied to walking time (see below), and although in this formulation the generalised cost is measured in time, it can just as easily be expressed in monetary units by multiplying the whole equation by VOT.  Similarly, out-of-pocket monetary costs such as parking charges and tolls may needed to be added. These would be converted into generalised cost units by dividing by the relevant value of time.

1.10.9 For public transport modes generalised cost will include:
• fares
• in-vehicle time
• walking time to and from the service
• waiting times
• interchange penalty
• non-walked access, e.g. park and ride
so that, for example, in time units
\[ G_{\text{PT}} = v_{wk}A + v_{wt}W + T + F/VOT + I \]
where A is the total walking time to and from the service, W is the total waiting time for all services used on the journey, T is the total in-vehicle time, and I is the interchange penalty if the journey involves transferring from one service to another (I is normally calculated as a time penalty multiplied by the number of interchanges).  \( v_{wk} \) and \( v_{wt} \) are the weights to be applied to time spent walking and waiting.

1.10.10 Values of walk and wait times and interchange penalties are usually related to the value of in-vehicle time by applying weights such as \( v_{wk} \) or \( v_{wt} \) above.  IHT’s Guidelines on Developing Urban Transport Strategies (May 1996) and ITS and John Bates’s review of value of time savings in the UK in 2003 suggest:

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

1.10.11 Equivalent weights are likely to be equally applicable to the walk from and to parking locations for car journeys.  Equivalent information is available in Transport Models (TAG Unit 3.1.2) and DMRB 12.1.1.

1.10.12 It should be noted that there are other factors that affect travel choices.  Probably the most important omission is that of reliability.  This has been subject to a considerable amount of research, and mechanisms whereby reliability can be included in the generalised cost formulation are currently under development.  While recent research has suggested that this factor should include an explicit estimate of travellers’ scheduling costs (i.e. the cost they place on not being able to travel at their preferred time), in practice
the approach is likely to be based on including the standard deviation of travel or waiting time in the utility/generalised cost function, representing the uncertainty of arrival time. These effects are potentially important, and useful advice can be found in research reports on the DfT website (see www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/032180.hcsp). An interim approach is given in The Reliability Sub-Objective (TAG Unit 3.5.7) as a post-model calculation.

1.10.13 For public transport schemes, the effects of comfort may need to be represented. Stated Preference exercises have produced plausible results whereby time spent in crowded or standing conditions incurs a higher cost than time spent seated in relative comfort. In these circumstances the estimation of the generalised costs of using public transport has an additional cost related to the degree of overcrowding, which in turn depends upon the number of passengers and capacity of the service, in terms of seating and standing capacity. This is most likely to be relevant only in peak-hour travel conditions. To be effective, models including an overcrowding feature need to be embedded in a feedback procedure so that they are demand-sensitive. In principle this is necessary if overcrowding changes significantly in either the base or forecast situations.

1.10.14 The example below, from a rail model, shows how the impact of seating and standing capacity can be modelled as influencing the perceived journey time by using a Crowding Factor $F_c$:

$$F_c = 1 + 0.12 \times \left(\frac{V - 0.6 \times C_s}{0.4 \times C_s}\right) \text{ for } 0.6 \times C_s \leq V \leq C_s$$

$$F_c = 1 + \frac{1}{2} \times \left[0.12 \times C_s + (V - C_s) \times (1.25 + 0.35 \times \frac{V - C_s}{(C_s - C_t)})\right] \text{ for } V \geq C_s$$

where:
- $V$ = Volume
- $C_s$ = Seating Capacity
- $C_t$ = Total capacity seating and standing

In this model, the Crowding Factor increases the cost of in-vehicle time by a factor which is zero when 60% of the seats are occupied, rising to 1.12 when all the seats are occupied and to 2 when all the standing room is full.

1.10.15 In general, because the generalised cost methodology is relatively robust, the inclusion of additional elements does not present major modelling problems for demand forecasting. If required, it should be possible to build models that extend the standard definition of generalised cost, and also allow for greater behavioural variation between person-types and purposes.

1.10.16 All the above discussion has related to a (dis)utility function where the generalised cost is made up of a weighted linear combination of quantities such as time, distance toll etc. It is however possible that the (dis)utility function may include these quantities in a non-linear form e.g. costs may be expressed logarithmically. In these situations the concept of generalised cost, measured in time units, with a constant relationship between time and cost quantities does not hold. Such a modelling system is currently rare in the UK (the 2004 PRISM model of the West Midlands currently being the only example), but is more common elsewhere in Europe.

Composite costs

1.10.17 Where more than one demand response is incorporated in the demand model, the transfer of costs from one demand response to another is expressed through the concept of composite costs. The estimation of these composite costs takes account of the generalised costs and shares of the alternatives from the demand response considered lower in the modelling hierarchy. This concept is explained in more detail in VDM Key Processes (TAG Unit 3.10.3).
2 Further Information

The following documents provide information that follows on directly from the key topics covered in this TAG Unit.

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<td></td>
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<td>Transport Models</td>
<td>3.1.2</td>
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3 References

DETR (July 1998) A New Deal for Transport: Better for Everyone


National Travel Survey 1998-2000 (DfT) update, July 2001, DfT


4 Document Provenance

This Transport Analysis Guidance (TAG) Unit reflects the consultation comments received on the Model Scoping Stage of the draft Variable Demand Modelling Advice produced by TRL in June 2003.

Technical queries and comments on this TAG Unit should be referred to:

Integrated Transport Economics and Appraisal (ITEA) Division
Department for Transport
Zone 3/06 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
Variable Demand Modelling – Key Processes

TAG Unit 3.10.3

June 2006

Department for Transport

Transport Analysis Guidance (TAG)
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This Unit is part of a family which can be accessed at [www.webtag.org.uk](http://www.webtag.org.uk)
1 Variable Demand Modelling – Key Processes

1.1 Background

1.1.1 TAG units 2.9 and 3.10 explain why variable demand modelling needs to be considered and provide guidance on how to carry out such modelling for highway schemes. This unit forms stage 3 of the variable demand process and provides the detailed advice required for those carrying out variable demand modelling. TAG Units 3.10.1 and 3.10.2 detail previous stages with TAG Unit 3.10.4 forming the subsequent stage.

1.1.2 Important recommendations are shown highlighted and in bold. If those actions are not followed analysts will need to provide rigorous justification for the course of action taken.

1.1.3 The key summary of this part of the advice is as follows:-

- Most variable demand models use some form of “hierarchical logit” formulation, in which the choice between travel alternatives (frequency, modes, destinations, time periods) depends upon an exponential function of the generalised cost or disutility.
- It is expected that distribution models will be included in all variable demand models. Details of the different model formulations are discussed, as is the representation of the fringes of a study area, which is particularly important when using trip distribution models.
- The representation of different modes in the variable demand model is discussed, and how it is normally acceptable to include the alternative mode(s) merely as a set of fixed costs. Occasionally, however it may be necessary to model the journey components in detail, including the effect of changing road conditions on bus travel.
- The modelling of departure time choice as a demand response or in close association with assignment is discussed. It is recommended that large “macro” adjustments only need to be modelled when considering differential pricing between time periods, or access restrictions.
- Wherever possible the variable demand mechanisms should be calibrated on local data, to reflect the local strengths of the choice mechanisms. This is not always possible, however illustrative values obtained from a review of UK transport models are reported, which may be used when accompanied by realism tests where it is deemed too difficult to establish local values.

1.2 Elasticity Methods or Full Variable Demand Modelling

1.2.1 “Own-cost” elasticity models assume that the demand for travel between two points is purely a function of the change in costs on that mode between the two places. The strength of that function can vary for different trip lengths.

1.2.2 However, a own cost elasticity model applied to all trips cannot recreate all of the changes in trip lengths which are forecast by a trip distribution model, nor can it properly represent the transfer of trips from one mode to another or from one time period to another when there are changes to the cost of several modes. The importance of these deficiencies may vary from study to study, and research has
been undertaken to assess the importance of these theoretical deficiencies for scheme appraisal. The initial results of this research suggest that elasticity models may significantly overestimate the effect of variable demand responses on scheme benefits, giving an overestimate of reductions from fixed trip matrix appraisal benefits. It is anticipated that further research will be commissioned by the Department to better understand the deficiencies of elasticity models.

1.2.3 Pending further research it is recommended that own cost elasticity models are not used instead of full variable demand models.

1.2.4 However, whilst an elasticity approach should not be used as a direct replacement for a full variable demand model, there may be a role for elasticity models in option testing. Once a variable demand model has been set up, then an elasticity model may be developed to reflect the results of this in terms of scheme benefits, (adjusting elasticity values so that user benefits of a given scheme are the same using the elasticity model as when using the fully specified variable demand model), which can then be used to refine a large number of scheme options. This method may be attractive where the full variable demand model requires significant run times and testing a large number of options would be impractical.

1.2.5 If an elasticity approach is to be applied in this way, then Appendix 1 sets out the different possible formulations.

1.3 Functional Form and Overview of Variable Demand Models

1.3.1 Most variable demand models use some form of “hierarchical logit” formulation, in which the choice between travel alternatives (frequency, modes, destinations, time periods) depends upon an exponential function of the generalised cost or disutility. That mechanism, and its application in variable demand models, is described here.

1.3.2 Any model of the demand for travel relies on a mathematical mechanism which reflects how demand will:

- fall if the generalised cost (time or money) increases; or
- rise if the cost decreases.

For example, the “own cost” elasticity mechanisms described in Appendix 1 modify an earlier estimate of demand using a curve which is as illustrated in Figure 1: the demand approaches (and is asymptotic to) zero, but never actually falls to zero even at very high costs.

![Figure 1 “Own cost” elasticity](image1)

![Figure 2 Choice model](image2)
1.3.3 In a variable demand model, a different mechanism is normally used to apportion the total demand in a particular travel category between two or more available choices, as for example between car and public transport, or between many different destinations. In this case, when the generalised cost of the specified choice is very much lower than the alternative choices almost all travellers will choose it, and if it is very much greater then very few will. Again, the function used is asymptotic to 100% or zero, as illustrated in Figure 2, since in any large population of travellers there will be a small but finite number who will take the apparently expensive choice. This arises even when only considering travellers with a car available and in general reflects how individual circumstances or choice preferences may be very different from the average.

1.3.4 The choice is unlikely to be based purely on simple formulations of generalised cost of travel: it will also depend upon appropriate zone or mode specific constants estimated in model calibration or implied by incremental models (see Section 1.5). They represent any extra utility gained by making that choice. For example, some modes will be inherently more attractive than others. Models assume that these hidden differences in the utility of travelling to any particular destination remain unchanged through time, and most therefore only need to reflect changes in the specific terms included in the generalised cost, as explained in VDM Scope of the Model (TAG Unit 3.10.2).

Logit Formulation

1.3.5 Appendix 2 describes some alternative forms of the many mathematical functions that can represent the behaviour shown in Figure 2. Logit is commonly used because it is easy to manipulate mathematically. In general, it is formulated as:

\[ P_p = \frac{\exp(-\lambda U_p)}{\sum \exp(-\lambda U_q)} \]

Where \( P_p \) is the proportion of travellers choosing alternative \( p \) out of \( q \) possibilities, \( U_p \) is the disutility of option \( p \) (based on composite costs at lower levels in the hierarchy), and the summation in the denominator is over all \( q \) alternatives, including \( p \). If there are only two choices this is called a binary logit model with the simple formulation \( P_1 = \frac{\exp(-\lambda U_1)}{[\exp(-\lambda U_1)+\exp(-\lambda U_2)]} \); for more choices it is referred to as a multinomial logit model as described in more detail in Appendix 2.

1.3.6 The mechanism should be applied separately to different categories of travel, such as trip purposes, as the sensitivity of the model is likely to be different in each category. For different trip purposes, for example, the logit sensitivity parameter \( \lambda \) is likely to be numerically larger where there is more freedom to choose. Thus more optional travel, such as shopping trips, tends to be more elastic and have a numerically larger \( \lambda \) value than, say, travel to work.

Hierarchical Logit

1.3.7 A single logit model may be applied to the entire range of choices available using a multinomial (i.e. many choices) logit model. However, that would implicitly assume that the sensitivities of those choices were all the same. Experience and intuition suggests that this is unlikely to be the case. This leads to a hierarchical system of logit formulations in which at each level a limited number of choices are considered. For example, a variable demand model might:

- first estimate the number of trips from any given origin (trip frequency - usually as an elasticity formulation);
then estimate how many trips will choose each available mode (mode split); and

then estimate how these trips choose amongst the available destinations (trip distribution)

(Note: this example excludes any time of day choice mechanism.)

1.3.8 The sequence chosen often varies between types of trip and does not necessarily represent the sequence of thought that makes these decisions. All the choices are interconnected, so that in a model that is converged, choices made earlier in the sequence are consistent with choices later in the sequence as the calculation is repeated. As a consequence the model has to be iterated to equilibrium.

1.3.9 Choices made higher in the hierarchy act as constraints on those made later. Hence, if the sensitivity of choice does not increase down the sequence there is a danger of later choices being too strongly influenced by earlier choices. Further discussion of the hierarchy of responses can be found in Section 1.9.

1.3.10 Within any of the steps (known as hierarchical levels), it may be desirable to model some secondary choices, for example, because travellers seem not to discriminate between different public transport modes in the same way as they treat the choice between car and public transport. Consequently, it may be preferable to split mode choice into a “high-level” two-way choice between car and public transport, with a “lower level” split into the different public transport modes, although this level of complexity is unlikely to be warranted for road scheme appraisal. This is often referred to as nested logit. It avoids the common problem with forecasting trips across three modes, car, bus and rail, of making the choice over-sensitive to changes in what travellers perceive as competing public transport services.

Application of the Nested Logit Function and Composite Costs

1.3.11 The logit function can be used in each stage of the variable demand model, in slightly different formulations, as described in Appendix 2. However, at each level in the hierarchy, it is necessary to calculate a disutility or generalised cost. For all except the lowest (last) level in the hierarchy this cost must reflect the available choices at lower levels: because it encompasses more than one type of choice it is called a composite cost or composite disutility. For example, the cost used in the trip frequency stage must represent a weighted average across the choices made in mode choice, where included across the time periods chosen, and across destination choices. **It is not sufficient to take a simple average across all the available choices, since the more costly choices will rarely be chosen.** For this reason the “composite cost” incorporates the probability that a given choice will be made. The logit formulation has the advantage that its composite cost is normally easy to calculate and is normally referred to as a “logsum” composite cost (see Section 1.9).

1.3.12 The logit mechanism can be applied in two ways:

- as an **absolute** prediction, to predict the absolute numbers of trips made between each origin and destination, by each mode, in each traveller category, and each time period;
1.4 Which Responses?

1.4.1 Although this advice gives guidance on the four variable demand mechanisms – trip frequency, mode choice, trip distribution, and time of day choice – it may not be necessary to include all of them in your demand model. Which to include depends upon the circumstances and policy interests of your assessment, and also on the data you have available and the amount of effort which seems justified by the particular application.

1.4.2 Where available a higher level model may provide an indication of the relative importance of the mechanisms. Nevertheless, there is a wide consensus that trip frequency is less sensitive to changes in travel costs than either trip distribution or mode choice. Mode choice for those with a car available will have a strong effect only where public transport offers an acceptable alternative. Time of day choice is likely to be important if there is substantial traffic congestion in the area of interest, and if the forecast changes in demand increase or reduce this appreciably, or if some form of differential charging or access is to be examined.

Trip Generation and Frequency

1.4.3 It is important to understand that the trip generation/frequency stage involves two rather different aspects:

- modelling trip generation as a function of the demographic and socio-economic characteristics of the area; and
- implicitly representing the response of the trips so generated to changes in travel cost (this is referred to as trip frequency).

If the population or car ownership or built development of the area is changing appreciably over the time period of interest, then the first of these mechanisms will be essential. Once that growth has been established for the reference case (see VDM Scope of the Model (TAG Unit 3.10.2)) it may be appropriate to make forecast trip numbers responsive to travel costs. This requires the incorporation of the elasticity mechanism to represent trip frequency as described in Appendix 2.

1.4.4 If the modal split mechanism includes slow modes, then overall trip rates will be fairly stable and there will be no need to model the response of trip frequency to changes in travel cost. However, in this case the mode-choice modelling will have to be more complex. Even if slow modes are not included, but there is a realistic representation of choice between car and public transport, the effect of trip frequency is likely to be small. However, in general, the inclusion of a trip frequency mechanism requires no additional information beyond that required for trip distribution, and the only extra complication involved is the calculation of a mean composite cost of trips from each zone (see Section 1.9).
Mode Choice

1.4.5 The mode choice mechanism allocates trips to each of the main modes included in the model. The importance of this mechanism will depend upon how competitive other modes are with car travel on the road network affected by the scheme. It will also depend on the willingness of people to transfer between car and other modes. Generally, the relevant alternative mode is public transport, though if the scheme is used by short local trips slow modes may offer some alternative. Note that the modelled modal split should consider public transport usage by those with a car available for the journey. For this category of person the mode-choice will inevitably be much more inclined towards car use than the observed modal split overall. The importance of the mechanism can be judged by the prevailing modal split between car and the alternative for such journeys, as described in Section 1.6. Where modal split to public transport is deemed to be important, then mode-choice will need to be considered in the demand modelling. If the scheme is expected to have a great impact on public transport and/or public transport alternatives are to be tested it will be desirable to model the public transport options in greater detail (see Section 1.6).

1.4.6 A few models omit the mode choice mechanism altogether because modal transfer is not considered to be important. This is not recommended (see Section 1.6), but if that approach is used it will be important to include a trip frequency elasticity at a greater strength than usual, since this will act as proxy for trips transferred to the car mode from other modes and vice versa.

Trip Distribution

1.4.7 Trip distribution models spread the forecasts of generated trips over the available destinations, depending on the generalised cost of reaching that destination. This leads to an estimate of the number of trips between each pair of zones and intrazonal movements.

1.4.8 When modelling individual variable demand responses it is expected that a distribution mechanism will be included. This can have a substantial effect on the trip pattern and the amount of traffic using the scheme. Note that its effect on road traffic arises from its changing the mean length of trips over a number of years rather than the numbers of trips, but its net effect on demand between individual origins and destinations and on economic benefit is likely to be stronger than mode choice.

Time of Day Choice

1.4.9 It is unlikely that a variable demand model for a road-based scheme will need to look at time of day choice over all 24 hours in a day but there will be circumstances where the choice of time of travel in certain parts of the day could be expected to be influenced by changing travel costs.

1.4.10 Many large-scale models with a variable demand model containing any or all of the responses of trip frequency, mode choice and distribution have been built on a 12 or 24 hour weekday basis depending on time restrictions on surveys. In these cases the proportion of travel that takes place in each time period will need to be estimated separately, probably by factoring methods.

1.4.11 There are two distinctly different aspects of time of day choice; these are termed macro time period choice and micro time period choice. Macro time period
choice represents the choice between broad modelled time periods, whereas micro time period choice represents choices within a modelled time period.

1.4.12 Some trip timing is, forced by changing journey conditions and times, but there may also be a deliberate choice to travel at a different time to reduce travel time and or costs. Macro time period choice occurs when travellers alter the timing of their activities and hence the time of day in which they are travelling. Micro time period choice modelling represents much smaller adjustments to departure times and packages to do this are currently under development. Peak spreading is mainly a micro response and represents travellers adjusting their travel behaviour without substantially altering their preferred arrival time or the timing of their destination activities. To date, apart from some specialist modelling, variable demand models have only included macro time period choice to represent transfer of traffic between broad time periods.

1.4.13 Macro time period choice between broader time periods would be essential if the scenarios to be examined include differential charging or other large changes in cost at different times of day. If this mechanism is included, as described in Section 1.8, then sensitivity testing (see VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4)) of the strength of the parameters should be used to examine the possible range of responses.

1.4.14 If modelling predicts unrealistically severe congestion in the peak hour, micro time period choice modelling to reallocate trips between the peak hour and the shoulders may be used to achieve a more realistic estimate.

1.5 Form of Models

1.5.1 An important issue that needs to be decided is the form of the demand model used for particular applications. There are a number of model forms that can be employed and these can generally be placed into three categories:

- absolute models, that use a direct estimate of the number of trips in each category;
- absolute models applied incrementally, that use absolute model estimates to apply changes to a base matrix; and
- pivot-point models, that use cost changes to estimate the changes in the number of trips from a base matrix.

1.5.2 The use of these models would depend on the compatibility of the based demand matrix if in P/A format (see Section 1.3 of TAG Unit 3.10.2) and the assignment matrix used.

- If the base demand matrix [P/A] is compatible with the base assignment matrix [O-D], in the sense that by applying time of day factors to the P/A matrix, adjusting for vehicle/person factors, and transposing the matrix to get the return trips, the required O-D matrices are generated, then (demand) changes to the base P/A matrix may be modelled either absolutely, or incrementally. In the latter case, this is done by incorporating the base values explicitly in the demand formulation;

- If the base demand matrix [P/A] is not compatible with the base assignment matrix [O-D], then (demand) changes to the base P/A matrix may be modelled either absolutely, or incrementally. In the latter case the base values are incorporated explicitly in the demand formulation, but only the...
implied change in demand after converting to O-D form is used to adjust the base assignment matrices.

1.5.3 The latter two methods in Section 1.5.1 retain all the detail of the observations, but generally face difficulties where too many (or key) cells in the observed matrices are empty because of the limited amount of surveying possible. This section explains the differences and the preferred approaches.

Absolute Models

1.5.4 Absolute demand models generate estimates of trip numbers, based on a model that is calibrated to fit as closely as possible to the known observed movements and the resulting model is used to directly forecast future trips. Base year and forecast trip patterns are produced independently of each other, using common model parameters. The sensitivity parameters used in absolute models should be calibrated from local data. In addition to the calibrated sensitivity parameters, however, mode-specific and movement-specific constants will usually be required to achieve an acceptable fit to the observed data.

1.5.5 The simplest approach to forecasting with absolute models is to run them separately for each combination of forecast year and scenario. Comparison of the 'without scheme' to the 'with scheme' case then gives an estimate of the impact of the scheme under consideration. This was the common practice with many traditional multi-stage models in the past. However, the fit of these models to the observed base year data was often quite poor, even where calibration constants, disaggregated by area type, had been used.

Absolute Models Applied Incrementally

1.5.6 In recent years, forecasting approaches have attempted to make use not only of the absolute model but also the 'observed' base trip matrices on which it was calibrated. This could be by factoring the forecast trip matrices by the ratio of the base year synthesised matrix to that of the base year observed matrix, so that:

Future year matrix = (Base year 'observed' matrix / Model absolute base year forecast) * Model absolute future forecast

1.5.7 However, this could lead to odd results where the cells of the observed trip matrix are zero. A way around this problem that has been used by some multi-stage models is to employ an additive approach so that:

Future year matrix = (Model absolute future forecast - Model absolute base year forecast) + Base year 'observed' matrix

1.5.8 Thus, the future forecast by the model is increased by the difference between the base year observed trip matrices and those produced in the base year by the model. The danger with this approach is that, sometimes, negative cell values can result.

1.5.9 In either of these ways the important differences between the observed matrices and the base year model that were not picked up in the calibration process are reflected in the forecasts. The first approach has been used in the recent PRISM model of the West Midlands and the second approach has been used in the Transport Model for Scotland (TMfS).
Pivot-Point Models

1.5.10 Pivot-point models estimate changes in trip patterns relative to a base matrix in which, normally, observed movements are used as much as possible. Such model applications are often described as ‘incremental’ or ‘marginal’. The predicted relative changes are applied to the base matrix, so that the complexities of the base matrix are preserved. Where it would be difficult to calibrate a demand model to reproduce the observed pattern of travel these incremental models can be used to predict from (pivot off) this base matrix and associated costs. The matrix can also be updated in whole or in part without altering the forecasting model since the parameters controlling the mechanisms can be independent of the calibration of the base model.

1.5.11 In such pivot-point models the forecasting mechanisms estimate changes in trip patterns as a function of the observed base, rather than estimating absolute numbers of trips. With true incremental models the base year conditions (costs) and the reference trip pattern (derived from the base year trip matrix assuming no changes in travel costs) are direct inputs to the forecasting process. Such an approach has a number of benefits. It can use existing data relatively easily, and the parameters used in the model can reflect known sensitivities to changes in input variables without having to perform the additional and time-consuming task of fitting to an observed pattern. That time consuming task requires the analyst to identify differences in mode specific constants, in the case of mode-choice, and sensitivities in different parts of the network (known as calibration areas). However, by not carrying out that task, the parameters will generally need to be calibrated using external data sources, or imported from other demand models (see Section 1.11 below which discusses illustrative parameter values). Models that use this approach to forecasting are described further in VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4).

1.5.12 The recommended pivot-point approach is given below and illustrated in Figure 3, which highlights the way that the forecasts pivot off the base year costs (reference cost).

**Recommended pivot-point approach:**

**Step 1.** Growth factors are applied to the base year matrix A to produce a reference case matrix B.

**Step 2.** Pivot off the reference case to get to point C which is the do-minimum

**Step 3.** Pivot off point C to get to D which is the do-something. Note that point C represents a well converged do-minimum scenario.
1.5.13 While this is the recommended approach to using pivot-point models, it is possible to pivot off the reference case B, to get to the 'with scheme' case D without going through C. It is also possible to use different definitions of reference trip matrix and costs, for instance, when some of the demand responses are modelled in another external model. However, these points would have to be on the future year demand line. Whatever variation of this approach is used details should be given in the forecasting report.

1.5.14 There is a number of proprietary software packages available that will undertake the required VDM forecasts but the user has to choose the underlying costs matrices and the reference trip matrix to enter into the software (see VDM \textit{Convergence Realism and Sensitivity} (TAG Unit 3.10.4).

\textbf{Choice of Model Form}

1.5.15 In summary there are a number of different approaches to producing forecasts of future travel demand. On the one hand there is the pivot-point method that uses trip matrices directly and forecasts by estimating the impact of incremental changes in the travel costs between a base situation and the forecast year/scenario. In most cases the base year costs are used as the pivot-point for the forecasts but in some circumstances other pivot-points may be used. On the other hand there are absolute models where the forecasts make no direct use of base year trips or costs. The approach of using the observed trip matrix to adjust absolute forecasts (Incremental Forecasting Approach) has blurred the distinction between forecasts produced from absolute models and incremental models. Whilst all pivot-point approaches are incremental, absolute models may be used directly or with an incremental adjustment.

1.5.16 Whilst the usefulness of the pivot-point methods of being able to make use of any peculiarities of the observed trip matrix is important, an equally important issue is the relative reliability of any observed trip pattern compared with that of an absolute model estimate. Both are limited by the expense associated with attempting to observe all the cells of the matrix, covering all the dimensions (of mode, time of day, on the one hand, and purpose and segments on the other). In addition, there are questions of temporal variability (seasonal, day-to-day, etc.). Thus, except in models that have very large zones, ‘observed’ matrices drawn from survey data are likely to contain a very high proportion of cells with zero trips. Without importing synthetic data an incremental model will never fill these cells. If the travel that the cell represents is truly infeasible then zero trips may be a reasonable assumption, but if the cell is empty merely because of sample limitations some matrix infilling may be advisable. These infilling techniques are discussed in detail in DMRB Volume 12.1.1.

1.5.17 In contrast, traditional absolute forecasting models do not use the local observed data directly but use it only for calibration purposes. Advocates of their use argue that this provides greater confidence that the model is properly fitted (in behavioural terms) to local conditions, and that estimates can be made of the
statistical accuracy of the model. Additionally, estimates are automatically produced for all movements including those that pass through the survey points, but were zero because of sampling variation.

1.5.18 However, in practice, often a large number of calibration factors need to be used with most absolute models to provide a reasonable fit to the observed data, often in a rather arbitrary way especially in the case of distribution models. In addition the parameter values so obtained may have arisen from some masking of observed differences (which may for example be distance-related effects) by the zonal or mode specific constants and may therefore either underestimate or exaggerate the true sensitivity of travellers to changes. Consequently, the apparent superiority of local calibration is often not fulfilled in practice except in large-scale transport studies, where the data collection and calibration can be sufficiently comprehensive.

1.5.19 Pivot-point approaches are attractive, but it is necessary to sound a note of caution. In the first place, any deliberate decision not to attempt to synthesise observed cross-sectional variation has potential forecasting implications. To the extent that a model is deficient in synthesising, it may be equally deficient when used incrementally. This is called model mis-specification.

1.5.20 However, the observed data are themselves affected by sampling error considerations. One way around this problem is to use a mixture of observed and synthesised data, even for movements supposedly wholly observed, particularly where sample sizes are small and sampling error consequently high. The relative quality of the data and the synthetic model need to be considered, especially if long-term redistribution processes might not have been fully realised. Usually the potential model mis-specification errors of distribution models are such that the observed data should be given greater weight in any mixed base.

1.5.21 However, by taking a weighted average of the observed and synthetic matrices empty cells are eliminated and greater weight is given to cells where there are more observed trips than expected from the locally-calibrated synthetic model. Relative weights should reflect the relative accuracy of the two forms of estimates. If these are not known then a rough guide would be to use 90% of the observed estimate and 10% of the synthesised estimate. Synthesised data is also required for movements not captured by the survey strategy.

1.5.22 The main problem with using pivot-point models occurs when the base matrix contains few or no trips for a set of movements, but the forecasts expect large changes in these movements to occur. This often arises when a zone is re-developed or has no trips to or from it in the base situation. In these situations the forecast will have to be synthesised exogenously for these movements.

1.5.23 In practice, the base matrix may have elements of both observed and synthetic approaches as some parts of the 'observed pattern' of travel may have to be synthesised from other observed data. This is most obviously true when the partial matrix technique is used to fill unobserved cells in the observed OD matrix (an absolute demand model may be used to estimate the likely values for empty cells), but the synthesising of various combinations of household structure from incomplete information, especially for forecasts, is another example.

1.5.24 The Department's preference for road-scheme appraisal is to use an incremental form of model whether pivot-point or based on incremental application of absolute estimates, unless there are strong reasons for not doing so. Such reasons could
include situations where there are large changes in land use between the base and forecast years, which will significantly change the distributions of origins and destinations.

1.6 Which Modes at What Detail?

1.6.1 This section discusses the representation of different modes in the variable demand model. Usually, the main alternative mode to car will be public transport in its various forms. In some circumstances it may be desirable to represent competition from walk and cycle; however, in most highway assessments explicit modelling of slow modes is unlikely to be worthwhile, especially in inter-urban areas. It may be acceptable to include the alternative mode(s) merely as a set of fixed costs. Where mode-choice is important to the assessment, it may be necessary to model the journey components in detail, including the effect of changing road conditions on bus travel. Further advice on public transport modelling will be released as a series of TAG Units in due course.

1.6.2 As Section 1.4 explained above, it is almost always desirable to include some representation of modal choice in variable demand modelling, but the level of detail depends upon the importance attached to it.

Public Transport

1.6.3 It is likely that the competitive public transport mode will be rail, or intercity coach, for longer distances, and bus or LRT for shorter urban distances. In some cases more than one mode may offer a competitive alternative to car, in which case the demand model should include a higher level car/public transport modal split mechanism, with a separate split between the available public transport modes below this in the hierarchy (this is known as a nested approach - see Section 1.9). That nested approach avoids the so-called “red bus/blue bus problem”, in which merely splitting one existing mode into two identical ones will apparently predict mode shift when using a multi-nominal logit model. Nested models should have at least two levels, with choice between private and public transport at the higher level, and then between different public transport modes at a lower level. The choice sensitivity lambda parameters should be larger at these lower levels than at the higher level. If there is a separate public transport assignment model, then this secondary choice can be made in the assignment stage, with (in that case or when using a nested approach) the generalised costs fed back to the higher-level mode choice as flow-weighted or composite averages across the public transport modes. Detailed advice on these issues will be released as part of the public transport modelling guidance to be released in due course.

Figure 4 Example of a nested choice structure

```
car ←→ public transport
     ↓
bus ←→ rail
```
1.6.4 If there is little real competition between public transport and car, the public transport generalised cost estimates can be made with limited precision. The level of competition can best be judged from local knowledge of modal split for car-available travellers. This can only be obtained by travel surveys, which set out to identify car availability: in most cases it will have to be proxied by household car ownership, but this will generally overestimate true availability. Approximate values for an area can be obtained from the 2001 Census.

1.6.5 As a general guide, if public transport is chosen by less than 5% of travellers, use of fixed public transport costs will suffice, unless public transport alternatives need to be assessed as part of the scheme appraisal.

1.6.6 Consideration also needs to be given to the future role of public transport. If public transport is expected to play a significant role in the future (either through specific scheme or policy implementation) then, irrespective of current mode choice, development of a mode choice model may be appropriate.

1.6.7 Where more detailed assessment of the impact on public transport will be needed or it is known that changes to the public transport network will be assessed, the reader is referred to the guidance on Public Transport Modelling and Forecasting for further advice.

1.6.8 Rail travel can be represented by a fixed-cost matrix even if it takes a larger than average share of car-available travel, since it is not subject to road congestion. However, an equivalent effect is rail overcrowding as demand changes, but the effect is difficult to estimate and is often ignored. Access to the stations is likely to be by car for some trips, and a mean generalised cost of access across all relevant modes (walk, bus, and car including parking charges) should be estimated. Large changes in demand for either rail or bus might result in changes in service frequency, but these effects are best examined using a specialised public transport model.

1.6.9 If the modal competition is considered important, then a more detailed representation and costing of the public transport alternative will be required. The reader is referred to the guidance on Public Transport Modelling and Forecasting for further advice.

1.6.10 Where public transport is an important component of the transport scheme, and a detailed public transport network (assignment) model is needed the generalised costs for each OD can be extracted directly from it. However, the access costs to each mode may need to be added. Competition between different public transport services, or modes, can also be modelled in assignment. Where an existing highway assignment model is to be used in conjunction with an existing public transport assignment model, the generalised costs of the two models need to be consistent with one another.

1.6.11 If the scheme being assessed affects the journey times of the public transport services appreciably, this should be estimated. This will usually only be the case for bus services, which may be speeded up or hindered by the scheme, and which may also be affected by changes in traffic congestion. In practice, there is a low propensity of car users to see bus as a realistic alternative, except perhaps for park and ride schemes.
1.6.12 A worked example of estimating modal split and the effect of changes in road speeds on bus users is provided at Appendix 3.

**Slow Modes**

1.6.13 Mostly, assessment of a road scheme is unlikely to be affected by whether slow modes are included or excluded from the modelling. Walking from car parks can be modelled in the car assignment process. Walking for the whole journey only offers appreciable competition to the car for short journeys, typically no more than a kilometre or so, and while cycling can be competitive over much longer distances (and especially so where traffic congestion slows the car), it is rarely considered an acceptable choice by the majority of car-available travellers. This is not to argue against the merits of the slow modes which are environmentally friendly and healthy, but merely to treat them realistically in transport demand modelling, especially when trips are too long to be feasible by slow modes.

1.6.14 There may be special reasons for examining the role of slow modes in the modelling (for instance for schemes on radial routes in urban areas with high cycle usage) and their inclusion may well affect predictions of short trips on a road scheme. If they are included, they will stabilise total trip rates, and there is less reason to model trip frequency. This is because when the costs of mechanised travel fall, as speeds increase or operating costs fall, there will be modal transfer from slow modes to mechanised modes. This appears as the trip frequency response in a model lacking the slow modes, but as modal shift in a model which contains them. Over time, the inverse effect may be as important. When the costs of congestion increase, or operating costs rise (perhaps due to congestion charging or increases in parking charges), there may be modal transfer from car to slow modes. This appears as “trip suppression” in a model lacking the slow modes, but as modal shift in a model which contains them.

1.6.15 When slow modes are omitted trip frequency elasticities should be stronger, since then it has to represent the effect of this “slow modal” transfer. If slow modes are to be included, then a cost-responsive trip frequency mechanism can be omitted altogether. If they are treated as a separate mode, as opposed to them being included in a general non-car mode, it will normally be adequate to treat their generalised costs as linearly dependent on OD distance travelled, via an average speed that is conventionally 4 km/h for walking and 12 km/h for cycling. Walking speeds in particular are a function of the number of roads crossed, and the amount of traffic on these roads, but this aspect is rarely captured in modelling.

1.6.16 Slow modes may be included in mode split at either level of the hierarchy, as part of a higher level car/public transport/slow split with perhaps a sub-modal split between walk and cycle, or, more usually, the higher level split may be kept binary between car and public transport plus slow, and the latter split at the sub-modal level.

1.7 **Trip Distribution**

1.7.1 Trip distribution models spread the forecasts of generated trips over the available destinations, depending on the generalised cost of reaching that destination. Most distribution models are designed to guarantee that the total number of trips from the origin zone (or to the destination zone) is equal to the total number of trips for that zone forecast at the trip generation/frequency stage. If the design
guarantees that property for both origins and destinations the model is known as doubly constrained.

1.7.2 Distribution models can be applied in terms of zonal productions and attractions or less satisfactorily in terms of origin and destination trip totals. *VDM Scope of the Model* (TAG Unit 3.10.2) discusses the distinction and the implications for the modelling process. Various functional forms are available, but most models in this country have used a logit-type formulation to represent the influence of travel costs on choice of destination, in a similar way to choice of mode etc. It is common to use doubly-constrained models for forecasting commuting and education trips, so that each zone attracts and generates a fixed total of work trip ends, and singly-constrained models for other purposes, where only the total number of trips originating in each zone is fixed, using the techniques described below.

1.7.3 In addition to cost, distribution also depends on some measure of the attraction of a zone, estimated in terms of the numbers of “opportunities” such as jobs or retail floorspace in the zone. These reflect the likelihood that the zone will be chosen as a destination, other things being equal (though in doubly-constrained models the attraction is simply the number of trips required to end in the zone).

1.7.4 Whilst trip distribution models were originally expressed as “gravity models” (using a negative power of distance) they are now usually formulated as a logit model, as underpinned by random utility theory for discrete choice modelling and because of its mathematical tractability. Other functions such as simple power, Tanner or Box-Cox functions are available as well as the commonly used exponential formulations (see *VDM Appendices* (TAG Unit 3.10.5)).

1.7.5 The main stumbling block in their use lies in estimating the trip attraction factors for each zone in a robust and reliable way, and in determining parameters which have real predictive values. This is difficult, since the distribution parameters are normally calibrated to recreate the (cross-sectional) data observed at a given point in time, which depend on a wide range of historic and socio-economic factors, which cannot be captured fully in the modelled transport factors. Those historic factors can be large enough sometimes to mask the true choice process amongst closely competing destinations in an equilibrium model.

1.7.6 Consequently, the models’ ability to predict choices and changes in trip patterns due to changing transport factors is generally unproven. For this reason it is recommended that trip distribution models normally have an incremental form, building on a largely observed base. Local parameter values should be calibrated for use in the model; however, if there is insufficient observed data for satisfactorily calibration, externally derived parameter values should be used, although some adjustment may be needed to deal with any under-representation of competing destinations and situations where major changes to land-use are expected to occur.

1.7.7 Predictions of trip distribution are usually “Production Constrained” to a total based on forecasts of trip-ends (see *VDM Scope of the Model* (TAG Unit 3.10.2)). Similarly, the trip matrix can be constrained to match a required number of total trip attractions. In general, the trip matrix and productions will be disaggregated by trip/traveller segments, and will have to satisfy the constraints within each individual segment, such as each trip purpose or traveller type.
There are four main decisions that have to be made about the use of trip distribution models within a variable demand model:

**Production/Attraction or Origin/Destination Modelling**

The implications for this are discussed in *VDM Scope of the Model* (TAG Unit 3.10.2) and the choice is likely to be made based on the availability of data, what other demand responses are being modelled, and what form of demand/assignment model is being used. However, when building a new model, or substantially updating one, the presumption should be that any new matrices are assembled and used as P/A defined trip matrices.

**Doubly or Singly Constrained**

In general, doubly constrained models should be used for commuting and education. 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.

Other purposes such as shopping, social and leisure trips are typically modelled as singly production-end constrained. For these purposes, the trip end factors reflect the attraction of destinations, not the actual numbers of trips attracted and ideally the availability of intervening similar destinations between the origin zone and the zone in question. In practice the required estimates need be only relative, and usually depend on a weighted combination of quantities like shopping floorspace or employment, with the weights obtained from fitting regression models, or they may be obtained from trip-end models such as TEMPRO.

**Incremental or Absolute (based on wholly synthetic models) Forecasting Models**

Where possible incremental models should be used, since these usually have the benefits of a more directly observed trip matrix (see Section 1.5 for a discussion of this issue). This matrix reflects not only the pattern of trip ends and the costs of travel between them, but also the cumulative impact of past travel and settlement decisions - which an absolute trip distribution model, based on current costs and trip patterns, cannot take into account except via the inclusion of a multitude of area-specific fitting constants. These special factors (usually known as 'K' factors) represent that part of the interaction between zones that does not conform to the general synthetic model expectations. In calculating those factors it is advisable to first identify calibration areas and then vary the distribution parameter by calibration area as well as traveller type before resorting to such zone-to-zone factors. None of this is necessary when the model is incremental.

**Model Form**

There are a number of different model forms suitable whether the model is doubly or singly constrained, incremental or absolute. It is expected that the model form will generally be logit; however, a number of different deterrence functions are possible. These are discussed more fully in Appendix 2. Starting with an absolute model formulation since they are easier to understand (discussion on incremental models can be found in appendix 4), the trip distribution model can be written in a number of equivalent forms such as the general form:

\[ T_{ij} = a_i b_j O_i D_j f(G_{ij}) \]
Here $a_i$ and $b_j$ are simple or iteratively calculated “balancing factors”, whose values depend on trip end constraints. In multi-stage models it is clearer if this general form is expressed as a destination choice model.

If the distribution model is singly (origin)-constrained the equivalent destination choice model is:

$$T_{ij} = \frac{O_i D_j f(G_{ij})}{\sum_k D_k f(G_{ik})}$$

which satisfies the origin constraint:

$$\sum_j T_{ij} = O_i$$

If the distribution model is doubly-constrained, the destination choice model is:

$$T_{ij} = \frac{O_i b_j D_j f(G_{ij})}{\sum_k b_k D_k f(G_{ik})}$$

where the $b_j$'s are calculated iteratively to satisfy the destination constraint:

$$\sum_j T_{ij} = D_j$$

In the case of origin constrained trip distribution $D_j$ is some function of the attractiveness of destination zone $j$, and in the case of a doubly-constrained trip distribution model $O_i$ and $D_j$ represent total origin and total destination trip ends respectively. $G_{ij}$ represents the generalised costs of travel between $i$ and $j$ and $f(G_{ij})$ the deterrence function which may or may not contain (multiplicative or additive) $K_{ij}$ factors.

1.7.14 In the above equation there are a number of different deterrence function forms that can be adopted for $f(G_{ij})$. In a true gravity model the deterrence functions are power functions $f(G_{ij}) = G_{ij}^a$ (and originally interzonal distance was used instead of $G$), but it is standard now to use an exponential form:

$$f(G_{ij}) = \exp(-\lambda \text{dist} G_{ij})$$

or with multiplicative $K_{ij}$ factors:

$$f(G_{ij}) = K_i \exp(-\lambda \text{dist} G_{ij})$$

or with additive $K_{ij}$ factors:

$$f(G_{ij}) = \exp(-\lambda \text{dist}(G_{ij} + K_{ij}))$$
1.7.15 The calculation of costs should use composite cost $G_{ij}^{\text{comp}}$ (see Section 1.9) calculated only across the stages lower in the hierarchy of mechanisms.

1.7.16 Different values of the distribution parameters can be used for different cells, or over different cost bounds, or a completely empirical relationship between deterrence and cost can be used. However, since most of the evidence on suitable parameter values relates to the logit form, and this form is the most common for other demand responses, this should be the first choice. Where alternative parameters are justified by a study of the base situation, the logit parameter value may vary by origin or destination zone. However, any logit or exponential distribution model implies that the sensitivity to a given absolute change has the same effect on travel between zones far apart as on those close together, and this sometimes leads to large percentage changes in long-distance trips. This can be mitigated by careful choice of calibration areas. It should not be a problem for local models, but could give rise to unusual forecast changes for models with very long and very short trips (though trip-end constraints will mitigate the effect somewhat for doubly-constrained models). Where locally derived parameters have been produced by calibration area, then the trip matrix may need to be split into categories based on these calibration areas (for instance trips to an urban centre) before forecasting is undertaken.

1.7.17 There will not normally be a requirement to model trip frequency for doubly-constrained trips, since the constraints on total travel are usually assumed to be binding. This normally implies a constant frequency of travel to work, with changes limited to the choice of mode and destination. This implication does not hold if slow modes have been omitted and they may form a sizeable percentage of commuting trips. In these circumstances a trip frequency response could be added although care would need to be taken that the response is not simply affecting long distance trips rather than the short distance trips the response is acting as a surrogate for.

1.7.18 Shopping, social and leisure trips are typically modelled as “Singly Production Constrained”. For them, the trip end factors reflect the attraction of destinations, and not the actual numbers of trips attracted. This is not especially easy to estimate, since it will depend not simply on the amount of the activity available in the zone (for example, the retail floorspace) but also on its type and quality, and on the availability of intervening similar destinations between the origin zone and the zone in question. For some of these purposes it may be logical to consider a trip frequency effect on top of the distribution effect; that is decreasing costs will lead to greater numbers of trips of that purpose as well as change the destinations. An example of this is leisure or holiday trips, but shopping trips too are likely to be elastic, especially if the model does not include slow modes, since walk trips to the local shop may become mechanised trips to more distant shopping centres if travel costs fall.

**Spatial issues**

1.7.19 Trip distribution models are likely to be the demand responses most sensitive to the spatial extent of the model area but the degree of sensitivity will also depend on the form of the distribution model chosen. Three issues are worth highlighting with respect to trip distribution models.

- Where possible, all likely destinations for zones within the main area of interest should be modelled. This is particularly important for trip distribution models since trip increases in one area, say within a corridor of interest after
improvements, should lead to decreases to other destinations. This will have implications for traffic quantities and benefits (overall, and within given areas).

- Average intra-zonal trip costs should be calculated as accurately as possible to remove bias against shorter trips in the distribution model. The modelling of intra-zonal trips is especially important and usually needs to be considered separately, as most assignment models do not assign intra-zonal trips and hence no costs are output. Power function models are particularly sensitive to very low intra-zonal costs, and where mode-choice is undertaken lower down the hierarchy than distribution the distribution of car trips using a power function could lead to an excess of very short-distance car trips.

- If destinations outside the main study area are potential alternative destinations then the costs to these destinations should be calculated reasonably accurately, even if the network, and the zoning system outside the study area, is of a coarse nature.

1.8 Time of Day Choice

Macro Time Period Choice

1.8.1 Macro time period choice, involving the transfer of trips between broad time periods, can be modelled as a logit choice in a similar way to the choice mechanisms described for the other stages of demand modelling. However, if the demand modelling uses the typical division of time into two peak periods and an inter-peak (see VDM Scope of the Model (TAG Unit 3.10.2)), the freedom of most trips to transfer between them will be severely constrained: few work trips, for example, could move outside the three-hour peak periods entirely, and such a mechanism might be applied predominantly for shopping as opposed to the journey to work.

1.8.2 To model macro choices, it is necessary to know what proportion of each type of trip takes place in each period. At a macro level trips must be allocated to a discrete time period even those which start and finish in different periods. An incremental logit model can then be used to modify the total number of trips of each type of trip in each time period according to the changes in the mean generalised costs in each period.

1.8.3 Macro time period choice should be considered when strong cost differentials between time periods are expected to develop or change. This is obviously the case where different charges are introduced for use of a road, rail or bus service in the peak and inter peak or off-peak, or where different levels of access to road capacity are being contemplated, or perhaps where peak surcharges are introduced for parking in a way which affects a large proportion of traffic. In these cases it is obviously important to choose the modelled time periods to facilitate the modelling of the differential costs.

1.8.4 There is limited evidence on the strength of the macro time choice mechanism. Recent Departmental research (http://www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/040158.hcsp) suggests that time period choice is generally more sensitive to changes in travel conditions than mode choice. The report also concluded that the choice of time period is generally more sensitive for changes between short than long periods: however
this finding cannot be extended to 15 minute periods on the basis of the tests made in the study...

1.8.5 Where circumstances justify the use of this technique, it can be important to apply different sensitivity parameters to different trip purposes. For further details see analysis in (http://www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/040158.hcsp)

Peak Spreading (Micro Time Period Choice)

1.8.6 It is common experience that when demand grows in a congested network the peak in demand tends to occupy a longer time. The peak is unable to grow higher for lack of capacity, so additional demand is accommodated in the shoulders of the peak. This effect is known as “peak spreading”, but it occurs because of a mixture of responses, both involuntary and voluntary:

The length of the peaks will spread as congestion grows, because lower speeds mean that any given journey will take longer to complete and will occupy a longer period. The traveller has little influence in this, and the delays caused by this effect are often represented within the assignment modelling itself, as described in VDM Scope of the Model (TAG Unit 3.10.2).

Travellers can deliberately change their time of travel, departing and arriving earlier, or later, than their preferred time. It is common experience in congested conditions that a quarter hour change in departure time can change the expected mean travel time significantly. Some travellers will find such a change acceptable, because the saving in journey time outweighs the benefit they attach to arriving at a preferred time. The response is clearly more available for travellers who have some flexibility in precisely when they must arrive and is applicable to those work trips that have some degree of flexibility for earlier or later arrival.

1.8.7 In the face of increasing congestion, some travellers will adjust their departure times or arrival times to gain a reduction in travel time. In principle, this can be represented as a choice mechanism reflecting the generalised cost of travel to which has been added the cost of not arriving at the preferred time: this is a “schedule disutility term”, essentially an extra component to the generalised cost which measures how far the actual arrival time is before or after the preferred time.

1.8.8 When a micro time period choice response (that will include a schedule disutility term) is included in a variable demand model, evidence suggests that this is likely to be the more sensitive than other responses except route choice.

1.8.9 DfT has developed a departure time choice model (HADES) which interfaces with standard assignment packages (Van Vuren, 2002). This represents a continuous range of departure times and interfaces with a range of assignment software which use a small number of time periods. For further information see www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/032182.hcsp. The HADES model is being developed within the DIADEM software (see VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4) for further details) and is expected to be available in due course. In the meantime further advice on the use of HADES in particular local applications should be sought from the DfT.
1.8.10 Other approaches can be used to represent peak spreading between the peak hour and shoulders, such as multinomial logit, although there are theoretical reasons why this form of model may not be a reliable predictor of choice between shorter time periods. Some of these techniques are described in DMRB 12.2.1. These may be suitable in particular local applications until the DIADEM package offers an appropriate micro time period choice facility.

1.9 Hierarchy of Responses and Composite Costs

1.9.1 Once decisions have been made on which responses to include in the model, the hierarchy in which those responses are considered must follow certain rules. This is not simply a question of mathematical or computational convenience. The sequence of the mechanisms is important to the overall outcome, and the resultant elasticities of demand and the predicted travel pattern will be affected by it. This section describes how the hierarchy should be determined.

1.9.2 The appropriate hierarchy or sequence of choice mechanisms must be determined by the relative sensitivities (the lambdas of a logit model) of the choices to the generalised costs or disutilities of travel. Different sequences for different purposes and/or segments of the travel market are often appropriate.

1.9.3 A mechanism placed “higher” in the hierarchy of demand mechanisms should reflect the “composite cost” of choices lower in the hierarchy and allow for how a choice with high costs is unlikely to be chosen. A “logsum” of costs as described later in this section has that property, but requires “higher” demand mechanisms to have a smaller sensitivity, to avoid a plausible change in generalised cost producing an implausible shift in demand.

1.9.4 The sequence of calculations is that, during each cycle, the composite costs must be calculated for each level in the hierarchy, since each level refers to different combinations of choice lower in the hierarchy.

1.9.5 Thus the cost calculation starts at the bottom of the hierarchy and works its way up the levels, adding one more choice into the composite cost at each level. The choice calculations are then made down the hierarchy and the whole cycle is recalculated in the next iteration until an acceptable degree of convergence is achieved. An example sequence of mechanisms is shown below; however it is unlikely that a model would be developed in this form and the mechanisms may
need to be positioned at different places in the hierarchy, depending on their relative sensitivities.

1.9.6 Available evidence suggests that the sensitivity of trip frequency is very much smaller than for the other mechanisms, and it is justifiable to always treat this choice as first in the hierarchy. That argument and the discussion set out below leads to the following practical hierarchies. However, if the model represents slow modes, there is less need to make the trip frequency stage responsive to local travel costs. The hierarchy is therefore likely to be one of the following (excluding time of day choice responses):

```
1) Trip frequency
   2) Mode split
   3) Distribution
   4) Assignment
```

least sensitive

most sensitive

1.9.7 **Route choice** is invariably modelled as the most sensitive response below the other demand mechanisms. In equilibrium, there is little or no difference in utility or generalised cost between the routes which are likely to be used for any given origin-to-destination journey; if costs change, a new equilibrium involving some change of route between the minimum cost alternatives is quickly established. Thus the route assignment part of the modelling can be considered separately, though of course demand and assignment must be treated iteratively to obtain an equilibrium solution (i.e. the Wardrop equilibrium).

1.9.8 Where **macro time period choice** is thought applicable (where there is expected to be differential changes in the costs or capacity in different time-periods) evidence suggests that the position of this mechanism is at a similar level to main mode choice for most purposes.

1.9.9 Where **micro time period choice** is being modelled, this should be placed above assignment but otherwise at the lowest level (most sensitive) of the hierarchy.

1.9.10 The main decision centres on the relative positions of distribution (destination choice) and mode split (choice).

1.9.11 The distribution model should precede the mode split if the distributional parameter (lambda) is smaller than that for mode split, and mode split preceding distribution if the opposite is true. If the two are similar, within the uncertainties that are likely to be relatively large, there is a case for simultaneous calculation using a single sensitivity (lambda) value for each traveller segment.

1.9.12 However, if for example, destination choice has a larger sensitivity parameter than mode choice, yet mode split was mistakenly calculated after distribution, an increase in the cost of, say, car travel might increase the mean (composite) cost of travel on which distribution is based. In extreme cases that could shorten all trips to such an extent that not only is car use decreased, as required, but also travel on the competing modes, which is implausible. (Such an effect is often described as a perverse cross-elasticity.)

1.9.13 In the multinomial logit formulation described in Appendix 2, a given level of the main choice hierarchy may split the choice into separate sub-levels. Such “nesting” is most often met in mode choice, where the split between competing public transport modes is made at a lower level than the primary split between car
and public transport (and possibly the slow modes also). This avoids the “red bus/blue bus problem” where separating the bus mode into two without nesting apparently affects the predicted total bus share. Nested logit can be applied to other demand mechanisms; however, as for example in a time-period split between broad peak and off-peak periods, and then subsequently between narrower periods within the peak. Nesting can also use high-level large zones in distribution, and subsequently a further distribution within the larger zone to finer zones, but this is likely to be relevant only to more specialised models than the ones addressed by this advice.

1.9.14 Where sufficient local data of suitable quality exist, and the skilled resources required are available, lambda values should be estimated (calibrated) from that data and the hierarchy selected so that the less sensitive of the two responses is positioned above the more sensitive.

1.9.15 Where suitable data or resources are not available to permit parameter values to be estimated, then it may be possible to select the hierarchy on the basis of local knowledge about the relative sensitivities of destination and modal choice (from existing local models, for example, where the lambda values have been estimated and the adopted choice hierarchy has been justified).

1.9.16 If there is insufficient local data or resources for estimation, and no suitable local model from which the parameters can be transferred, it will be necessary to consider the illustrative values provided from Section 1.11 as the basis for the choice hierarchy. All the models used to derive the parameter values quoted in Section 1.11 were rigorously calibrated against local data and all showed that main mode choice was less sensitive than destination choice. In the absence of any information to the contrary, this is therefore the hierarchy which should be adopted.

1.9.17 Whichever approach is adopted, it is essential to apply “realism testing” to a broad range of transport changes (see VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4)) to ensure that the model responds rationally and with acceptable elasticities.

Composite Costs

1.9.18 Unless mechanisms at two adjacent levels in the hierarchy are calculated simultaneously (which is likely to apply only to the mode and destination choice stages), it is necessary to formulate a composite cost or utility across the most sensitive (or lower) choice to use as an “average” in the least sensitive (or higher) choice calculation. This cannot be an arithmetic average, since it is clear that where a choice has high costs and is unlikely to be chosen it should be given little weight in the composite cost. Various forms of composite cost have been used in the past – see for example Senior and Williams (1977) – but the following, known as a logsum, is the appropriate formulation where logit models are used to determine the choices in an absolute choice model. The general formulation of the composite cost to reflect the costs faced by travellers given their previous choices lower in the hierarchy is as follows:

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

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

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

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

\( \lambda_y \) is the choice sensitivity parameter for choice stage \( y \).

1.9.19 For example, if mode split is less sensitive than (above) distribution in the hierarchy, then the composite cost of car travel from zone \( i \) is obtained from the logsum of travel by car (choice \( y \)) to all the possible destination zones (choice \( x \)). There will be fewer trips to destinations with high travel costs, but the exponential weighting means that they will contribute little to the total composite cost. At the lowest level, the absolute composite costs should also be weighted by the zonal attractiveness. If distribution is less sensitive than (above) mode split, then the composite costs used for distribution will be the logsum costs across the available modes for each origin-destination pair.

1.9.20 As trip frequency is invariably the least sensitive response, in that case for each origin the summation in the composite cost must be across all destinations, modes and time periods if those choices that are being represented in the model. If time-period choice is included, then the composite costs should include trip-weighted sums across the time periods.

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

\[
\Delta G_{\text{comp}}^{y-1} = -\frac{1}{\lambda_y} \ln \left( \sum_i \frac{T_x^y}{T_{\text{tot}}^y} \exp(-\lambda_y \Delta G_x^y) \right)
\]

Where:

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

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

1.9.22 If the same lambda value applies to both distribution and mode choice calculations, then both sequences of calculation, distribution-modal split or modal split-distribution, are mathematically equivalent to simultaneous calculation, where the logit split would be across all possible combinations of destination and mode, and it is not necessary to calculate composite costs from one choice set when considering the other choice set. However, if there were other responses above these two in the hierarchy, say trip frequency or time-of-day choice, then the logsum of the mode-choice and distribution choices will still need to be calculated to give the correct 'costs' for these higher level responses.

1.10 Local Calibration of Demand Models

1.10.1 As explained in paragraphs 1.9.14 to 1.9.16, there are three alternative approaches to choosing the parameter values that control the travel responses:
• use local data to calibrate parameter values;
• use parameter values obtained from other local models;
• use “illustrative” parameter values based on general modelling experience.

1.10.2 This section provides advice on the first of these alternatives. If, after considering the issues below, it is impractical to calibrate local values, then consideration should be given either to importing values from existing locally calibrated models or to using the illustrative values given Section 1.11.

Using Local Data to Calibrate Parameter Values

1.10.3 Calibration of the parameters in the demand response mechanisms can be a very time-consuming and expensive phase, and for smaller schemes the alternatives of using other local model parameters and/or standard illustrative values should be considered.

1.10.4 Calibration of the different demand responses varies in both the amount of data required and the ease of the calibration itself. In some cases the surveys used for calibration of the model can be used for other purposes (such as eliciting behaviour in response to tolling or parking restraint), so making the necessary survey work more cost-efficient. Demand model calibration complements the equivalent estimation in the assignment phase of the correct ratio between time and money costs in the assignment of traffic to the network.

Mode Choice

1.10.5 The practicality of local calibration of the mode choice mechanism depends on the quality of the data available and the ability to distinguish between public transport travellers with and without a car available, since these two categories of traveller will have very different choice-sets. It will also depend on the extent to which choice of mode is exercised by car available travellers. These data, coupled with estimates of times and costs by the various modes using standard values of time, can enable mode-choice parameters to be estimated.

1.10.6 The quality of data about trip purpose will determine how disaggregate a model can be estimated. That is likely to be most problematic for public transport data. Whichever approach is used, a check should still be made that the model reproduces the modal-split correctly for the important movements. Similar considerations apply when using parameters from other local studies such as a regional multi-modal study.

1.10.7 Relatively simple mode-choice calibration can be undertaken where the number of car trips and public transport trips for which a car is available are known for a large number of important flows, together with estimates of times and costs by the various modes and appropriate values of time. This has been a common approach by the multi-modal studies where detailed transport modelling, as opposed to strategic models, has been required. It is important to distinguish between travellers with and without a car available for their journey. This data can only be obtained by personal survey, either in the household or on public transport, though even then the travellers’ claim to have a car available often ignores competition for the car within the household. As always, the quality of data on trip purpose will determine the disaggregation possible.

1.10.8 An alternative mechanism would be to use Stated Preference (SP) surveys to estimate the important determinants of mode-choice. SP survey work provides a
useful approach when considering the introduction of states that are not present in the current situation, such as tolling or parking restraints, or where new modes (to the area) are being considered. In these cases the surveys are more likely to be geared towards estimating the relative impact of items that make up the definition of generalised cost than to provide evidence of the parameters controlling the mode-choice. Specialist advice should be used to establish the mode specific constants of the relative attractiveness of the new modes. These issues will be dealt with in more detail by public transport modelling advice soon to be released as a series of TAG units. Where household surveys are being undertaken to collect other data for modelling purposes, it may be possible to attach an SP study at marginal cost. The software available to calibrate models using SP (and other data) can handle a variety of forms of hierarchy of travel responses. The output statistics can help to shed light on the most likely choice structure. This is particularly important for mode-choice, where nested choice structures are often required but this will be a rare requirement for the bulk of road schemes. Thus, one can estimate models where a traveller chooses from all available modes at one level or chooses between say car travel and public transport and then makes a subsequent choice between bus and rail or any other such mode if the circumstances require such a detailed modelling of the demand for public transport.

1.10.9 One of the characteristics of calibration using SP methods is that the results tend only to give the relative importance of different modes and their attributes, and may not reproduce current market shares, without using a “scaling factor”. To do this, observed data on the actual choices made are normally required: this is known as the Revealed Preference (RP). That observed data are more complex than the clearer-cut comparisons of Stated Preference data making it more difficult to identify the relationships between costs and choice.

1.10.10 Calibration to reproduce the cross-sectional details of the base case is less of an issue when using incremental or pivot-point modelling (the recommended approach), since the observed OD matrices are used directly and only changes from the base or pivoted reference case are to be forecast. In general, Stated Preference methods cannot be relied on for estimating the scales of the responses accurately, and they tend to overestimate the response to change.

1.10.11 Whatever approach is used, a check should still be made that the model reproduces the modal-split correctly for all major flows in the base year in the face of no cost changes, especially when using parameters from other local studies such as a regional Multi-Modal study. In absolute models, adjustment (K) factors may be needed to achieve this. These usually take the form of constants added to the generalised costs to account for the inherent attractiveness of the different modes in the absence of differences in costs. If, for example, a smaller fraction of travellers is observed to use public transport than the estimated difference in generalised cost, and the selected sensitivity (lambda) parameter value (see Section 1.4), suggests, then the addition of a public-transport-specific constant to the public transport cost can adjust the balance to the observed modal split. The constants may vary according to the type of travel modelled, i.e. by purpose, or by region, or by destination.

1.10.12 For the type of scheme assessment considered in this advice, however, it is desirable to keep the number of adjustments of this type to a minimum, even if this means that the modelled base-case departs from the observations in some respects. A great advantage of incremental models is that this type of fitting is
avoided, since the model merely predicts the relative changes from the observed base, with all its cross-sectional and category detail, and in a multinomial logit model any mode-specific constants have no effect on the predicted changes. Even so, it is important to ensure that the incremental model does indeed predict no change from the base for no change in costs.

**Distribution**

1.10.13 Calibration of a trip distribution model can be more difficult and to fit the observed data sufficiently well the calibration may need to be done separately for different sectors. Even if this is done, the estimated parameters are not necessarily the correct values for estimating the responses to changes in costs, since the observed trip patterns occur for a range of historical and land-use reasons not necessarily closely linked to travel costs. To provide a satisfactory local calibration the data available must be of sufficient quality and quantity. This will require that either the range of trip lengths in the observed part of the trip matrix on which the distribution parameter(s) are being calibrated is representative of the whole trip matrix or account is taken of the variations in sampling rate over the full range of trips. The aim is to ensure that the synthesised trip length distribution is correctly representative of the full range of trips.

1.10.14 In practice the main approach to calibrating distribution models is to use observed data.

1.10.15 Given observed or part-observed/part-synthesised trip matrices, it is possible to estimate parameter values based on the present-day distribution of trips quite easily, provided a simple form of distribution model formulation is chosen. Single parameter models (i.e. the lambda of a logit model or the elasticity of a power function) are calibrated by adjusting the parameter iteratively for each calibration area until the average cost (for an exponential or logit function) or the weighted average of the logarithmic costs (for a power function) equals that observed. The theoretical background to the method of calibrating a demand function with a single parameter is available in standard texts such as that by Ortuzar and Willumsen (2001), and in the references for matrix manipulation programs in such transportation modelling suites as Cube (TRIPS), SATURN and EMME/2. A similar approach can be adopted whether a singly or doubly constrained model form is assumed. In practice, the simple demand function may not fit the trip pattern well, and the expected trip-length distribution should be checked against the observed distribution, even where the mean values are well estimated. In addition, the observed trip pattern is likely to contain particular movements that are not properly represented by the modelled function, and additional constants will be needed to reproduce the observed base. As with mode choice use of an incremental model rather than an absolute one avoids most of this complication.

1.10.16 The output values of the sensitivity parameters are then assumed to control the response of travellers’ trip distribution to changes in travel costs.

**Trip Frequency**

1.10.17 If a trip frequency response is included in a variable demand model, the parameters which govern the response to cost changes will be dependent on what other responses are in the model. The ‘true’ travel cost will be that signified by the composite cost derived from responses lower in the hierarchy: i.e. costs and hence “accessibility” will depend upon the trip distribution and mode-split mechanisms (see Section 1.9). To disentangle these complex interactions
unambiguously requires data on responses to large changes in travel costs, and there have been no such studies in this country, although a study of the consequences of completing the Manchester Motorway M60 Box is underway.

1.10.18 In most cases any trip frequency responses to changes in travel costs will be quite small (especially if trips by the slow modes are included).

Time Period Choice

1.10.19 Advice on calibrating models concerning time-period modelling is likely to be modified by the on-going research into better techniques for modelling choice between time-periods, whatever their length. SP techniques can be used to estimate travellers’ broad time-period switching in response to travel cost changes, and this may be especially appropriate if one of the policy options relates to encouraging time-period switching. Otherwise, at present, the analyst should follow the advice given in Section 1.11.

General

1.10.20 Calibration of many of the travel responses for specific situations will depend to some extent on SP work, and it will normally be possible to cast the survey methodology to consider more than one demand response, making the use of such techniques more cost-efficient. However, for the general assessments at which this advice is aimed it is likely that such surveys will be not be warranted. Where such sources are not available, and in general where an incremental model is used, the parameter values should be taken from relevant local modelling work or based on the illustrative values of Section 1.11.

1.11 Illustrative Parameter Values

1.11.1 As explained in paragraph 1.9.14, wherever possible, each variable demand response should be calibrated on local data, to reflect the local strengths of the choice mechanisms. Where calibration is not possible, parameter values may be derived from existing, locally calibrated, models of the area, or they may be based on the illustrative values provided in this section. In general, use of values from existing, locally calibrated, models should be considered before adopting the illustrative values given below.

1.11.2 This section suggests illustrative values obtained from a review of a number of UK transport models for situations and responses where either local calibration or derivation from existing models and/or local knowledge is not possible. The values should be compared with local values or modified in the light of local circumstances and accompanied by realism tests. The illustrative values can provide an acceptable approach to including variable demand modelling in transport appraisals where it is deemed too difficult to establish local values.

1.11.3 No matter how carefully the model has been constructed and coded, if the parameter values it contains are wrong the appraisal will be wrong. The base year demand matrix and travel costs will be based on measured local data. It should present a reasonably accurate account of the prevailing situation, but the mechanisms which model travellers’ behaviour, and the choices they make, must be calibrated against appropriate evidence of that behaviour. That should ideally include evidence of how choices change as costs change rather than the observed cross-sectional variations.
1.11.4 Although locally calibrated parameters should be used wherever possible, some of the sensitivity parameters may have to be obtained from generalisations of other modelling work. The illustrative values given in the tables below are values obtained for transport models which have been developed by means of rigorous estimation processes. They are not necessarily appropriate for all circumstances, and need to be assessed and modified where necessary but, in the absence of a specific local calibration, they may be the best available estimates. Whatever values are selected, whether from local knowledge or based on the illustrative values, it is essential to conduct “realism” tests (see VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4)) to ensure that the actual behaviour of the model against variation in travel times and costs accords with experience.

1.11.5 The illustrative values have been obtained from a review of transport models which have been developed, for areas in the UK, by means of rigorous estimation processes. The parameter values for main mode and destination choice have been derived from “Multi-Modal Model Data Provision”, by MVA, dated June 2005. Information was also obtained from Rand Europe on the PRISM model of the West Midlands, but the parameter values in this model are not easily applicable in the models recommended in this guidance due to the fact that the generalised cost formulations and coefficients were determined from local data and do not therefore accord with the advice in Units 3.10.2 and 3.5.6 (see “The PRISM Model: Evidence on Model Hierarchy and Parameter Values” by Charlene Rohr of Rand Europe, dated 3 May 2005). Macro-time period choice parameter values are not provided because the only advice available at this time, from research conducted for the Department, is that these parameter values should be broadly similar to those for main mode choice. The trip frequency parameter values were derived in part from “User-friendly multi-stage modelling advice, Phase 2: Modelling parameters, calibration and validation”, by TRL, dated November 2001 – this report has now been largely superseded by the MVA report but may still offer some useful insights. These illustrative parameter values represent the current “best estimates” but are inevitably uncertain.

1.11.6 The Department is keen to obtain further evidence on illustrative values and would welcome information on parameter values from models that have been rigorously calibrated.

1.11.7 All the illustrative parameter values provided in this section relate to generalised costs in minutes, as derived using the Department’s standard formulations of generalised cost (see Unit 3.10.2) and standard values of time (see Unit 3.5.6).

1.11.8 If other units or some functional form other than logit were to be used, it is always possible to ensure that the model sensitivity, measured for the local circumstances, is equivalent to that of a logit formulation using the default values as follows:

- estimate “typical” values of the relevant generalised costs;
- apply a modest change to a time or cost component;
- calculate the appropriate change in demand using both the logit formulation and the functional form of the model; and
- adjust the parameters of the model mechanism to obtain a similar change in demand to that given by the logit form.
Trip Frequency

1.11.9 If slow modes are represented in the model, the overall trip rates from each zone can be considered to be constant, and not responsive to changes in travel costs. If slow modes are omitted, then a small sensitivity value can be assumed for the more optional or elastic trip purposes. As VDM Scope of the Model (TAG Unit 3.10.2) notes, there should be segmentation by trip purpose as a minimum, and some purpose categories, such as work and employer's business, should be regarded as inelastic. Note that here we are concerned solely with the response of the total number of trips from each zone changing as travel costs change: dependence on the demographics and land use of the zone is a different issue. If the demand model includes slow modes, then trip rates can be assumed not to be responsive to changes in travel cost.

1.11.10 Some models include trip frequency but the evidence on the appropriate sensitivity parameter value is limited and as a result we do not currently have any suitable recommended values.

Destination Choice

1.11.11 Illustrative destination choice parameter values are shown in the table below. On the presumption that destination choice will follow main mode choice in the model hierarchy (see Section 1.9), parameter values are provided separately for car trips and public transport trips. See Appendix 4 for the model formulation to which these parameter values apply.

1.11.12 The parameter values for public transport trip distribution will only be required in fully-specified multi-modal models – that is, they will not usually be required for a model designed solely for the appraisal of highway schemes.

<table>
<thead>
<tr>
<th>TRIP PURPOSE AND MODE</th>
<th>CAR</th>
<th>MINIMUM</th>
<th>MEDIAN</th>
<th>MAXIMUM</th>
<th>SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home-based work</td>
<td>0.054</td>
<td>0.065</td>
<td>0.113</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Home-based employers business</td>
<td>0.038</td>
<td>0.067</td>
<td>0.106</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Home-based other</td>
<td>0.074</td>
<td>0.090</td>
<td>0.160</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Non-home-based employers business</td>
<td>0.069</td>
<td>0.081</td>
<td>0.107</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Non-home-based other</td>
<td>0.073</td>
<td>0.077</td>
<td>0.105</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRIP PURPOSE AND MODE</th>
<th>PUBLIC TRANSPORT</th>
<th>MINIMUM</th>
<th>MEDIAN</th>
<th>MAXIMUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home-based work</td>
<td>0.023</td>
<td>0.033</td>
<td>0.043</td>
<td>7</td>
</tr>
<tr>
<td>Home-based employers business</td>
<td>0.030</td>
<td>0.036</td>
<td>0.044</td>
<td>4</td>
</tr>
<tr>
<td>Home-based other</td>
<td>0.033</td>
<td>0.036</td>
<td>0.062</td>
<td>4</td>
</tr>
<tr>
<td>Non-home-based employers business</td>
<td>0.038</td>
<td>0.042</td>
<td>0.045</td>
<td>2</td>
</tr>
</tbody>
</table>
1.11.13 The parameter values shown above for public transport trips strictly apply to trips from car-available households. They may also be used for trips from non-car available households without significant loss of accuracy.

1.11.14 It is difficult to generalise about when low values should be used and when high values would be more appropriate. (Note that the ranges shown above are not targets within which parameter values must lie; they are simply the minimum and maximum values from the sample available.) The MVA Report provides parameter values for a variety of models, of London, a large region in Scotland, and a number of smaller urban areas. This report should be consulted in deducing parameter values for models of more complex areas where the use of the single mean or median values may be considered too simplistic. The TRL Report may also provide some guidance on variations in parameters under different circumstances, although it should be borne in mind that this report contains limited information about the extent to which model parameters were derived by rigorous calibration procedures and validated by realism tests.

**Main Mode Choice**

1.11.15 Main mode choice (that is, the choice between car and public transport) parameters are specified as scaling parameters –see Appendix 4 for further details. These scaling parameters show the sensitivity of main mode choice relative to destination choice. Thus, to be consistent with the default hierarchy recommended in Section 1.9, of destination choice following main mode choice, the main mode choice scaling parameters are all less than or equal to one, as shown in the table below.

<table>
<thead>
<tr>
<th>TRIP PURPOSE</th>
<th>MINIMUM</th>
<th>MEDIAN</th>
<th>MAXIMUM</th>
<th>SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home-based work</td>
<td>0.50</td>
<td>0.68</td>
<td>0.83</td>
<td>6</td>
</tr>
<tr>
<td>Home-based employers business</td>
<td>0.26</td>
<td>0.45</td>
<td>0.65</td>
<td>2</td>
</tr>
<tr>
<td>Home-based other</td>
<td>0.27</td>
<td>0.53</td>
<td>1.00</td>
<td>4</td>
</tr>
<tr>
<td>Non-home-based employers business</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>1</td>
</tr>
<tr>
<td>Non-home-based other</td>
<td>0.62</td>
<td>0.81</td>
<td>1.00</td>
<td>2</td>
</tr>
</tbody>
</table>

1.11.16 Again, it is difficult to generalise about when low values should be used and when high values would be more appropriate. (Note that the ranges shown above are not targets within which parameter values must lie; they are simply the minimum and maximum values from the sample available.) The MVA Report should be consulted in deducing parameter values for models of more complex areas where the use of the single mean or median values may be considered too simplistic. The TRL Report may again be of some use, noting the caveat in paragraph 1.11.13.

**Time of Day Choice**
1.11.17 Less evidence is available about the sensitivity of the macro-time period choice than either main mode or destination choice. Recent research conducted for the Department suggests that the sensitivity of the choice between relatively long time periods, such as three hours or so, should be about the same as that of main mode choice. The research also suggests that, as the time periods are reduced, the sensitivity increases. Thus, when long time periods, of the order of three hours, are being modelled, macro-time period choice should be positioned either just before or just after main mode choice, with parameter values similar in magnitude to the main mode choice parameter values. Peak spreading, or micro-time period choice that will include a schedule disutility term, if included in the model, should be positioned after destination choice.

Testing

1.11.18 Whatever values are selected, whether from local knowledge or based on the illustrative values, it is essential to conduct “realism” tests (see VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4)) to ensure that the actual behaviour of the model against variation in travel times and costs accords with experience.

2 Further Information

The following documents provide information that follows on directly from the key topics covered in this TAG Unit.

<table>
<thead>
<tr>
<th>For information on:</th>
<th>See:</th>
<th>Link:</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Multi-modal models</td>
<td>TAG Unit Introduction to modelling</td>
<td>TAG Unit 3.1.1</td>
</tr>
<tr>
<td>An overview of modelling issues</td>
<td>Summary Advice on Modelling</td>
<td>TAG Unit 2.4</td>
</tr>
<tr>
<td>An overview of variable demand modelling</td>
<td>Variable Demand Modelling</td>
<td>TAG Unit 2.8</td>
</tr>
<tr>
<td>Detailed advice on transport modelling</td>
<td>Modelling</td>
<td>TAG Unit 3.1</td>
</tr>
</tbody>
</table>

3 References

DETR (July 1998) A New Deal for Transport: Better for Everyone

DfT (2003) Transport Economics Note (TEN)


4 Document Provenance

This Transport Analysis Guidance (TAG) Unit reflects the consultation comments received on the Key Processes Stage of the draft Variable Demand Modelling Advice produced by TRL in June 2003.

Technical queries and comments on this TAG Unit should be referred to:

Integrated Transport Economics and Appraisal (ITEA) Division
Department for Transport
Zone 3/06 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
1 Appendix 1 Elasticity Models

1.1 Functional Forms and Parameter Values of Elasticity Models

1.1.1 Where an elasticity model is appropriate the functional form and parameter values need to be selected. The simplest functional form – an ‘own-cost’ elasticity model – assumes that changes in the demand for travel between two points can be adequately estimated purely by a function of the change in costs between the two places.

1.1.2 ‘Own-cost’ elasticity models assume that the demand for travel between two points is purely a function of the change in costs on that mode between the two places. The strength of that function can vary for different trip lengths.

1.1.3 However, if costs do indeed change, the relationship between change in demand and change in costs can take a number of forms, but only exponential and power formulations, and a composite of the two forms (called a Tanner function), will be considered here. With a power formulation the proportionate change in trips is related to the proportionate change in costs, as shown in the equation below. With an exponential formulation, on the other hand, the proportionate change in trips is a function of the absolute change in costs. Other, more complex, relationships are described in VDM Appendices (TAG Unit 3.10.5).

1.1.4 For most applications the Power relationship below which is a simple own cost elasticity model due to its constant elasticity value is recommended:

\[ T_{ij} = g_{ij} \times \frac{\Delta T_{ij}}{0T_{ij}} \times \left( \frac{G_{ij}}{0G_{ij}} \right)^A \]

Where

1. \( T_{ij} \) is the forecast number of trips between zones i and j
2. \( G_{ij} \) is the forecast disutility or generalised cost
3. \( g_{ij} \) is the forecast growth rate relative to an earlier or base year
4. \( \Delta T_{ij} \) is the number of trips in the earlier or base year
5. \( \Delta G_{ij} \) is the disutility or generalised cost in the earlier or base year
6. \( A \) is the elasticity, which should be negative and is the same for all trips in the same user class.

1.1.5 This is a well-behaved formulation that is simple to apply, and is base independent: that is, it is guaranteed to give the same results if forecasts are produced from one year to another directly or via an intermediate year. It assumes that a proportionate change in trips is related to a proportionate change in costs. As the parameter A is constant the implied elasticity is the same for all lengths of trip within the same user class (i.e. it is “distance neutral”).

1.1.6 This formulation can easily be set up using the matrix manipulation facilities available in modern transportation modelling suites, or in some modelling suites combined directly with the assignment process. The facility is also available within the DIADEM modelling framework.

1.1.7 An alternative formulation is the “Exponential” relationship. In this case the effective elasticity increases with increasing trip cost, and hence for study areas where there are a wide variety of trip lengths the effective elasticities could vary markedly. Thus the exponential approach should only be considered in the case
where the study area is small and urban, and where a general elasticity approach is being combined with a logit choice mechanism to jointly represent the individual demand mechanisms. Most logit mechanisms in the variable demand hierarchy share this exponential function characteristic, but some have a more benign effect since trip re-distribution, for example, can be constrained to avoid changing the overall number of trips. In that case trip re-distribution in the face of changing travel costs effectively adjusts the proportions of trips of different length to compensate for the changes. Similarly mode-choice models estimate shares rather than absolute numbers.

1.1.8 The “Exponential” formulation assumes that the proportional change in trips is a function of the absolute change in costs:-

\[ T_{ij} = g_{ij} \cdot 0T_{ij} \cdot \exp \{B^*(G_{ij} - 0G_{ij})\} \]

Where the elasticity of demand with respect to generalised cost \( U \) is \( B^*G_{ij} \) with \( B \) negative. This is an own cost elasticity which is not simple due to the elasticity not being constant.

1.1.9 These equations can be used in two ways. They can be based or pivoted on a base year, where items 4 and 5 in paragraph 1.1.4 (base trips and costs) are known from empirical data, and the product \( g_{ij} \cdot 0T_{ij} \) represents what is referred to as the Reference Case Matrix, see VDM Scope of the Model (TAG Unit 3.10.2). Alternatively, the equations can be formulated to compare costs between alternatives for the same year, where the ‘earlier’ year costs and trips are derived from the other scenario. More details on how these equations are to be used are given in VDM Appendices (TAG Unit 3.10.5). This should be read in conjunction with the guidance given with the software employed to undertake the transport modelling (see also VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4).

1.1.10 Both these formulations are closely incremental in nature, allowing the number of trips in the system to change up or down. This is in contrast to most of the individual demand-response mechanisms that are set out as share formulations where the total number of trips is fixed (say by TEMPRO all-mode forecasts) and merely allocated to one choice or another (e.g. to different modes or destinations).

1.1.11 Whilst the formulation is relatively easy to set up, there are some issues that must be dealt with when considering the parameter values to assign to a demand segment.

1.1.12 ‘Own cost’ elastic assignment modelling in congested Urban Areas should be undertaken at a peak hour unless there are significant variations in demand, or congestions levels are high in which case the modelling should cover linked time-periods, sub-divided into time slices and sub-periods.

1.1.13 The size of the parameter value will reflect the number of responses that the elasticity formulation is acting as proxy for. For instance, if the elasticity formulation is taking the place of all responses then it will be larger than if it is acting as proxy for only one or two responses. The table below sets out the recommended starting values for the elasticity of demand with respect to journey time.
Table 1 Derived long-term journey time elasticites for different uses (derived from 1997 DMRB Vol 12 Section 2 Part 2 Table C2 and its para C13)

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Time elasticity – High modal competition</th>
<th>Time elasticity – Low modal competition</th>
<th>Time elasticity – High modal competition including time-switching</th>
<th>Time elasticity – Low modal competition including time switching</th>
<th>Trip frequency effect (only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HB Work</td>
<td>-0.22</td>
<td>-0.14</td>
<td>-0.48</td>
<td>-0.30</td>
<td>-0.04</td>
</tr>
<tr>
<td>Employer's Business</td>
<td>-0.60</td>
<td>-0.35</td>
<td>-0.96</td>
<td>-0.55</td>
<td>-0.15</td>
</tr>
<tr>
<td>Essential Other</td>
<td>-0.47</td>
<td>-0.26</td>
<td>-0.65</td>
<td>-0.36</td>
<td>-0.12</td>
</tr>
<tr>
<td>Discretionary Other</td>
<td>-0.35</td>
<td>-0.20</td>
<td>-0.50</td>
<td>-0.28</td>
<td>-0.10</td>
</tr>
</tbody>
</table>

Note:- The values are based on car journey time elasticities - equivalent generalised cost elasticities would be about 10-50% higher, depending on the value of time and average network speed. Short-term elasticities are 28%, 8% & 5% less for HBW, Employer’s Business and Discretionary purposes.

1.1.14 Equivalent journey cost elasticities can be calculated from the above table by dividing the elasticities by the proportion of the total generalised cost made up of journey time. For instance, if a model assigns on the basis of generalised cost \((t+kd)\), the appropriate time elasticity must be multiplied by a factor \((1+kv)\) where \(v\) is the average speed in the base year in kilometres per minute if journey time \(t\) is in minutes and distance \(d\) is in kilometres. Values of Time and Operating Costs (TAG Unit 3.5.6), can be used to provide the relevant factors for given combinations of purpose, forecast period and congestion level if standard values of time are being used. In practice, the generalised cost elasticities will be between 10% and 50% higher than the values shown in the table above with values at the lower end for Employer’s Business trips, urban areas and later forecast years.

1.1.15 If an exponential formulation is used then the above values will need to be subsequently divided by the mean generalised cost to give the equivalent parameter value.

1.1.16 The estimated generalised cost elasticities (and associated parameter values if an exponential model is used) may need to be adjusted so that the fuel cost elasticity estimate from the model reflects the national overall estimate of -0.3 (see Variable Demand Modelling – Convergence Realism and Sensitivity (TAG Unit 3.10.4)).

1.1.17 Where possible, the trips should be split by trip purpose (and any other known major variation such as willingness to pay or movement type). If this is not possible, for instance where only a single private vehicle user class is available, then they should be split by time-period. VDM Appendices (TAG Unit 3.10.5) shows how, by using the national car driver journey purpose mix for each period of the day (from NTS), the above elasticities can be converted to elasticities for all trips by time period. If local data suggests
a significantly different mix of purposes by time-period, then the local proportions can be substituted for the national ones.

1.1.18 Care should be taken when dealing with intra-zonal trips. Because most assignment models do not output intra-zonal costs (since intra-zonal trips are not assigned) there may be problems with using incremental models where there are observed intra-zonal trips in the base year trip matrix. It is desirable that robust estimates of intra-zonal costs should be estimated in these instances. These could be some function of the inter-zonal costs, for example half the minimum inter-zonal costs for that zone. Further advice is given in section VDM Scope of the Model (TAG Unit 3.10.2). Power function elasticity models will be particularly sensitive to very small intra-zonal costs, and this is one reason why they should be avoided when this is the case.

2 Appendix 2 Functional Forms for VDM

2.1 Detailed Advice on Functional Forms of VDM

2.1.1 There are various mathematical functions that can provide a suitable relationship between travel demand and the disutility or generalised cost of a trip. These all offer broadly similar behaviour, but have subtly different mathematical properties. Section 1.1 of Appendix 1 discussed the equivalent subtle differences of power functions and exponential functions for own cost elasticity models, both of which can provide a convenient downward sloping relationship as shown in Figure 1 in Section 1.3 and the parameters can be adjusted to give an elasticity of any required strength.

2.1.2 Most of the mechanisms required in a variable demand model allocate trips between a set of choices, giving rise to the slightly more complex relationship of Figure 2 in Section 1.3. Here again a range of mathematical functions, most based on powers or exponentials, or both, can recreate the desired relationship. VDM Appendices (TAG Unit 3.10.5) discusses the detailed functional forms of VDM models and the derivation of many of the forms, while for example Ortuzar and Willumsen (2001) provides even more detail.

2.1.3 The multinomial logit choice function is one of a number of possible formulations of “random utility” models in which a random component is added to the deterministic utility of choice p as follows:

\[ U_p = \sum \beta_n x_n + \epsilon_p \]

Where the utility (or disutility) \( U_p \) of choice p is calculated as the sum of:

- the generalised cost \( G_p = \sum \beta_n x_n \) of choice p, with the set of cost components \( x_n \) weighted by coefficients \( \beta_n \), summed over all components relevant to choice p as explained in VDM Scope of the Model (TAG Unit 3.10.2). (For example, if G is measured in units of time, x might be the money cost of a journey and \( \beta \) the inverse of Value of Time), and

- a random component \( \epsilon_p \) used to represent variations in the situation or tastes of individual travellers, or modelling errors, or unobserved elements of the alternative choices. (In the most general case this random component can depend on both the traveller and on the choice alternative).
A choice-specific calibration constant (i.e. constant specific to the mode or areas used in calibration) could be added to the generalised cost function to adjust the calculated choice to the observed value.

A random utility model assumes that the alternative with the maximum utility (or minimum disutility) is chosen, so that a probabilistic model results.

2.1.4 The assumed statistical distribution of the error terms or residuals $\varepsilon_p$ determines the exact mathematical formulation. For example, assuming one particular distribution for the random components, that they are Independent and Identically Distributed (IID) extreme value variables, leads to the widely-used multinomial logit model:

$$T_p = \frac{T_{tot} \exp(-\lambda U_p)}{\sum_q \exp(-\lambda U_q)}$$

2.1.5 Conventionally, different Greek symbols have been used for this sensitivity parameter $\lambda$ according to the mechanism it is applied to (for example $\alpha$ for trip frequency, and $\beta$ for mode split), but usage varies and here we will use the $\lambda$ formulation for all applications, distinguishing between the different mechanisms of variable demand by a subscript.

2.1.6 The elasticity of demand in this formulation is $-\lambda U_p (1-T_p/T_{tot})$, so that the elasticity scales with $U$, and tends to be larger for longer trips for a given value of $\lambda$ and larger for choices with a small share of the total. If those implications are inappropriate for the model area a different functional form or a series of calibration areas should be used to produce a model with suitable implications.

2.1.7 Other forms such as the power function or the Tanner function, which have been described in relation to ‘own cost’ elasticity models, or formulations assuming a normal distribution of error terms (Probit models) are possible but little used in modelling for scheme appraisal. However, different formulations of the logit model which have less restrictive statistical assumptions are also possible and are being investigated in current research (See VDM Appendices (TAG Unit 3.10.5) for more details).

2.1.8 The remainder of this Advice focuses on hierarchical and multinomial logit. The logit formulation (and its nested variants) can be used, in slightly different formulations, for each of the mechanisms of the variable demand model. These are discussed in turn below.

Trip Generation and Frequency

2.1.9 In the trip generation stage the numbers of trips of different kinds made from each zone can be predicted as a function of the numbers of different types of households and inhabitants in the zone. For the purposes of this advice, however, we are interested primarily in how the externally estimated demand from each zone might respond if travel costs change, i.e. trip frequency change. The growth factors derived for fixed OD matrices usually assume that travel costs would be unchanged from the base situation. If so they are known as a reference case and are a suitable starting point for variable demand modelling. If as part of that modelling trip generation is to be made responsive to changes in travel cost (see Section 1.4) the requirement is to make trips in any category elastic to changes in cost and thus model trip frequency.

2.1.10 The elasticity function could be a power function or an exponential function as described in Section 5.1. However, if logit is used for the other mechanisms, a similar exponential function is generally used to adjust trip frequency.
case, the function operates simply as an elasticity with respect to disutility or generalised cost, since the relevant choice is to travel or not to travel, and the disutility of not travelling remains constant:

\[ T_i = O_i \exp(-\lambda_{freq} G_{icomp})/\exp(-\lambda_{freq} 0 G_{icomp}) \]

Where \( T_i \) is the number of trips from origin zone \( i \), prefix 0 denotes the base values, \( \lambda_{freq} \) is the choice sensitivity parameter for the trip frequency stage and the generalised cost \( G_{icomp} \) is the composite cost or disutility calculated across the trip origins.

**Composite Costs**

2.1.11 In the above and equivalent equations the disutility (or generalised cost) \( G_{icomp} \) must be calculated to represent the “average” perceived cost, or compound cost, across all alternative choices available at lower levels in the hierarchy. Thus for trip frequency the compound cost of travel for trips from a given zone must be calculated across all available choices of destination zone, mode and time-period if the latter is included. \( G_{icomp} \) is intended to provide an estimate of the likely average cost from zone \( i \) and incorporates the probability of making each choice, to give a “logsum” cost as described in Section 1.9. This calculation is applied to each category of travel (e.g. trip purpose by SEG) in each origin zone separately. When a scheme is introduced, only trips from those zones where an appreciable proportion of trips experience the scheme, or its surrounding effects, will be noticeably affected.

**Trip Distribution**

2.1.12 Distribution models spread the generated trips over the available destinations, depending on the generalised cost of reaching that destination. Early demand modelling based distribution on distance rather than cost, and often as a simple negative power function of distance. These were known as “gravity” models in analogy with the gravitational attraction between masses, but use of logit functions based on utilities or generalised costs is now almost universal in demand models. In addition to cost, distribution also depends on some measure of the attraction of a zone, estimated in terms of the numbers of “opportunities” such as jobs or retail floorspace in the zone.

2.1.13 Most distribution models are designed to guarantee that the total number of trips from the origin zone (or to the destination zone) is equal to the total number of trips for that zone forecast at the trip generation/frequency stage. If the design guarantees that property for both origins and destinations the model is known as doubly constrained.

2.1.14 Some distribution models do not depend on travel costs and merely estimate future OD matrices directly from a base-year matrix and the future row and column totals. These methods are known as Fratar or Furnessing and are used to provide reference case growth factors for movements between zones to reflect the forecast growth in zonal trip ends. Apart from that role in providing inputs to variable demand modelling they are not relevant in the context of multi-stage demand modelling.

2.1.15 The general form for a doubly-constrained distribution model is:

\[ T_{ij} = a_i^*b_j^*O_i^*D_j^*f(G_{ij}) \]
Where \( T_{ij} \) is the number of trips from zone i to zone j,

- \( O_i \) is the total number of trips originating in zone i
- \( D_j \) is the total number of trips ending in zone j

\( T_{ij} \) depends on the travel disutility or cost via the deterrence function as \( f(G_{ij}) \),

Which in most models is a logit function

\[
\exp(-\lambda_{\text{dist}} G_{ijcomp})/(\sum_i \exp(-\lambda_{\text{dist}} G_{icomp})),
\]

Where \( G_{ijcomp} \) is a composite cost calculated across the available modes and time periods, if these choices are to be calculated after distribution.

\( a_i \) and \( b_j \) are balancing factors which are only used when the model is singly or doubly constrained (see Section 1.17) to ensure that \( \sum_j T_{ij} = O_i \) (ie there are \( O_i \) trips originating in zone i), and \( \sum_i T_{ij} = D_j \) (ie there are \( D_j \) trips ending in zone j), and are calculated at each iteration of the constraining routine as \( a_i = 1/\sum_j b_j D_j f(G_{ij}) \) or \( b_j = 1/\sum_i a_i O_i f(G_{ij}) \).

(see VDM Scope of the Model (TAG Unit 3.10.2) for conversion from Production/Attraction matrices to O/Ds).

Mode Choice

2.1.16 For mode choice, trips between each origin-destination pair of zones are allocated to the available modes according to the composite disutility or generalised cost of travel by that mode:

\[
T_{ijn} = T_{ij} \exp(-\lambda_{\text{mode}} G_{ijn})/(\sum_m \exp(-\lambda_{\text{mode}} G_{ijn}))
\]

if mode choice is the only demand response; and

\[
T_{ijn} = T_{ij} \exp(-\lambda_{\text{mode}} G_{ijncomp})/(\sum_m \exp(-\lambda_{\text{mode}} G_{ijncomp}))
\]

if mode choice is a more sensitive response than distribution. \( T_{ijn} \) is the number of trips choosing mode n from a set of modes m and \( \lambda_{\text{mode}} \) is the choice sensitivity parameter for the trip mode stage. The composite cost \( G_{ijncomp} \) is calculated across the time periods in a way that weights the average according to the probability of choosing that period. The summation is across all available modes m, including n. However, if mode choice is less sensitive than distribution, the composite cost \( G_{ijncomp} \) must be calculated to forecast an overall modal split for each origin zone. If there is more than one public transport mode it is usual to use a nested or hierarchical model, with a higher level split between car and public transport (and possibly slow modes also). The allocation to the different public transport modes (and between walk and cycle if modelled) is then made at a lower level (see Section 1.9) or possibly in assignment.
Time of day choice

2.1.17 **Macro time period choice** (or the allocation of trips between broad time periods) assuming this is the most sensitive response takes the form:

\[ T_{ijms} = T_{ijm} \exp(-\lambda_{time} G_{ijms})/(\sum \exp(-\lambda_{time} G_{ijmt})) \]

Where \( T_{ijms} \) is the number of trips between zones i and j by mode m in time period s. \( G_{ijmt} \) is the disutility or generalised cost of travel between zones i and j by mode m in time period t, which may typically be peak and inter-peak and \( \lambda_{time} \) is the choice sensitivity parameter for the time period stage. However, if it is above mode choice and distribution, it would take the form:

\[ T_{is} = T_i \exp(-\lambda_{time} G_{is})/(\sum \exp(-\lambda_{time} G_{it})) \]

Where \( T_{is} \) is the number of trips in Zone i in time period s and \( G_{is} \) is the disutility or generalised cost of travel in zone i in time period s.

2.1.18 It should be noted that the sequence of responses given in this section is arbitrary and should not be taken as the recommended structure.

2.1.19 Research is underway into the modelling of **micro time period choice** to improve the robustness of current models. Research results can be found at www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/032182.hcsp.

3 Appendix 3 Example Estimation of Modal Split

3.1.1 Modal split for those travellers who have a car available is likely to be substantially different from the overall split across all travellers. The method described below is very approximate, but it gives a general indication of how important the alternative public transport is likely to be (or for any alternative mode, since the principle is the same).

3.1.2 First, it is necessary to estimate the generalised costs by the car and non-car modes (bus in this example) for trips affected by the scheme being assessed. This may involve several different groups of traffic movements, in which case the estimate should be made for an “average” journey in each group (though, for the purposes of this exercise, the judgement of an “average” or “typical” journey can be very approximate). The generalised costs are as follows

**Car Travel:**

\[ G = 2^*A + 60^*D/V + D^*VOC/(occ*VOT) + PC/(occ^*VOT) \]

where A is the access time at both ends of the trip: since this will generally be walked, it is weighted by 2; D is the mean journey distance in kms; V is the mean traffic speed in kph; occ is the mean car occupancy; VOC is the mean car operating cost in pence per km; and VOT is the value of time per person in pence per minute; PC is half the mean car parking cost in pence. G is measured in minutes in the calculations described here.

**Bus travel:**

\[ G = 2^*Walk + 2^*Wait + 60^*D/V + Fare/VOT + I \]

Where Walk is the sum of the time spent walking to the stop or station at the origin end of the journey and the time spent from the destination stop or station to the actual destination, and Wait is the mean time spent waiting for the service, which will be half the service interval for frequencies of two per hour or better, rising to a nominal 15 (minutes for less frequent services). Walk and Wait are
weighted by 2 since this time is costed highly. \( V \) is the mean journey speed, including stopping. The mean fare appropriate to those travellers likely to choose between car and public transport (i.e. probably not concessions) should be for a single journey divided by the mode-specific value of time as for car. If access is by Park and Ride it will be necessary to add in the car access generalised cost, including half any parking fee, and if access at either end of a rail journey is by bus the extra generalised cost should be calculated as described here and added on. If the journey requires interchange between services the extra wait time (and walk time if relevant) should be included and an interchange penalty of, say, 6 minutes per interchange added.

3.1.3 Taking as an example the following cost components:

<table>
<thead>
<tr>
<th></th>
<th>Car trip</th>
<th>Bus trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access walk – both ends (mins)</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Wait time (mins)</td>
<td>NA</td>
<td>8</td>
</tr>
<tr>
<td>In-vehicle time (mins)</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Fuel, fares and other costs (pence)</td>
<td>160</td>
<td>250</td>
</tr>
<tr>
<td>Park cost - half of charge per one-way trip(pence)</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>Interchange penalty (mins)</td>
<td>NA</td>
<td>5</td>
</tr>
<tr>
<td>Mean occupancy</td>
<td>1.3</td>
<td>NA</td>
</tr>
<tr>
<td>Generalised cost (mins)</td>
<td>51.4</td>
<td>122.2</td>
</tr>
</tbody>
</table>

Then the generalised cost in the last line is obtained via the calculations above, using a Value of Time of 11 pence/minute.

3.1.4 The notional modal split is calculated as:

\[
P_{PT} = \exp(-\lambda_{PT} G_{PT})/(\exp(-\lambda_{PT} G_{PT}) + \exp(-\lambda_{car} G_{car}))
\]

Where \( P_{PT} \) is the proportion of travellers choosing public transport, \( G_{PT} \) and \( G_{car} \) are the generalised costs of travel by public transport and car respectively, and \( \lambda_{mode} \) is the mode choice sensitivity parameter, (which can be given a value of say 0.04), unless there is local knowledge of the prevailing value. This gives 5.5% to bus, but note that this calculation does not include any mode-specific constant beyond that implied by any mode specific value of time: it is not possible to generalise about the values of these constants, but they are generally found to reduce the share to public transport, so the 5.5% estimated in this case is likely to over-estimate the use of bus by car-available travellers.

3.1.5 Consider a highway improvement that saves 1.5 minutes in journey time for road traffic. The bus has to stop periodically and with acceleration and deceleration cannot make full use of the higher road speeds. Assume it gains only half this time, 0.75 minutes. Then in the “after” case, the car generalised cost falls to 49.9 minutes, and the bus generalised cost to 121.5 minutes. The mode split to bus falls to 5.4% whereas, if it had been assumed that the bus journey time had not changed, the reduction in car generalised cost would reduce the mode split to bus to 5.2%. Thus in this example inclusion of the effect on bus times means that the modal share hardly changes from the “before” situation.
3.1.6 However, although the effect on mode split is very small, this gain in journey time for bus travellers may account for an appreciable part of the total economic benefit. Car-available travellers account for only 5.4% of the total flow, and with only half the saving in travel time they account for only 2.7% of the benefit to car users. However, bus users who do not have a car available also gain this benefit, and they are likely to be much greater in number than the car-available bus users.

3.1.7 Such detailed assessment of the impact on public transport, in the absence of a full public transport modelling will be largely confined to circumstances where no public transport alternative is being proposed but the impacts on public transport of the scheme (or the congestion in the without scheme scenario) are thought to be significant.

4 Appendix 4 Incremental Model Formulation

4.1.1 When specifying an incremental hierarchical logit model, scaling parameters as provided in section 1.11.15 could be used. These parameters refer to the probability of nests of alternatives or composite alternatives. They reflect the ratios of the lambdas for different response mechanisms as you move up the model structure. The scaling parameters are applied to the logsums of the composite or nested alternatives. They should have a value between 0 and 1 if the responses have been included in the correct order in the model, such that the sensitivity of the responses changes down the hierarchy from lower to higher.

4.1.2 The standard incremental multinomial logit model is given as

\[
P_i = \frac{p_i^0 \exp(\theta \Delta U_i)}{\sum_j p_j^0 \exp(\theta \Delta U_j)}
\]

where

- \( p_i \) is the forecast probability of choosing alternative \( i \)
- \( p_i^0 \) is the reference case probability of choosing alternative \( i \) (calculated from the input reference demand)
- \( \theta \) is the scaling parameter (always =1 for the bottom level of the hierarchy)
- \( \Delta U_i \) is the change in the utility of alternative \( i \)

For the choice at the bottom level of the hierarchy the change in utility is given by

\[
\Delta U_i = \lambda (C_i - C_i^0)
\]

where

- \( C_i^0 \) is the reference generalised cost and
- \( C_i \) is the forecast generalised cost, skimmed from the latest assignment
\( \lambda \) is the spread or dispersion parameter (defined by the user); it should be negative.

For choices above the bottom level of the hierarchy the change in utility is the composite change over the alternatives in the level below:

\[
\Delta U^* = \ln \left( \sum p_i^0 \exp(\Delta U_i) \right)
\]

4.1.3 This model formulation can be used for mode choice, time period choice and singly constrained distribution.

A modified version of the logit model is used for doubly-constrained distribution as follows:

\[
T_{ij} = O_i \frac{B_j T_{ij}^0 \exp(\theta \Delta U_{ij})}{\sum_{k=1}^{N} B_k T_{ij}^0 \exp(\theta \Delta U_{ik})}
\]

where

- \( T_{ij} \) is the forecast number of trips travelling from zone i to zone j
- \( T_{ij}^0 \) is the reference case number of trips travelling from zone i to zone j
- \( O_i \) is the number of trips travelling from zone i
- \( B_j \) are destination-based constants, normalised so that \( \sum_j B_j \) is equal to the number of zones

Note that destination constraints are summed over all person types within a purpose, and across all modes and time periods, if those choices have been modelled.

The change in composite utility for origin zone a is calculated using:

\[
\Delta U_{a}^* = \ln \left( \sum_b B_b \frac{T_{ab}^0}{O_a^0} \exp(\theta \Delta U_{ab}) \right)
\]

4.1.4 The illustrative parameter values currently provided in Section 1.11 can be used in an incremental model structure as follows:

Suppose we assume the follow choices available:

- Single trip purpose (say commuting) split into:
- Two person types (say car available and car not available)
- Car available hierarchy (from top to bottom): frequency, mode choice, time period choice, distribution (doubly constrained)
* Car not available hierarchy (from top to bottom): frequency, time period choice, distribution (doubly constrained)

**Inputs**

4.1.5 Inputs to the demand model are:

- \( C_{ijmtpc}^0 \) reference generalised cost from zone i to zone j by mode m in time period t, trip purpose p, person type c
- \( C_{ijmtpc} \) corresponding forecast generalised cost, skimmed from latest assignment
- \( T_{ijmtpc}^0 \) corresponding reference demand, defined via the user interface

In all the above, there is no data for the highway mode for the no-car person type

**Bottom level utilities**

4.1.6 The first step is to calculate the change in utility for the lowest level of the hierarchy:

\[
\Delta U_{ijmtpc} = \lambda_{mc}^{mode} \left( C_{ijmtpc} - C_{ijmtpc}^0 \right)
\]

Where \( \lambda_{mc}^{mode} \) is the mode-specific distribution \( \lambda \) parameter

**Doubly-constrained distribution**

4.1.7 Since the lowest level is a doubly constrained distribution model we need to find the balancing factors \( B_{jp} \). This requires solving the set of equations given by:

\[
T_{ijmtpc} = O_{nm} \frac{B_{jp} T_{ijmtpc}^0 \exp(\Delta U_{ijmtpc})}{\sum_{k=1}^{N} B_{kp} T_{ikmtpc}^0 \exp(\Delta U_{ikmtpc})}
\]

such that the destination trip end constraints are met:

\[
\sum_{mtpc} T_{ijmtpc} = D_{jp}
\]

The destination constraints are calculated from the reference demand matrix:

\[
D_{jp} = \sum_{mtpc} T_{ijmtpc}^0
\]

Note that the destination trip end constraints depend on destination and trip purpose only.

The balancing factors are normalised so that
\[ \sum_{j} B_{jp} = N \]
where \( N \) is the number of destination zones.

On the first iteration only of the demand model the origin trip ends are calculated from the reference demand matrix:
\[ O_{impc} = \sum_{j} T_{ijimpc}^{0} \]
For subsequent iterations they are obtained from the application of the conditional probabilities described below.

**Composite Utilities**

4.1.8 The change in the composite utility from the distribution, time period choice and mode choice stages is then calculated:

\[ \Delta U_{impc}^{*} = \ln \sum_{j} B_{jp} \frac{T_{ijimpc}^{0}}{O_{impc}^{0}} \exp \left( \Delta U_{ijimpc}^{0} \right) \]

\[ \Delta U_{impc}^{*} = \ln \sum_{t} P_{tjimcp}^{0} \exp \left( \epsilon_{c}^{time} \Delta U_{impc}^{*} \right) \]

\[ \Delta U_{qpc}^{*} = \ln \sum_{m} P_{mijklpc}^{0} \exp \left( \theta_{c}^{mode} \Delta U_{impc}^{*} \right) \]

(car available person type)

\[ \Delta U_{qpc}^{*} = \Delta U_{impc}^{*} \]

(car not available person type, \( m = \text{PT} \))

The reference case probabilities are calculated from the input reference demand as follows:

\[ P_{mijklpc}^{0} = \frac{\sum_{j} T_{ijimpc}^{0}}{\sum_{j} T_{ijklpc}^{0}} \]

\[ P_{ijklpc}^{0} = \frac{\sum_{j} T_{ijimpc}^{0}}{\sum_{j} T_{ijimpc}^{0}} \]

**Conditional Probabilities**
4.1.9 Having calculated the change in the composite utilities it is possible to calculate
the conditional utilities for each level of the model

Mode choice:

\[ P_{m|ipc} = \frac{P_{m|ipc}^0 \exp(\theta_{c|mode}^m \Delta U_{ipmc}^*)}{\sum_k P_{k|ipc}^0 \exp(\theta_{c|mode}^k \Delta U_{ikpc}^*)} \]

(car available person type)

\[ P_{m|ipc} = \begin{cases} 1 & \text{if } m = \text{public transport} \\ 0 & \text{otherwise} \end{cases} \]

(car not available person type)

Time period choice:

\[ P_{t|impc} = \frac{P_{t|impc}^0 \exp(\theta_{c|time}^t \Delta U_{impc}^*)}{\sum_k P_{k|impc}^0 \exp(\theta_{c|time}^k \Delta U_{ikmpc}^*)} \]

Distribution (destination choice):

\[ P_{j|impc} = \frac{B_{j|i} T_{j|impc}^0 \exp(\Delta U_{ijmpc})}{\sum_{k=1} B_{j|i} T_{k|impc}^0 \exp(\Delta U_{ikmpc})} \]

**Updated Trip Matrix**

4.1.10 The application of the conditional probabilities gives an updated trip matrix

\[ T_{ijmpc} = T_{ijmpc}^0 P_{m|ipc} P_{t|impc} P_{j|impc} \]

and updated origin totals:

\[ O_{impc} = O_{impc}^0 P_{m|ipc} P_{t|impc} \]

**Application of Frequency Model**

4.1.11 The frequency model is only applied after the above process has converged. This
gives the final trip matrix from the demand model:

\[ T_{ijmpc} = \exp(\theta_{c|freq}^m \Delta U_{ipmc}^*) T_{ijmpc}^0 P_{m|ipc} P_{t|impc} P_{j|impc} \]
5 Appendix 5 Absolute Model Formulation

5.1.1 The illustrative parameter values currently provided in Section 1.11 can be used in an absolute model structure as follows:

Assumed Nesting

Layer 1 (Highest): Frequency
Layer 2: Main Mode
Layer 3: Macro Time Period
Layer 4 (Lowest): Destination

Notation

| Trip Origin: | i  | Trip Destination | j, k |
| Macro Time period | t, s | Main Mode | m, r |
| Trips | T | Generalised Cost | G |
| Distribution parameter | \( \lambda_{\text{dist}} \) | Attraction Factor | B |
| Composite Utility | U | Tree parameters | \( \theta_{\text{time}}, \theta_{\text{mode}}, \theta_{\text{freq}} \) |
| Pivot (reference) Trips | \( oT \) | Pivot (reference) Utilities | \( oU \) |

Composite Utilities:

5.1.2 The incremental composite utilities summed over the choices in the destination layer are given by:

\[
U_{int} = \ln \sum_j B_j \exp(-\lambda_{dist} G_{ijm}) - \ln \sum_j B_j
\]

Initial values for the attraction factors \( B_j \) are needed (see notes given later about the destination choice probabilities).

5.1.3 The composite utilities summed over choices in the time period layer are given by

\[
U_{im} = \ln \sum_t \exp(\theta_{\text{time}} U_{int})
\]
This uses the scaling parameter $\theta_{\text{time}}$ which reflects the ratio of the lambda for macro time period to the lambda for distribution.

5.1.4 The incremental composite utilities summed over the main mode layer are given by

$$U_i = \ln \sum_m \exp(\theta_{\text{mode}} U_{im})$$

These composite utilities are used to calculate the choice probabilities in the various layers as follows. Where required, base utilities can also be calculated from the same composite utility formulae given above, but using base values for the generalised costs and balancing factors.

**Choice Probabilities:**

5.1.5

**Layer 1, Frequency:**

$$T_i = \frac{T_i \exp(\theta_{\text{freq}} U_i)}{\exp(\theta_{\text{freq}} U_0)}$$

Note that this calculation makes use of a reference utility value

**Layer 2, Main Mode Choice (m):**

$$T_{im} = \frac{T_i \exp(\theta_{\text{mode}} U_{im})}{\sum_r \exp(\theta_{\text{mode}} U_{ir})}$$

**Layer 3, Macro Time Period Choice (t):**

$$T_{int} = \frac{T_{im} \exp(\theta_{\text{time}} U_{int})}{\sum_s \exp(\theta_{\text{time}} U_{ins})}$$
Layer 4, Destination Choice (j):

\[ T_{ijmt} = \frac{T_{int}B_j \exp(-\lambda_{dist}G_{ijmt})}{\sum_k B_k \exp(-\lambda_{dist}G_{ikmt})} \]

**Notes**

All distribution models satisfy the constraint: \( \sum_j T_{ijmt} = T_{int} \)

For doubly constrained destination choice models \( B_j \) needs to be calculated to satisfy the additional constraint: \( \sum_{int} T_{ijmt} = T_j \)

Some models employ area specific, mode specific, and time period specific constants and/or sensitivity parameters which vary by zone or zone pairs. Advice on these matters can be found in sections 1.7.14 to 1.7.16.
Variable Demand Modelling – Convergence
Realism and Sensitivity

TAG Unit 3.10.4

June 2006

Department for Transport

Transport Analysis Guidance (TAG)
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1 Variable Demand Modelling – Convergence Realism and Sensitivity

1.1 Background

1.1.1 TAG units 2.9 and 3.10 explain why variable demand modelling needs to be considered and provide guidance on how to carry out such modelling for highway schemes. This unit forms stage 4 of the overall process; TAG units 3.10.1, 3.10.2 and 3.10.3, detail the previous stages.

1.1.2 Important recommendations are shown highlighted and in bold. If those actions are not followed, analysts will need to provide rigorous justification for the course of action taken.

1.2 Use of DIADEM

1.2.1 Once the extent of the necessary variable demand modelling has been decided, the next question is how to build the model. Few users will have the resources available to build their own model from scratch, nor is this a sensible approach unless there is a need for a general-purpose model for policy analysis much wider than assessment of an individual scheme. Most users will need to identify available software packages which incorporate the necessary demand mechanisms, and can accept the data and parameters appropriate to the scheme under study. In most cases these mechanisms are provided by way of macros developed for each study, rather than as generic model formulations.

1.2.2 In tandem with the development of this TAG unit, software called DIADEM: Dynamic Integrated Assignment and Demand Modelling has been developed to provide simple multi-stage demand models and an interface with commercially available packages.

1.2.3 The DIADEM procedures provide an adjustable hierarchical structure of trip frequency, mode choice, distribution, and time of day choice, and an interface to assignment. It is also possible to use DIADEM for a simple “own-cost” elasticity calculation where applicable. The DIADEM framework controls iteration within assignment, and between demand and assignment, to ensure that the calculation reaches an acceptable equilibrium.

1.2.4 At present, DIADEM has been developed with an interface to the CONTRAM and SATURN assignment packages. It is expected, however, that the suppliers of other assignment packages will provide equivalent functionality or suitable interfaces with DIADEM, so that it can be used with whatever assignment model is available for the scheme to be assessed. As ever, there is no monopoly on the most convenient way to achieve best practice: as with choice of assignment package, which one to adopt is a matter of individual preferences and priorities. If a decision is made to use DIADEM then Section 1.3 provides a summary of the approach. If other software is to be used then Section 1.4 gives guidance on how alternative software should be used.

1.3 DIADEM Procedures

1.3.1 The DIADEM procedures cover all the demand-side issues that must be considered when applying multi-stage models, as described in VDM Key Processes (TAG Unit 3.10.3), and provides the user with the necessary choice between alternative formulations and full control over each aspect.

1.3.2 Model Type: the model can be incremental at present although an absolute alternative is ultimately envisaged to every response in the overall application.

1.3.3 Demand responses: DIADEM allows the following responses to be included:

- elasticity model: the elasticity model has a 2-parameter Tanner form, which is intended to be used in its extremes, setting one of the parameters to 0 to return either a power or an exponential form, as discussed in VDM Key
Processes (TAG Unit 3.10.3). The use of both parameters together in the
Tanner form is not recommended.

- trip frequency model: the trip frequency model is an exponential elasticity
  function, but unlike general elasticity models (which operate at the OD level),
  the trip frequency model applies to the zone level, using composite zone
  (accessibility) costs as discussed in VDM Key Processes (TAG Unit 3.10.3).

- modal choice model: the mode choice model is a binomial logit formulation.
The model does not automate the hierarchical modelling of public transport
modes i.e. sub mode choice. Any lower-level split between different public
transport modes would have to be estimated independently or at assignment
as discussed in VDM Key Processes (TAG Unit 3.10.3). However, this sub-
mode choice will rarely be needed in a road-based scheme appraisal.

- distribution model: the trip distribution model can be singly-origin
  constrained or singly-destination constrained (to approximate to Production
  /Attraction constraints) or doubly-constrained as discussed in VDM Key
  Processes (TAG Unit 3.10.3).

- time of day choice model: a macro time period choice model in logit form is
currently available. Micro time period choice using HADES is planned for
future release.

1.3.4 There are still a number of technical issues to be resolved, concerned with
incremental formulation of the HADES model, the composite cost formulae, and
the use of scheduling costs. For a discussion on alternative model forms of
departure-time choice, see VDM Key Processes (TAG Unit 3.10.3) and Batley et

1.3.5 Model hierarchy: DIADEM allows a different range of responses, a different
model form and a different hierarchy to be applied to each individual purpose
and traveller type combination.

1.3.6 Model parameters: Each modelled response is driven by a single user-defined
\( \lambda \) parameter, per purpose and traveller type combination, apart from the
elasticity models which as Tanner formulations are driven by 2 parameters
(though normally one of these should be set to zero, returning the Tanner
function to either a power or an exponential function). Calibration areas with
potentially different parameters in each area will ultimately be provided.

1.3.7 Generalised costs: Generalised cost coefficients are defined for each
purpose and traveller type combination, allowing for time, distance and
monetary components. Any weighting of in-vehicle, waiting or walking time
must be done within the assignment stage or outside the DIADEM environment,
and a similar argument applies to crowding effects. The analyst will be provided
with a flexible tool in DIADEM to arrange the sequence of demand responses
and warned if the proposed sequence does not reflect demand sensitivities.
However, the analyst will still need to ensure that the definitions of generalised
cost in the demand and assignment phases include all the necessary terms and
are sufficiently compatible.

1.3.8 Model running: Guidance on how to run the DIADEM software is given in the
user guide to the software. It should be noted that the solution closest to
equilibrium may not necessarily be the one produced by the last iteration of the
DIADEM demand/assignment modelling system. The solution from the iteration
with the lowest GAP value should be used for appraisal purposes. This may
require an additional run of the assignment package using this ‘best’ trip matrix
to obtain a converged solution.

1.4 Other Software

1.4.1 Section 1.3 outlined the use of the DIADEM procedures. However, using
DIADEM is not the only approach that could be adopted and the practitioner
may wish to develop an approach based on existing software packages that
have not developed interfaces with DIADEM. Such software is being developed continually, and only the more widely used packages are mentioned here.

1.4.2 There are a number of different approaches than can be adopted when using non DIADEM procedures:

1.4.3 **Combined assignment-demand models.** Firstly, one can use other software that can handle demand-supply responses as a combined assignment-demand model. This is the preferred alternative solution to using DIADEM in most cases since the software will be constructed to ensure, as far as possible, that the model is properly integrated, computationally efficient and sufficiently converged to a correct solution. At present the main drawback is that the demand responses that can be modelled may be limited, either in number or in the sequence order. For example, in the case of the SATURN software package, assignment can be combined with elastic demand and one or both of mode-choice and singly constrained trip distribution. The approach, at present, does have the disadvantage that the sequencing allowed is restricted. Similarly, the EMME/2 transportation suite allows a combined model of trip assignment with elastic demand or mode-choice through the use of built-in modules but other combinations need to use individual models of demand and assignment constructed by the user using the suites macro language. With these models, more exact measures of convergence can be defined than the % relative GAP measure recommended in Section 1.5. This arises from the nature of the combined demand-supply formulation (such as that used by the SATURN program). At present, no fixed level to be obtained from such measures has been set but details of the approach to improve convergence should be given in the Validation Report. (The latest version of the SATURN suite can give values from which to calculate the % GAP function.). The TUBA tests outlined in the next section can be done to ensure that convergence is to the level required by the scale of the scheme.

1.4.4 **Combining separate demand and assignment models:** The next best alternative is to make use of a transportation suite software's matrix manipulation software to construct the model of demand responses oneself and iterate between the assignment program and the demand model. This will at least ensure that the supply and demand data are in compatible format. However, it is likely to require expertise both in transportation modelling and in knowledge of the workings of the transportation software. Various transportation software packages are available which cover both demand and assignment functions. The most widely-used in the UK are probably the Citilabs' TRIPS transportation suite (now part of the CUBE family of models), which includes public transport and highway assignment and demand functions within the same modelling environment, the EMME/2 suite as noted above and PTV's VISEM (in the form of tours instead of trips) and VISUM suites will also perform similar functions.

1.4.5 The user in these circumstances will need to ensure that that the final solution meets the convergence criteria set out in Section 1.5. To do this, it may necessary to devise a sophisticated approach to cycling between the assignment and demand responses that will ensure a stable converged solution in a reasonable time. The most common solutions are simply to iterate between the converged assignment model and the demand response model, passing travel costs from the assignment model to the demand model and passing trips (or most commonly vehicle trips) from the demand model to the assignment model. However, this approach is not guaranteed to converge, except when using techniques such as the Method of Successive Averages (MSA). Both techniques can, in some circumstances, take a long time to reach a sufficiently converged solution. (This is one of the reasons that algorithms that incorporate both the demand and assignment phases in one procedure have been developed.) It is difficult to provide a single ready-made solution for all software and all schemes, and it may be necessary to seek advice from the software developers. For these models the iteration between supply (assignment) model
and demand models should give statistics from which to calculate the % GAP statistic, as recommended in section 1.5. The approach to iterating between the supply and demand models, and the monitoring of the convergence progress should be detailed in the Validation Report. Evidence should be provided that the models meet the convergence requirements set out in Section 1.5 (1.5.7).

1.4.6 **Combining models from different transportation suites:** In some cases the assignment package and the software used to model the demand responses may not be from the same package, or software used in highway assignment may be different from that used for public transport assignment. Examples of this can be found in many of the Multi-Modal Studies, for example using SATURN for the highway assignment and TRIPS for the demand. This should not, in itself, prove too much of a problem provided that care is taken in transferring data from one package to another. In other Multi-Modal Studies the demand modelling was split between two different software packages, for general road traffic and public transport. However, the difficulties in transferring data from one transportation suite to another should not be underestimated and time and resources should be allowed to ensure that the data is compatible.

1.4.7 Users are responsible with most software for arranging the sequence of demand responses and for ensuring that the proposed sequence reflects demand model sensitivities. Analysts also need to ensure that the definitions of generalised cost in the demand and assignment phases include all the necessary terms and are sufficiently compatible. They also need to ensure that a stable, converged, solution to both the assignment and demand responses is produced in a reasonable time. This is particularly important when assessing small schemes with large models. For these models the iteration between supply (assignment) model and demand models should give statistics from which to calculate the recommended convergence statistic. The approach to iterating between the supply and demand models and the monitoring of the convergence progress should be detailed in the Validation Report.

1.4.8 Whatever approach is adopted the user should ensure that documentation is provided in sufficient detail for a third party to follow all the steps and the convergence properties of the combined model are detailed.

1.4.9 **Convergence:** This is a key to achieving good modelling practice. **High levels of convergence should be achieved in any assignment modelling.** This applies to both small networks and, especially, large networks where small percentage changes in convergence may result in large changes in flows and times around a potential scheme. In addition, the demand - supply convergence should be monitored by using the convergence measure (% relative GAP) defined in 1.5.2, with the aim of reaching the convergence level determined by para 1.5.7. If that cannot be reached then a convergence level of at least 0.2% is recommended.

1.4.10 In summary, if an integrated approach similar to DIADEM is not used the main issues are:

- That the approach adequately addresses the issues of correct sequencing of demand responses and consistency in the definitions of generalised cost in the demand and assignment phases
- Where a combined assignment/demand model is used, that the convergence statistics output at the end of the modelling meet the requirements set out in Section 1.5 below.
- Where a combined model is not used or not applicable, then care needs to be taken over the cycling between assignment and demand modelling modules so that convergence in travel costs and trips is reached in a reasonable time.
- Sufficient documentation is provided that the approach adopted can be understood and the convergence properties of the model clearly stated.
1.5 Convergence

1.5.1 The original impetus for DIADEM was in the need to improve convergence of demand-supply models, and DIADEM procedures have internal capabilities to apply a range of convergence improving techniques, guided by a number of convergence measures and desired stop criteria. Preliminary tests indicate that improved demand convergence can reduce the convergence errors to less than 10% of the economic benefit. Demand modelling software, such as DIADEM may provide a number of measures of convergence, both relating to proximity (how close to the true equilibrium), and stability (how much the results are changing each iteration). For our purposes the proximity measures are the more important.

1.5.2 The recommended criterion for measuring convergence between demand and supply models is the demand/supply gap defined by:

$$\sum_{ijctm} \frac{|C(X_{ijctm})D(C(X_{ijctm})) - X_{ijctm}|}{\sum_{ijctm} C(X_{ijctm})X_{ijctm}} \times 100$$

Where:
- $X_{ijctm}$ is the current flow vector or matrix from the model
- $C(X_{ijctm})$ is the generalised cost vector or matrix obtained by assigning that matrix
- $D(C(X_{ijctm}))$ is the flow vector or matrix output by the demand model, using the costs $C(X_{ijctm})$ as input
- $ijctm$ represents origin $i$, destination $j$, demand segment/user class $c$, time period $t$ and mode $m$

This is a measure of how far the current flow is from the equilibrium point and will be zero in a perfectly converged model. The demand-supply gap is represented, for one flow, by the shaded area in the figure above. As convergence improves, and the difference in trips between successive iterations...
decreases so the shaded area decreases until the equilibrium point is reached. One of the reasons for the choice of this statistic is that it is easily calculated and is not dependant on the precise form of demand-supply modelling undertaken. It is referred to as the %GAP, reflecting its relative nature.

1.5.3 The demand/supply model used may report other measures of convergence. Some of these may be stability statistics that indicate how much the solution is changing from one iteration to the next. An example of this could be the maximum change in flows. It is often assumed that a stable solution implies convergence. However, it can also be an artefact of the particular algorithm being used so stability statistics are, in general, not a good indicator of how close the solution is to equilibrium.

1.5.4 The demand/supply gap, as defined in 1.5.2 above, is the most appropriate measure for gauging the error in economic benefit calculations caused by imperfect convergence. It can be calculated for any variable demand/supply modelling system and is not dependant on the form of demand/supply modelling approach.

1.5.5 Tests indicate that gap values of less than 0.1% can be achieved in many cases, although in more problematic systems this may be nearer to 0.2%. Where the convergence level, as measured by the %GAP, is over 0.2% remedial steps should be taken to improve the convergence, by increasing the assignment accuracy.

1.5.6 **Convergence and scheme benefits.** The required level of convergence needs to be linked to the scale of the benefits of the scheme being appraised, relative to the network size. For instance the calculation of benefits from small schemes in large networks will be much more sensitive to convergence than large schemes in small networks. On the basis of testing it has been discovered that ideally the user benefits, as a percentage of network costs, should be at least 10 times the % Gap achieved in the Do-Minimum and Do-Something scenarios. The estimation of user benefits can be estimated either by using matrix manipulation of the with and without scheme trip and skimmed generalised cost matrices to produce an estimate of the consumer surplus by the rule of a half, or by using the DT’s TUBA program. In either case the worst case convergence of the with and without scheme runs should be taken as the one to compare with the size of the benefits.

**Example:**

<table>
<thead>
<tr>
<th>DM&amp;DS_USER_COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total value of user costs, DM and DS. £000s.</td>
</tr>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Road</td>
</tr>
</tbody>
</table>

(TUBA output table modified to show DM costs only)

<table>
<thead>
<tr>
<th>MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>User benefits and changes in revenues by mode, all years. £000s.</td>
</tr>
<tr>
<td>Mode</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Road</td>
</tr>
</tbody>
</table>

From the MODE table we can obtain the total user benefits. This is done by ignoring the change in operator and indirect tax revenues and summing the user time, charge and VOC benefits. In this case this is equal to 2236+0-211-36=1989.
From the DM&DS_USER_COSTS table we can obtain the total DM network costs. In this case this is equal to 34897+0+2022+966=37885.

Dividing the former by the latter and expressing as a % we obtain 1989/37885=5.3%

Suppose now that in our model runs we obtained demand/supply gaps of 0.3% and 0.5% for the DM and DS respectively. Taking the worse of the these (0.5%) we can see that it is very much smaller than the benefits expressed as a proportion of network costs (5.3%) and can conclude that in this case we have a robust estimate of economic benefits.

This example shows one modelled year and mode only. In practice this calculation will need to be done for each modelled year.

Note that these calculations can be carried out with TUBA

1.6 Realism Testing

1.6.1 Once a variable demand model has been constructed, it is essential to ensure that it behaves “realistically”, by changing the various components of travel costs and times and checking that the overall response of demand accords with general experience. If it does not, then the values of the parameters controlling the response of demand to costs should be adjusted until an acceptable response is achieved. This recognises the large and unavoidable uncertainties in some of the parameter values, and the importance of reflecting local conditions in relative values.

1.6.2 By the time this Advice has been digested and the model constructed, it will be apparent that many of the parameters controlling the behaviour of the model have to reflect local circumstances. However, even if there is adequate local data to achieve a good calibration of the model, a fitting of the model to the travel patterns between various pairs of zones (usually referred to as seen in cross-section) does not necessarily guarantee that it will be a good predictor of the response of demand to changes in travel costs over time.

1.6.3 In other cases a local calibration may not have been possible, and it may have been necessary to resort to importing values for the parameters or using “illustrative” values, in which case it is obviously important to check that the behaviour these give rise to is plausible in the new context. However before any parameters in the variable demand model are adjusted the base model (and trips matrices) should have been fully validated and the results outlined in a validation report (see section 1.8).

1.6.4 If the model does not behave in accordance with past experience, it should not be used to appraise a transport scheme, unless a convincing case can be made to explain the differences in terms of special local circumstances. Instead, the model parameters and calibration areas should be modified until its responses are plausible (see 1.6.15 below). The outputs of the realism tests should be disaggregated to see if particular elements of the model are causing problems. If so then the lambda parameters should be changed in such a manner as to produce plausible results, provided that the hierarchy rules set out in VDM Key Processes (TAG Unit 3.10.3) are followed. Such changes should be noted in the Validation Report.

1.6.5 Demand elasticites: The acceptability of the model’s responses is determined by the demand elasticities it predicts. These are measured by changing a cost or time component by a small proportionate amount and calculating the proportionate change in trips made. The elasticity recommended which is the arc elasticity formulation is:

\[ e = \frac{(\log(T^1) - \log(T^0))}{(\log(C^1) - \log(C^0))} \]
where the superscripts 0 and 1 indicate values before and after the change in cost respectively. For example, if car fuel costs increased by 10% and trips by car fell by 2%, then the elasticity of car trips with respect to fuel price would be -0.2. The same calculation can be made with respect to car-kms travelled rather than to trips, to obtain a distance elasticity.

1.6.6 **Components to be tested:** Any component of cost or travel time can be checked in this way, but it should be realised that they are not all independent, so that there may be little point in checking all separately. The different components of generalised cost for any particular journey are interlinked by the weights applied in calculating the generalised cost (see *VDM Key Processes* (TAG Unit 3.10.3)). Thus if one weighted component accounts for twice as much as another in the total cost, the elasticity of demand relative to it will always be twice as much. Nevertheless, it is desirable to test the more important components in this way to ensure that the formulation of generalised cost in the model is correct.

1.6.7 The tests discussed here refer to the demand model: the responses will be modified by iteration with the assignment model, especially where congestion limits traffic growth on some parts of the network, but for realism testing it may be less necessary to establish a close convergence.

1.6.8 As a minimum, analysts should check the elasticity of demand with respect to:

- car fuel cost
- **car journey time** (this is linked to the journey-time elasticity via the car operating costs formula as a function of distance and speed, and by the value of time, but it is sensible to test both time and cost components separately)
- if modal split to public transport is a significant factor in the modelling, check the elasticity of public transport demand against public transport fares
- if parking is a significant factor, check the response of demand to parking charges.

1.6.9 The check should examine the response of demand for each category of travel, and in each time period. Obviously, there is overlap between these two aspects, but the check will ensure that there has been no misallocation between the categories.

1.6.10 Realism testing involves changing the important aspects that affect demand, whether globally or for selected trips, and ensuring that the response seems “reasonable” – a subjective judgement, but one which can often pinpoint aspects of the modelling which need attention. For each component to be tested, increase its value by, say, 10% and rerunning the model to obtain the new estimate of demand, either as car-kms or public transport trips.

1.6.11 A number of studies in this country using time-series data on car travel, and fuel prices and costs have shown an elasticity of car use with respect to fuel cost of about -0.3 (see Bradburn and Hyman (2002), Graham and Glaister (2002), Hanly Dargay and Goodwin (2002)) and this value equates well with a review of European research on this topic (TRACE, 1999). A realistic model does not necessarily provide precisely this value of -0.3, which is based upon a national mix of trip purposes and time periods. Variation by journey purpose will show elasticities in the range of -0.1 to -0.4 with employer’s business trips having values close to -0.1 and the more discretionary trip purposes nearer -0.4.

1.6.12 For most models used in this country, journey time elasticities can be related to the definition of generalised costs but the output elasticities will vary much more than the fuel cost elasticities. The output elasticities should be checked to ensure that the model does not produce very high output elasticities (say greater than -2.0).
1.6.13 Elasticities of public transport trips with respect to public transport fares have been found to lie typically in the range \(-0.2\) to \(-0.4\) for changes taking place within 12 months, and up to \(-0.9\) for changes over a longer period. (TRL, 2004) with those in the peak, or for more obligatory purposes, at the lower end and those in the off-peak, or for more discretionary purposes, at the higher end. These values apply to the totality of public transport passengers; arguably, those with a car available would be expected to show a greater elasticity since they have greater choice, but there is little consistent evidence on what values are appropriate.

1.6.14 Elasticities relative to parking charges will depend upon what fraction of the total generalised costs parking costs account for, and this will depend upon the fraction of motorists who pay for parking as well as on the general level of charges. Judgement of the plausibility of the model response will be very subjective, but unreasonable model response is generally readily identified.

1.6.15 If the “realism” tests suggest elasticities or model responses which are unconvincing, it will be important to experiment with adjusting the model to obtain more appropriate responses. There is a temptation to explain away unusual modelling results in terms of special circumstances applying to the particular modelling context, but unless such an explanation is very convincing it is better to adjust the model’s responses to values which are more generally accepted, especially in circumstances where the parameters may have been imported from other applications. The adjustment involves changing the values of the lambda parameters to weaken or strengthen the response, as required – taking care to adjust the hierarchy as necessary.

1.6.16 If the unacceptable responses refer only to particular categories of travel then only the lambdas for these categories need be adjusted. In general, it will not be clear which stages of the multi-stage variable demand calculation should be changed, though if the model contains a time of day choice stage and the unacceptable behaviour lies in the differences between peak and off-peak then attention will obviously be paid to this mechanism. Otherwise, it will be sensible to adjust both distribution and mode choice parameters in the same proportion, unless sensitivity testing (see Section 1.7) suggests that one of these is unreasonably sensitive. Since elasticities scale with the lambda values, if the model elasticity is too large then reduce the lambda values, and vice versa.

1.7 Sensitivity Testing

1.7.1 Sensitivity testing, as distinct from realism testing, is aimed at identifying the relative effects of the various parameters on the outcome of a scheme appraisal, rather than in checking the model responses against experience. Especially where the model parameter values are uncertain it is important to know how sensitive the appraisal results are to these uncertainties, so that confidence can be invested in the conclusions.

1.7.2 The realism testing of Section 1.6 was aimed at ensuring that the model’s responses were consistent with previous experience of travel demand and the way it responds to changes in travel costs. Even if the model is satisfactory in these respects, there may still be considerable uncertainty attached to some of its forecasts because of uncertainty in its parameter values. It is important to quantify the effects of this on scheme appraisal, as far as possible, so that the final conclusions on a scheme’s value can be robust against these uncertainties. This can be investigated by sensitivity testing of the model’s behaviour against variation in those parameters which are judged to:

- have a substantial effect on the model’s prediction of changes, and
- be uncertain in their calibration.

1.7.3 The most obvious values are the sensitivity parameters that govern the individual demand mechanisms (i.e. the lambda values). If they have been calibrated on local data, the extent of possible error in their calibration should be
examined from the statistics calculated during the fitting, which is usually substantial. If they have been imported, the uncertainty will be even greater since they are being used in a context different from their original application. The illustrative values given in VDM Key Processes (TAG Unit 3.10.3) were obtained from a review of current models, and typically the range of values was twice the mean value. This indicates the degree of uncertainty in values imported from other studies.

1.7.4 If the lambda values have been calibrated on local data, whether for the variable demand model itself or for an existing local model, then check the overall result of the scheme appraisal against runs of the model with the lambdas set at plus the standard deviation of the mean value, or at least +25% of the mean if the actual standard deviation is smaller. Behaviour of the model will not necessarily be symmetrical against increases and decreases in the parameter, but the increase will indicate the strength of the response, and if it is an important factor the result can also be tested against a decrease. If the values have been imported then test the result against +50% of the mean. This range is to reflect the greater uncertainty that occurs with imported values. Unless there are convincing reasons for not doing so, the changes are to be made to all parameters in the same direction at the same time so that the gradation of parameter values is still consistent with the hierarchy.

1.7.5 Given the acknowledged uncertainty of distribution parameters obtained from cross-sectional fitting, this larger margin could be applied even to locally calibrated distribution lambdas. It is the stronger variable demand mechanisms which will have most effect on the assessment, so there may be no point in testing the result against a small trip frequency response, for example, when distribution or mode choice are dominant. Generally, in a scheme aimed at congestion relief, the net benefit will be reduced by increases in the demand for car travel, so that it is the increased lambda values that will test the robustness of the result. If the scheme remains well justified against these higher values then a conclusion that the scheme is beneficial will be robust against the effects of induced traffic. Where the model includes time of day choice it will be essential to test variation of the assumed sensitivity. Evidence for these values is more uncertain and wide sensitivity factors say: +50% and -50% are suggested. The range will be limited by the need to ensure that any changes in the values are still consistent with the hierarchy.

1.7.6 Sensitivity testing should not be limited to the response parameters, however. Any parameter that seems likely to have a substantial effect on the net benefit, and where appreciable uncertainty is likely to affect the assessment substantially, should also be tested. An example of this may be the assumed distribution of willingness-to-pay bands in road-tolling exercises.

1.7.7 There are other sensitivity tests that should be undertaken for forecast years to test the sensitivity of the appraisal to variations in other inputs such as changes in the build-up of demand, values of time, or differing economic forecasts. These tests are described in more detail in the advice on Major Scheme Appraisal in Local transport plans: part 3. Annex F (DfT, 2003).

1.7.8 Although sensitivity testing is important, there is a danger in using it to obtain such a wide range of values that any prediction is mistrusted. In interpreting the results it is important to understand (and to emphasise in presentation) that the central values are still the best available prediction of the likely outcome, and additional forecasts obtained by sensitivity testing are purely to establish the effects of uncertainty around this central forecast. The aim is for the modeller to make clear the extent of the possible uncertainty, while providing clear central predictions to support policy making and assessment.
1.8 **Reporting**

1.8.1 The results of the realism tests, along with the sensitivity tests discussed in Section 1.7 should be documented in a validation report, either as an addition to the Validation Report required of all road scheme appraisals with regards to model calibration and fit, or as a separate document validating the variable demand aspects of the model. The items that should be included in a Validation Report are set out in significant detail in DMRB Volume 12 Section 2 Part 1.

1.8.2 The items in the Validation Report should include:

- a description of the model used and its development (including evidence of the fit achieved to the calibration data, and a description of any sensitivity tests undertaken, and their results);
- a description of the data used in building and validating the model;
- evidence of the validity of the network employed;
- a validation of the trip matrices employed;
- a validation of the trip assignment;
- a validation of any other special features (e.g. higher tier model inputs, trip end models, modal choice models, etc) employed; and
- a present year validation, if appropriate.

1.8.3 The validation of special features including details of the variable demand model chosen and should include at least the following items:-

- The background to the decision on the particular demand responses included in the model. This will include a statement on any demand tests.
- A description of the reasoning behind the choice of lambda parameter values, including any local calibration should be given. The parameter values should be explicitly shown together with details of the elements of generalised cost, and the route-choice factors.
- Where public transport schemes are being considered then the public transport assignment model will need to be validated.
- Details should be given of any realism tests, which should, at least, include the estimation of the elasticity of car travel (trips or kilometres) to changes in car fuel cost and, if possible, to car journey time. Where a mode-choice has been included the realism checks should also include the sensitivity to changing bus/rail fares. The Report should also include details of any changes to the model parameters arising from these tests.

1.8.4 Details should be given of any base year sensitivity tests undertaken.

1.9 **Main Changes from Existing Advice**

1.9.1 This Section describes those aspects of the Advice where the Department for Transport’s expectations of good practice have changed and where departures from existing guidance have been recommended

1.9.2 The intention of this Advice is to describe the basis of variable demand modelling as clearly and simply as possible, and to recommend simple versions of best current practice. It suggests a minimum set of requirements for testing transport scheme appraisal against the likely response of demand, and is intended to represent generally-accepted practice at this relatively basic level. Consequently, it is not aimed at suggesting fundamental changes to existing practice in demand modelling. However, because it is intended for application in the wider area of scheme assessment where, until recently, the response of travel demand to a scheme was often considered rather cursorily, if at all, it
does represent a significant step forward in general appraisal practice, and a change in the Department for Transport’s expectations of good practice.

1.9.3 The main points to note are the following:

- Overall, there should now be a presumption that the effects of variable demand and induced traffic on scheme benefits WILL be estimated quantitatively unless there is a compelling reason for not doing so.

- Throughout the Advice there are a number of important recommendations shown highlighted and in bold: if these actions are not followed, analysts will need to provide rigorous justification for the course of action taken.

- Even if induced traffic does not weaken the case for the scheme appreciably, the assessment may be criticised if it cannot demonstrate that the case is robust against possible changes in demand.

- In modelling demand, some segmentation by trip and traveller type is essential: at minimum there should be categorisation by trip purpose (at least home-based work/education, employer’s business, and ‘other’ purposes; some form of distinction between travellers with and without a car available is also very desirable, especially where mode-choice is to be considered.

- The amount of detail required in demand modelling will depend upon the particular application, since the effort and cost involved should be commensurate with the investment being assessed and the scale of its effects. Where a multi-level variable demand model is appropriate, it should include a distribution mechanism, and it will generally be desirable to include other mechanisms which can generate or suppress car trips as congestion reduces or grows.

- The Department’s long-established preferred approach to use an incremental rather than an absolute model, unless there are strong reasons for not doing so is reinforced by the above changes.

- Where variable demand modelling is justified, compatibility (convergence) between the assignment and the demand model(s) is very important. To optimise processing time and ensure true converged solutions the travel cost formulations used in both should contain the same ratio of weights of journey time relative to journey distance.

- The sensitivity parameters in the demand mechanisms should use robust calibrated local parameters wherever possible (from existing local models, for example). Failing this the Advice provides illustrative values in obtained from a review of current multi-stage demand models.

- The sequence of the distribution and mode split stages in the calculation hierarchy should depend upon the relative strengths of the sensitivity parameters, but trip frequency should always be calculated first and micro time period choice (peak-spreading), if it is to be included, will generally be lowest in the hierarchy. However, the sensitivity parameters should always increase along this sequence from highest to lowest, and this may require different sequences for different categories of travel.

- It is essential to apply “realism testing” to ensure that the model responds rationally and with acceptable elasticities. As a minimum, it is necessary to check the elasticity of demand with respect to car journey time and car fuel costs.

- It is also desirable to apply sensitivity testing to the results of the assessment against variation in those parameters that are uncertain. Generally, in a scheme aimed at congestion relief the net benefit will be reduced by increases in the demand for car travel, so that increasing the
sensitivity parameters in the demand mechanisms will test the robustness of the result. If the scheme remains well justified against these higher values then a conclusion that the scheme is beneficial will be robust against the effects of induced traffic.

2 Further Information

The following documents provide information that follows on directly from the key topics covered in this TAG Unit.

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<thead>
<tr>
<th>For information on:</th>
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<th>Link:</th>
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</thead>
<tbody>
<tr>
<td>Individual demand responses</td>
<td>Variable Demand Modelling - Key Processes</td>
<td>3.10.3</td>
</tr>
<tr>
<td>Background information on elasticity values</td>
<td>Variable Demand Modelling - Appendices</td>
<td>3.10.5</td>
</tr>
</tbody>
</table>

3 References


DMRB 12.2.2 HMSO February 1997 - withdrawn Summer 2004


4 Document Provenance

This Transport Analysis Guidance (TAG) Unit reflects the consultation comments received on the Convergence, Realism & Sensitivity Testing Stage of the draft Variable Demand Modelling Advice produced by TRL in June 2003.

Technical queries and comments on this TAG Unit should be referred to:

Integrated Transport Economics and Appraisal (ITEA) Division
Department for Transport
Zone 3/06 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
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11 Annex A – Segmentation and Values of Time for Road Pricing Models

   11.2 Segmentation
   11.3 Values of Time
   11.4 Local Values of Time
   11.5 Freight

12 Annex B – Modelling marginal social cost based prices

   12.1 Introduction
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13 Annex C – Core requirements for modelling road pricing

   13.1 Introduction
   13.2 General
   13.3 Segmentation
   13.4 Assignment
13.5 Demand modelling
1 Introduction

1.1.1 This Unit provides guidance on modelling requirements when projects include road pricing schemes. Where appropriate, it refers to guidance in other TAG Units, rather than repeating that guidance.

1.1.2 An overview of the modelling and appraisal issues, including scheme design issues, arising in the analysis of road pricing schemes can be found in Introduction to Modelling and Appraisal for Road Pricing (TAG Unit 2.12). Further detailed guidance for analysts may be found in:

- Designing Effective Road Pricing Schemes (TAG Unit 3.12.1), which discusses approaches to the design of effective road pricing schemes;
- Guidance on the issues arising when appraising road pricing schemes is provided in Appraisal of Road Pricing Schemes (TAG Unit 3.12.3); and
- Measuring the Social and Distributional Impacts of Road Pricing Schemes (TAG Unit 3.12.4) provides guidance on the use of social research methods to assess the social and distributional impacts of road pricing.

1.1.3 This Unit represents the current state of knowledge. This is a rapidly developing area where we are likely to learn from further development in modelling and design approaches and also from the practical implementation of road pricing schemes. This Unit will be revised and updated as further information becomes available or in light of any comments received during the application of the advice provided.

1.1.4 This Unit sets out the core requirements for the modelling of road pricing to support the development of a business case. A summary of the core requirements is given in Annex C.

1.1.5 As discussed in The Overall Approach: The Steps in the Process (TAG Unit 2.1), modelling is a key component of the study process and models should be used to inform the development of options. However, it will often be necessary to carry out preliminary analysis with a less than full suite of fit for purpose models. Where that course of action is taken, key decisions and detailed design should be revisited using the full suite of models when it becomes available.

1.1.6 Models should be sufficiently flexible to enable them to be used to explore a range of different strategies, including interventions other than road pricing. Flexibility is clearly needed during the early stages of the study process, when the precise form and location of the road pricing scheme is uncertain. It is also likely to be needed at later stages, to cater for changes in design (reflecting, for example, changes in views or circumstances) and sensitivity testing. The potential for models to be used for other purposes should also be kept in mind.
1.1.7 In some cases, simpler methods may be appropriate, while in other cases, more complex methods may be required. However, model simplification risks inadvertently biasing results, while increased complexity can lead to higher development costs and unsatisfactory model run times. Analysts should, therefore, provide a clear justification, based on the analytic requirements of the study in hand, for the use of models that are more or less complex than the core requirements. As a general guiding principle, models should be fit for the purpose, in that they should be capable of reflecting the outcome of road pricing schemes in a way which allows their impacts to be satisfactorily assessed.

1.1.8 Taken overall, with regard to road pricing, the model structure should be able to make allowance for all significant responses (these include frequency, change of time of travel, mode, destination and route) to pricing, and to allow for variations in response by purpose, person type and so on, as far as is useful and practical. It should also deal with secondary effects such as changed speeds for all classes of highway user (including buses), plus the likely effects on other modes of significant increases in demand (bus and rail overcrowding, for example).

1.1.9 Thus, as a core requirement, properly formulated variable demand and traffic assignment models are required to refine the preferred options and to support the business case. The variable demand model should include modules representing trip frequency, mode choice, macro time of day and trip distribution. The assignment model should include capacity restraint and junction simulation.

1.1.10 In some circumstances, it may be acceptable to omit some of these modules, but the decision to do so should start from the presumption that all are required. For example, for pricing schemes which do not vary appreciably by time of day, the choice of time of travel response could be dropped. However, the need to test a range of different options (see Introduction to Modelling and Appraisal for Road Pricing, (TAG Unit 2.12)) suggests that a fully specified model meeting the core requirements will usually be required.

1.1.11 It may also be appropriate to include additional modules representing land use, vehicle occupancy, public transport supply, parking and exemptions from road pricing. The decision to include additional modules will depend on the study area, the objectives set for the project, and the nature of the schemes to be examined.

1.1.12 There are two key issues for the modelling of road pricing that are of particular importance. These are:

- enhanced segmentation definition, to ensure that variations in willingness to pay road prices are fully reflected in the modelling; and
- representation of road pricing, including capability to estimate marginal social cost based prices.
These requirements are discussed in some depth below. Analysts should note that some of the methods proposed to address these requirements are new and have not been widely applied. It may be necessary to modify or refine them to suit the needs of a specific study. Where this is the case, close liaison with the Department is recommended.

2 Segmentation

2.1.1 Advice on segmentation is given in Variable Demand Modelling – Scope of the Model (TAG Unit 3.10.2). The guidance given in that Unit represents a core requirement for modelling road pricing. The Unit notes that, for schemes specifically involving pricing, some additional segmentation by willingness-to-pay or income, and possibly also by trip distance, may be required. This section discusses segmentation in general terms; the specific requirements for segmentation of the assignment and demand models are discussed in the sections of this Unit dealing with those topics.

2.1.2 Segmentation is important for the modelling of road pricing because it enables the representation of the availability or level of service provided by transport modes (car availability for example, or crowding on public transport), and the variation in responsiveness to changes in conditions across travellers. The value of time of a traveller is a key determinant of the behaviour of a traveller in responding to road pricing. Research has shown that the assumptions made about the values of time have a significant impact on the model’s performance. For example, variation of values of time with income and with purpose produce a greater level of diversion than using a single value of time for all car drivers. These are important second order effects. Inclusion of these aspects of value of time in the modelling assumptions is important if predictions about choices are to be reliable.

2.1.3 Segmentations by income and journey purpose are presented in Annex A, together with values of time for each segment. These segmentations and values of time have been obtained from national studies conducted on behalf of the Department for Transport. Use of the segmentation and associated values of time presented in this Annex is a core requirement for modelling unless more localised approaches are considered to be appropriate.

2.1.4 More localised approaches may be appropriate if there is good reason to believe that the study area is significantly different from the national average. Local segmentations and values of time should be derived from surveys of travellers who are expected to be within the catchment area of the road pricing scheme that is being tested.

2.1.5 Where the distribution by income and distance of trips in the study area is available, and significantly different from national, this information may be used to establish a local
segmentation. Values of time for local segmentations may be estimated using the method given in the Annex.

2.1.6 It may be necessary to explore the differential impact of prices on behaviour, relative to fuel or parking costs, or the impact of different payment methods (cash, credit card, pre- or post-payment and so on). Where this is the case, stated preference studies may be undertaken to establish local values and distributions of values of time. Guidance on the use of, and analysis of the results from, stated preference studies is given in Mode Choice Models: Bespoke and Transferred (TAG Unit 3.11.3). For road pricing studies, if undertaken where the choice is between a price and time savings, there is a risk that there will be some form of strategic bias compounded by potential misperceptions of time spent in congested conditions. Care is required to ensure that this does not invalidate the results. Care is also required to ensure that resulting values of time are sufficiently robust for use in modelling.

3 Representation of road pricing

3.1.1 Road pricing schemes have many characteristics. These characteristics are discussed in detail in TAG Unit 2.12. The discussion below considers only those characteristics that need to represented in the modelling.

3.1.2 The form of road pricing to be considered will affect the way in which it is represented in modelling. While the form of road pricing has a substantial effect on the way it is represented on the modelled highway network used for assignment, the way it is included in the formulation of generalised cost is common to all. In addition, in most cases (circumstances where this may not be necessary are discussed in section 4 below), the basic components of generalised cost (time, distance, road price, and other money costs) are skimmed from the network used in assignment and used to construct generalised costs for use in the demand model. Therefore, this section discusses the representation of road pricing in generalised cost in general terms, then goes on to discuss its representation on the modelled highway network for each of the principal forms of road pricing.

3.2 Generalised cost

3.2.1 The generalised cost of travel – usually a linear weighted sum of journey time and other journey costs – is the key determinant of people's travel choices in most transport models. The concept of generalised cost is discussed in Variable Demand Modelling – the Scope of the Model (TAG Unit 3.10.2). By including road prices in the formulation of generalised costs, transport models can estimate the impact of road pricing on traveller behaviour. Most transport models measure generalised cost in time units, so the usual approach to incorporating road prices in generalised costs is to divide the price by the appropriate value of time and add it to the other components of generalised cost.

3.2.2 Within the assignment model, it is important to allow for vehicle occupancy. For example:
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\[ G_{\text{car}} = T + D \times \frac{\text{VOC}}{\text{occ} \times \text{VOT}} + \frac{\text{RP}}{\text{occ} \times \text{VOT}} \]

where \( T \) is the journey time spent in the car, \( \text{VOC} \) is the vehicle operating cost per km for a journey of \( D \) km, \( \text{occ} \) is the number of people in the car (who are assumed to share the cost), \( \text{VOT} \) is the appropriate value of time, and \( \text{RP} \) is the road price for the journey.

3.2.3 If the demand model does not distinguish between car drivers and car passengers, the same formulation of generalised cost may be used for car users. However, if the model has been extended beyond the core requirement to distinguish between car drivers and car passengers, some assumptions will need to be made about the distribution of costs between drivers and passengers. In the National Transport Model, it is assumed that car drivers perceive their costs in full (though, as usual, non-work drivers are assumed to perceive only fuel costs), while passengers are assumed to perceive ‘guilt’ equivalent to half the money costs of the journey, in addition to the time costs. Analysts will need to consider whether this assumption is suitable for their study, or whether an alternative assumption is appropriate. In either case, the assumption adopted should be clearly stated and justified in model documentation.

3.3 Point, Screenline and Cordon pricing

3.3.1 These forms of pricing are probably the easiest to represent in modelling. Each link in the highway network that is to be priced is assigned a price. For screenline and cordon pricing, the price on all links will usually be the same, though it may, in principle, vary from link to link and some links may be unpriced. Prices may be represented as applying in one direction only, or in both directions. Prices will usually be set outside the model.

3.4 Distance pricing

3.4.1 For distance based pricing, each link to be priced must be identified and assigned a price depending on the link length. The price for each link is dependent only on the link length — it is unaffected by the link flow or other model outputs. Thus, the price may be estimated within the assignment model, or it may be set outside the model — both approaches are acceptable. The rate per unit distance may be the same for all links, or it may vary from link to link.

3.5 Area licences

3.5.1 Area licences, as implemented in the London Congestion Charging scheme, are more difficult to model, for two reasons. First, one payment allows the vehicle to be used for as many journeys as the driver wishes. This means that the cost per journey is difficult to estimate. Second, a payment (possibly at a lower rate than for those entering the area) is levied on vehicles based within the priced area if they use the roads, even though they may not cross the cordon.
3.5.2 Modelling area licence schemes also depends on the form of the assignment and demand models. The following paragraphs outline an approach that has proved successful, but the precise method adopted will need to be tailored to the model structure that is available.

3.5.3 An area licence scheme can be modelled by a combination of an inbound cordon price applied to trips generated outside the charged area (‘non-residents’) and a penalty price applied to all trips generated within the charged area (‘residents’). To facilitate this, it is necessary to segment the demand and supply models into residents and non-residents. The need for this segmentation, which is in addition to the segmentation required as part of the core requirement – see Segmentation, above – is explained below.

3.5.4 It is reasonable to assume that most trips are part of a daily ‘tour’, comprising, as a minimum, an outbound and return trip. Therefore, the price of an area licence should be ‘shared’ across all the trips in a typical daily tour. Ignoring non-home based trips would lead to a halving of the price to obtain the price per trip. However, an allowance for non-home based trips should be made.

3.5.5 The resulting price per trip is suitable for use as an in-bound only cordon charge, applicable to non-residents only, for use in the assignment model. Used in this way, it will ensure that alternative routes for through trips are appropriately priced and hence ensure that diversion is correctly modelled. Costs skimmed from the network for through trips will also be suitable for use in demand modelling and in appraisal.

3.5.6 Route choice is not an issue for non-residents ending their trip within the licence area, since all cordon crossings will be priced the same. However, using the price per trip as an in-bound only charge will mean that the price per trip will not be included in the costs skimmed from the network for outbound trips by non-residents. It will, therefore, be necessary to allow for this when generating costs to be used in the demand model or the appraisal.

3.5.7 The price per trip will also be suitable for use in the demand model and in appraisal as a penalty price for all trips made by residents, whether they cross the cordon or not. Costs skimmed from the network for these trips will not include the price per trip, since that is applicable only to trips made by non-residents.

3.6 Marginal Social Cost (MSC) based pricing

3.6.1 MSC based pricing may not be practical to implement, but it provides a useful benchmark against which to gauge the efficiency of more practical schemes. However, MSC based pricing presents a significantly different challenge for modelling.

3.6.2 MSC based prices are related to the flow on a link. Thus, the challenge is to identify the price that is consistent with the flow on each link in the priced network. Prices cannot be
estimated outside the model and input as is the case for other forms of pricing. They must be estimated within the model.

3.6.3 The estimation process will require an iterative procedure, iterating between price setting and model responses to the price. An approach that has proved successful in tests using the National Transport Model is outlined in Annex B.

3.6.4 Annex B assumes that MSC based prices will reflect three elements of external costs: the congestion impact of vehicles in delaying other vehicles; the impact on fuel consumption; and environmental costs. In some cases, particularly for local pricing schemes, it may only be necessary to consider the congestion element of the external cost. The use of approaches that focus upon the marginal external congestion costs to determine prices is discussed further in *Designing Efficient Road Pricing Schemes* (TAG Unit 3.12.1).

3.7 Other elements of road pricing schemes

3.7.1 Road pricing schemes may include prices that vary by vehicle class and/or by time of day. They may also include exemptions and discounts. It will often be desirable to represent these elements of the design of a road pricing scheme in modelling.

3.7.2 Pricing (or exemption) by vehicle type can be accommodated in models, provided the assignment model is appropriately segmented. However, modelling is unlikely to be sufficiently sensitive to enable more subtle vehicle typologies (by vehicle emissions group, for example) to be distinguished.

3.7.3 The ability to test pricing by time of day will be limited by the modelling of time of day effects. The core requirement is for the morning and evening peak and the interpeak periods to be modelled. If a time of day model is implemented, this will allow transfers between these broad time periods to be modelled.

3.7.4 Exemptions need to be considered against the objective of a scheme, which is to tackle congestion. It is therefore suggested that the starting assumption should be that any vehicle that contributes to congestion should be covered by the scheme. Where exemptions cannot be avoided, their impact on the effectiveness of the scheme must be carefully and thoroughly analysed.

3.7.5 Exemptions can take many forms. Some may have a significant effect on the impact of road pricing, others may be negligible. Where exemptions are expected to have a significant effect, they should be represented in modelling, to the extent that it is possible to do so. The following paragraphs outline some examples of exemptions that can be represented in modelling relatively easily.
3.7.6 Exemptions (including discounts) applying to specific user groups can be represented by appropriate segmentation. However, this is only likely to be worthwhile if the user group is quite large. Exemptions for small user groups may be excluded from some or all modules of the model. For example, they may be excluded from the variable demand modelling (thus implying a fixed matrix) but added into the matrix to be assigned to the network. Or they may be preloaded to the network if their routeing is expected to be fixed.

3.7.7 Exemptions (or discounts) may apply to certain geographical areas. Again, segmentation will allow a separate pricing structure to be established for the exempt locations. Discounts for those within the boundary of an area licence scheme can be relatively easily dealt with (at least approximately) by adjusting the penalty price to be charged for trips generated within the boundary.

4 Network Detail and Assignment

4.1.1 A good representation of the highway network is required, to provide robust estimates of the impact of re-routeing on traffic flows and speeds on priced routes and alternatives. The assignment model must be capable of reflecting the possibility of reallocating road capacity between different types of user.

4.1.2 The core requirement is for highway assignment (choice of route) to be dealt with by means of conventional network procedures. Further guidance on highway assignment can be found in Transport Models, (TAG Unit 3.1.2) and in DMRB 12.2.1, Traffic Appraisal in Urban Areas.

4.1.3 The likelihood that road pricing will result in differential re-routing must be considered carefully. For some cordon or area licensing schemes, it may be clear that there is little or no through traffic currently passing through the proposed priced area, or that the charge will be sufficiently high that almost all through traffic will be diverted to routes avoiding the proposed priced area. Where that is the case, standard highway assignment techniques will be satisfactory. However, where differential re-routeing is considered likely, it will be important to ensure that it is satisfactorily represented.

4.1.4 To ensure that differential re-routeing responses are satisfactorily represented, the highway assignment model must be segmented by user class, with a separate value of time for each user class. The core requirement for assignment segmentation is to ensure that the number of user classes is sufficient to represent the heterogeneity of values of time. It is recognised that, for practical reasons, the number of user classes is likely to be smaller than the number of segments used in demand modelling. However, it will usually be helpful for the user classes to be consistent with the segmentation adopted in the variable demand model. A user class structure based on vehicle class (lights and heavies), journey purpose (business and other), and, for those purposes representing a major proportion of
trips within a modelled period (usually ‘other’), by income has proved to be practical in past studies. Further guidance on segmentation is given above, under *Segmentation*.

4.1.5 Diversion could be a significant response where there are feasible alternative routes. If this is to be predicted realistically, it is important that the model represents realistically both the levels of congestion prevailing on the surrounding network and the journey times through it. Thus, it is a core requirement to employ an adequate representation of the network containing the alternative routes, including the effective capacity of minor roads, and of the prevailing levels of traffic on these roads. Zone size should be consistent with the level of network detail. The need to represent adequately the responses of short trips may dictate the use of relatively small zones (and correspondingly detailed networks) in key locations.

4.1.6 The use of a simplified model of the road network which does not take into account delays at all key junctions, including those on secondary routes, may tend to overestimate the amount of diverted traffic for a given price level. The core requirement is to model junction delays (including flow metering and, where necessary, blocking back) at all junctions likely to be affected by diverted traffic and, where there is doubt, include more, rather than less, junction modelling. Clearly, a capacity restraint mechanism is a core requirement. Further guidance on assignment modelling is given in Chapter 4 of *Traffic Appraisal in Urban Areas*, DMRB 12.2.1.

4.1.7 The ease and cost of parking will affect traveller response to road pricing: fiscal aspects of company provision are also relevant here. It is unlikely that road pricing can be considered without some attention given to parking policy and parking charges. In some road pricing systems, parking could be subsumed in the road price. Capacity effects in parking supply will lead to increased search times (and hence greater congestion) and, potentially, longer walking times: these impact on demand through changes in generalised cost. Where parking policy is expected to be an important issue, consideration should be given to going beyond the core requirement by representing parking in the model.

4.1.8 The journey time impacts of road pricing will affect on-street public transport journey times as well as those of private vehicles. These changes in public transport journey times must be taken into account in the appraisal of road pricing schemes. However, these changes will also make public transport more attractive, thus affecting mode choice. Where this seems likely to be a significant effect, consideration should be given to the inclusion of a public transport network. Clearly, journey times in the public transport network will need to be consistent with those on the highway network. Thus, some linkage between the highway and public transport networks will be required.

4.1.9 A public transport network will also be required where complementary measures are expected to include improvements to public transport. Where public transport networks are required, they should include a level of detail appropriate to model the likely modal switching expected. In some cases, a public transport assignment model and/or a public
transport sub mode choice model may be required. Further guidance on this is provided in *Road Traffic and Public Transport Assignment Modelling* (TAG Unit 3.11.2).

5 Demand Modelling

5.1.1 Where road pricing is envisaged, there is a wide variety of possible responses that travellers (and non-travellers) could make in the face of such prices. For those travellers already using the road in question the choices are to:

- Pay the price and continue travelling as before
- Change to a route with no (or a lower) price
- Change to a destination to avoid (or reduce) price
- Change to a time of travel when there are no (or lower) prices
- Change mode of travel (including to car passenger)
- Change trip frequency or decide not to travel at all.
- Any combination of these responses.

5.1.2 The extent to which these responses are represented in the model will be conditioned by the particular application in question, but most are likely to be required. Detailed guidance on variable demand modelling is given in *Variable Demand Modelling*, (TAG Unit 3.10). This represents the core requirement for modelling for road pricing.

5.1.3 As discussed above under Segmentation, segmentation to represent the distribution of traveller values of time is important for road pricing applications. Guidance on segmentation for demand models is given in *Variable Demand Modelling – the Scope of the Model* (TAG Unit 3.10.2). Segmentation to reflect the variation in value of time with income is a core requirement for modelling for road pricing.

5.1.4 Note that *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) recommends that macro time period choice (that is, choice between broad time periods, such as the peak and interpeak periods) should be considered when strong cost differentials between time periods are expected to develop or change. This is obviously the case where different road prices are proposed for the peak and inter peak or off-peak periods. In these cases it is obviously important to choose the modelled time periods to facilitate the modelling of the differential costs. The time period model should also fully reflect the effects of changing congestion levels within each modelled time period.

5.1.5 For some studies, mode switching may be an important alternative. This will depend on the availability of alternatives, the generalised costs of alternative modes and personal perceptions of alternative modes. Where mode switching is likely to have a significant impact on public transport, provision of a public transport network model should be considered – see *Network detail and assignment* above. Further guidance on mode choice modelling may be found in *Specification, Development and Use of Models for Major Public Transport Schemes*, (TAG Unit 3.11).
5.1.6 Modelling for the Road Pricing Feasibility Study suggested that increased car sharing is a potentially important response to road pricing. Analyses using the National Transport Model (NTM) showed that reductions in car driver trips were accompanied by large increases in car passenger trips. Monitoring of the London Congestion Charging scheme has also shown some increases in average occupancies of cars that still enter the charging zone. Analysts should, therefore, consider whether to extend their model beyond the core requirement to include the means to model changes in car occupancy. The NTM models car drivers and car passengers as separate ‘modes’. The main problem this poses is what to include in the generalised cost of car passengers. Clearly, they perceive the same car journey times as car drivers, though their access and egress times may be different. However, it is unclear whether they perceive car money costs and, if so, what weight they give to them. The approach adopted in the National Transport Model has been outlined in the discussion of generalised cost – see Representation of road pricing, above.

5.1.7 It is important that the assignment and demand models are iterated to an acceptable degree of convergence, otherwise the scale of response cannot be accurately predicted. Variable Demand Modelling – Convergence, Realism and Sensitivity (TAG Unit 3.10.4) recommends the use of the ‘demand-supply gap’ statistic as a measure of convergence and provides guidance on what is an acceptable level of convergence. Convergence in line with this guidance is a core requirement.

6 Other modelling considerations

6.1 Tiered modelling

6.1.1 The concept of operating forecasting models at different spatial levels, essentially to ease the computational burden, has been a feature of a number of models. The weaknesses inherent in aggregation of the supply representation can be reduced by taking a tiered approach to model formulation. In this configuration, the upper tier is the demand model with a spatially aggregate supply representation. The lower tier is a detailed network assignment model. The linkages need to ensure that the detailed model characteristics can be compressed to form the supply representation for the upper tier model, where travel demand forecasts are estimated. Demand forecasts from the upper tier model can in turn be disaggregated to the level of the detailed model zoning system, allowing their detailed routing implications to be tested and understood.

6.1.2 However, it is clear is that the problems of operating at different spatial levels have not been satisfactorily resolved. The use of two tiers of modelling - as for example where a high-level strategic model is coupled with a spatially detailed network model – can lead to inconsistent estimates of the scale of expected diversion from a given level of toll unless the speed/flow relationships embodied in the different levels are internally consistent and there is some degree of iteration between the layers.
6.1.3 The key difficulty is deriving a simplified representation of the detailed highway supply model that retains the realism and responsiveness of the detailed version. Recent work has suggested that satisfactory results may be obtained by:

- Using the detailed model’s network structure (pattern of links and nodes) in the simplified model;
- Deriving speed/flow relationships for each link in the simplified model to represent the relationship between the sum of link transit and junction delays and link flows for the corresponding link in the detailed model;
- Confirming that the simplified representation is satisfactory by ‘validating’ it against the speeds and flows estimated by the detailed model;
- Revisiting this process whenever significant changes are made to either the network or the pattern of demand; and
- Checking that the gap between demand estimated by the simplified model and supply estimated by the detailed model is satisfactorily converged.

6.1.4 With ever-increasing computation power, the need to operate at more than one spatial tier is reducing. Where this allows the use of tiered modelling to be avoided, it removes a major source of difficulty. However, it remains an obstacle for applying transport models in large areas. In addition, tiered models offer the potential advantage of fast turnaround for strategy testing, suggest that they will continue to be attractive to those carrying out major studies.

6.1.5 Tiered modelling is not a core requirement. However, if a tiered modelling approach is being considered, it is a core requirement that the demand estimated by the higher tier model and supply estimated by the detailed model meets the Department’s published guidelines for acceptable demand-supply convergence (see Variable Demand Modelling – Convergence, Realism and Sensitivity (TAG Unit 3.10.4)). There must always be a check that the demand response to a particular price predicted by the upper level is consistent with that predicted at the lower level, and especially that the aggregate speed-flow relationship of the higher level is fully compatible with that governing the network model.

6.2 Land use modelling

6.2.1 Patterns of land use are an important driver for transport demand. It is standard practise, therefore, to take account of changes in land use when using a transport model for forecasting. It is also generally accepted that transport impacts on land use, both in terms of the way existing developments are used and the pressures for new development. While transport models reflect some of these ‘feedback’ effects, a land use module is needed if all effects are to be captured.

6.2.2 Land use models can be used to estimate changes in the distribution of employment in an area, as a result of a transport scheme. Changes in employment location are an input to the analysis of impacts on productivity – see Transport, Wider Economic Benefits and Impacts on GDP (DfT, June, 2006). However, tests have shown that changes in generalised cost, rather than changes in employment location, are the dominant factor in
estimating employment densities and hence in forecasting changes in productivity due to agglomeration effects. Changes in employment location are also needed to calculate changes in productivity due to moves to more productive jobs, but experience to date suggests that agglomeration effects tend to be substantially larger than effects due to moves to more productive jobs. Thus, omitting modest changes in employment will not result in serious inaccuracy. So a land use model may be of value in the assessment of the productivity effects of schemes if one is available, but should not be developed solely for this purpose.

6.2.3 Land use modelling is not a core requirement. It may be appropriate for major schemes which are intended to have land use and/or economic impacts, or where there is public or political concern that schemes may have unintended land use and/or economic impacts. Where there are concerns about unintended land use and/or economic impacts, land use modelling may help to put those concerns in context, relative to long term underlying trends. Where this is the case, consideration should be given to the need to go beyond the core requirement to include a land use model when designing models for road pricing studies. Business cases should provide a reasoned justification for the decision reached, whether it is to include or exclude a land use model. Where a land use model is to be included, analysts should discuss their proposals with the Department.

6.2.4 Land use modelling may also contribute to the supporting analyses as well as to the core transport modelling and economic assessment tasks. It can enhance the analysis of the distributional impacts of road pricing both in space and across social groups and can help in the assessment of the extent to which the scheme contributes to policy objectives. For example, if policies are to support the economic vitality of core city centres as employment and retail centres, land use modelling may help to show whether road pricing, together with the complementary measures proposed, will support those policies.

6.3 Reliability

6.3.1 In many studies of road usage the issue of reliability is seen as critical. Unfortunately, modelling reliability and its impact on behaviour is not well developed. Relationships between the reliability of journeys and network characteristics (link geometry, junction design, traffic levels and so on) are very poorly understood.

6.3.2 For urban networks, simple relationships between the standard deviation of link transit time (the commonly accepted measure of reliability for highway modelling) and link capacity and traffic volume have been derived for suburban networks. Relationships of this kind were used in APRIL, developed in the early 1990s for the London Congestion Charging Research Programme. Further work on the database used in this study and on data collected in Leeds has been re-analysed and is reported in The Variability of Urban Travel Times (Black and others, 2004). It may be possible to incorporate these into traffic assignment models. Analysts interested in incorporating reliability into urban models should discuss this with the Department.
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6.3.3 For inter-urban networks, work in the UK has focussed on the impact of incidents on motorways. This work is unlikely to be suitable for use in traffic assignment models, though it may be used in the appraisal of road pricing schemes. By estimating the number of incidents and their impact on reliability with and without the scheme, the change in reliability can be estimated and valued.

6.3.4 Estimating the value road users place on reliability is difficult and there have been few studies into this. However, the Department is able to offer advice on values of the ‘reliability ratio’ that may be used to incorporate reliability into generalised cost. The reliability ratio is the ratio of the value of one unit of the standard deviation of travel time to one unit of travel time itself.

6.4 Modelling packages of measures

6.4.1 It will often be necessary to model road pricing in conjunction with other measures. Where this is the case, the modelling must be fit for purpose for modelling road pricing and fit for purpose for modelling whatever other measures are to be examined. This guidance focuses on the requirements for modelling road pricing. Guidance on modelling for other measures is given in other guidance documents in WebTAG or in the Design Manual for Roads and Bridges (DMRB).

7 Validation

7.1.1 The usual requirements for model validation are as important for modelling road pricing as any other transport scheme. Models for road pricing are expected to meet the same validation standards as any other model. General guidance on validation is given in Chapter 11 of the Traffic Appraisal Manual (DMRB Volume 12), while Traffic Appraisal in Urban Areas (DMRB 12.2.1) provides guidance on assignment validation for congested networks. Guidance on fitness for purpose tests for variable demand modelling is given in Variable Demand Modelling – Convergence, Realism and Sensitivity (TAG Unit 3.10.4).

7.1.2 It is important that the network model correctly reflects not only the absolute values of delays on links and at junctions in the base year, but also has the correct gradient for delays. This can be difficult to validate as it requires observations of delays for different flow levels, preferably over a wide range. Peak and off-peak journey time data and flows can help in this respect.

7.1.3 In addition, comparisons of peak and off-peak flow differences between observed and forecast flows can reveal anomalous results, such as opposite signs in those differences or large changes, that may provide an indication of a gradient problem.

7.1.4 In any event, where significant changes in routes are forecast, the realism of the model’s capacities and junction modelling should be examined under a range of different price
levels. Correspondingly, where forecast re-routeing of through trips is low, the realism of the model’s representation of minor roads should be examined.

7.1.5 Some curious routeings are implied by some models. This suggests that great care should be taken to ensure that routeings between origins and destinations are sensible, even in the no-price case. In all cases a check should be made on vehicle routeings to ensure that the routes chosen are behaviourally realistic. However, it should be recognised that circuitous routeing may be a logical and rational response in some circumstances. The imposition of road pricing may result in routes that would otherwise be unattractive becoming realistic unpriced alternatives to priced routes.

8 Further Information

The following documents provide information that follows on directly from the key topics covered in this Unit.

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</tr>
</tbody>
</table>

9 References

DfT (June, 2006) Transport, Wider Economic Benefits and Impacts on GDP

Highways Agency (1996) Traffic Appraisal in Urban Areas (Design Manual for Roads and Bridges (DMRB) 12.2.1)


10 Document provenance

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Technical queries and comments on this Unit should be referred to:
Integrated Transport Economic Appraisal (ITEA) Division
Department for Transport
Zone 3/08 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
11 Annex A – Segmentation and Values of Time for Road Pricing Models

11.1.1 This Annex presents the segmentations by income and journey purpose, together with the values of time for each segment for use in the modelling of road pricing schemes. The segments and values of time have been derived using national studies conducted on behalf of the Department for Transport. Segmentation by income is a core requirement for the modelling of road pricing schemes unless more localised approaches are considered appropriate.

11.1.2 If information is available on the distribution by income and distance of trips in the study area, then this may be used to establish local segmentations and local values of time may be estimated. More information on estimating local values of time is provided in this Annex.

11.2 Segmentation

11.2.1 For non-work trips, segmentation is provided for journey purpose (commuting, other, and total non-work trips) and income. For trips made in the course of business, segmentation is by income and mode. Based on national research, income has been segmented into three bands representing household income per annum in 2002 prices.

Segmentation for non-work trips

11.2.2 If data on income has not been collected, the table below provides the relative proportions, at the national level, of trips in each income segment for commuting and ‘other’ trips. Matrices may be multiplied by the factors given in the table to create separate matrices for each income segment. If commuting and other trips are combined (for assignment, for example), the proportions in the ‘all non-work’ column of the table should be used.

<table>
<thead>
<tr>
<th>Income Band</th>
<th>Commuting</th>
<th>Other</th>
<th>All Non-Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>£0&lt;£17500</td>
<td>23.5%</td>
<td>36.5%</td>
<td>34.1%</td>
</tr>
<tr>
<td>£17500&lt;£35000</td>
<td>44.9%</td>
<td>37.5%</td>
<td>38.8%</td>
</tr>
<tr>
<td>£35000&gt;</td>
<td>31.6%</td>
<td>26.0%</td>
<td>27.1%</td>
</tr>
</tbody>
</table>
11.2.3 Table A2 provides the relative proportions, at the national level, of trips made for business purposes by income band and mode. Information on other modes is available on request from the Department.

<table>
<thead>
<tr>
<th></th>
<th>Car Driver</th>
<th>Car Passenger</th>
<th>PSV Passenger</th>
<th>Taxi Passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>£0&lt;£17500</td>
<td>25.2%</td>
<td>41.3%</td>
<td>46.9%</td>
<td>17.3%</td>
</tr>
<tr>
<td>£17500&lt;£35000</td>
<td>22.7%</td>
<td>50.1%</td>
<td>41.9%</td>
<td>30.0%</td>
</tr>
<tr>
<td>£35000&gt;</td>
<td>52.0%</td>
<td>8.6%</td>
<td>11.2%</td>
<td>52.7%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

11.3 Values of Time

Values for Time for Non-Work Trips

11.3.1 Table A3 below presents the values of time for commuting, other and all non-work purposes segmented by income. The values presented are perceived costs and as consumers perceive costs in the market price unit of account, these values are also the market prices. The resource cost values can be calculated by dividing the perceived cost by the indirect tax correction factor, (1+t), where t is the average rate of indirect taxation in the economy. For further information on unit of account and indirect taxation see Values of Time and Operating Costs (Unit 3.5.6).

<table>
<thead>
<tr>
<th></th>
<th>Commuting</th>
<th>Other</th>
<th>All Non-Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>£0&lt;£17500</td>
<td>£2.66</td>
<td>£3.38</td>
<td>£3.27</td>
</tr>
<tr>
<td>£17500&lt;£35000</td>
<td>£4.33</td>
<td>£4.36</td>
<td>£4.47</td>
</tr>
<tr>
<td>£35000&gt;</td>
<td>£6.30</td>
<td>£5.24</td>
<td>£5.63</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>£4.85</strong></td>
<td><strong>£4.33</strong></td>
<td><strong>£4.52</strong></td>
</tr>
</tbody>
</table>

11.3.2 Note that the average values of time, £4.85 for commuting trips and £4.33 for other non-work trips, differ from those presented in Values of Time and Operating Costs (TAG Unit 3.5.6). This is due to differences in uprating the values in line with GDP. To ensure consistency, the values given here should be used when comparing appraisal results.
based on segmented values with those based on aggregate values. See *Appraisal of Road Pricing Schemes* (TAG Unit 3.12.3) for further details.

11.3.3 Growth in income may be assumed to be the same across all income bands. This implies that the boundaries of the income bands (£17,500 and £35,000) will increase, but the proportion of trips in each income band will be unaffected. The growth in the values of time for each band should be estimated by applying the forecast growth in the real value of non-working time, given in Table 3 of *Values of Time and Operating Costs* (TAG Unit 3.5.6).

**Values of Time for Working Trips**

11.3.4 Table A4 below provides values of time for work trips segmented by income and mode. Values for other modes are available from the Department on request. The table presents the perceived costs and as businesses perceive costs in the factor cost unit of account these values are also the resource costs. Market price values can be derived by multiplying the perceived cost values by the indirect tax correction factor as discussed above.

<table>
<thead>
<tr>
<th>Table A4: Values of Time for Work Trips (£/hr (2002 prices))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Driver Car Pass Car User PSV Pass Taxi Pass</td>
</tr>
<tr>
<td>£0&lt;£17500 £9.15 £7.05 £8.77 £8.02 £5.10</td>
</tr>
<tr>
<td>£17500&lt;£35000 £18.60 £17.57 £18.48 £18.27 £21.24</td>
</tr>
<tr>
<td>£35000&gt; £41.85 £42.76 £41.89 £44.85 £55.25</td>
</tr>
<tr>
<td>Average Value £21.50 £15.41 £20.78 £16.45 £36.36</td>
</tr>
</tbody>
</table>

11.3.5 As for the non-work purposes (see above), the average values of time, displayed in the bottom row, differ from those presented in *Values of Time and Operating Costs* (TAG Unit 3.5.6). Again, to ensure consistency, the values given here should be used when comparing appraisal results based on segmented values with those based on aggregate values.

11.3.6 As growth in income may be assumed to be the same across all income bands, the annual growth rates for work values of time as given in Table 3 of *Values of Time and Operating Costs* (Unit 3.5.6) should be applied to the values in the table above.

11.4 **Local Values of Time**

Local Values of Time for Non-Work Trips

11.4.1 If information is available on the distribution by income and distance of trips in the study area, then local values of time can be estimated using the model below. This is taken from *Values of Travel Time Savings in the UK*, a research study commissioned by the
Department for Transport and undertaken by the Institute of Transport Studies, University of Leeds in association with John Bates Services.

11.4.2 Data on household income and mileage travelled is required. This data should be collected in the segments that are to be adopted (these need not be the same as those discussed above). An average household income and an average mileage must be calculated for each of the chosen income segments as well as for the overall sample. (Note that it is important to calculate the average mileage for each segment, as well as the average income. Average mileage is likely to increase with income, so assuming the same average mileage for all segments will result in a biased result. The values derived using national studies and presented above take account of the national distribution of average mileage with income.)

\[
V_oT = K \left[ \frac{\beta_I}{\beta_c} \right] \left( \frac{Inc}{Inc_0} \right)^{\eta_{inc}} \left( \frac{D}{D_0} \right)^{\eta_c}
\]

11.4.3 The term K is a correction for inflation between the year 1994 and the year in which local data is collected. It is given by the Retail Prices Index (RPI) in the relevant year divided by the same quantity for 1994. Table A5 below provides the RPI and K values for years between 2002 and 2005 compared with 1994.

<table>
<thead>
<tr>
<th>Year</th>
<th>RPI</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>144.1</td>
<td>1.00</td>
</tr>
<tr>
<td>2002</td>
<td>176.2</td>
<td>1.22</td>
</tr>
<tr>
<td>2003</td>
<td>181.3</td>
<td>1.26</td>
</tr>
<tr>
<td>2004</td>
<td>186.7</td>
<td>1.30</td>
</tr>
<tr>
<td>2005</td>
<td>191.98</td>
<td>1.33</td>
</tr>
</tbody>
</table>

11.4.4 The parameter values for each non-work purpose are presented in Table A6 below. Inc represents the average household income in £'000 p.a. based on local data. Inc_0 is set equal to K multiplied by 35. D is the average distance travelled in miles from the local data and D_0 is 7.58 miles.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Commuting</th>
<th>Other</th>
<th>Total Non-Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_I$ (time coefficient)</td>
<td>-0.10098</td>
<td>-0.082918</td>
<td>-0.086344</td>
</tr>
<tr>
<td>$\beta_c$ (cost (distance) coefficient)</td>
<td>-0.024729</td>
<td>-0.022275</td>
<td>-0.021143</td>
</tr>
<tr>
<td>Inc_0</td>
<td>35 x K</td>
<td>35 x K</td>
<td>35 x K</td>
</tr>
<tr>
<td>D_0</td>
<td>7.58</td>
<td>7.58</td>
<td>7.58</td>
</tr>
<tr>
<td>$\eta_{inc}$ (income elasticity)</td>
<td>0.358773</td>
<td>0.156806</td>
<td>0.222585</td>
</tr>
<tr>
<td>$\eta_c$ (cost (distance) elasticity)</td>
<td>0.421305</td>
<td>0.314727</td>
<td>0.307487</td>
</tr>
</tbody>
</table>
The model and the parameters given in the table above will calculate the values of time for non-work purposes in the year you specify. The values will be expressed as market prices and in pence per minute. To convert to pounds per hour simply multiply the values by 60 and divide by 100.

Growth in the values should be treated in the same way as the nationally based values (see above). Table 3 in *Values of Time and Operating Costs* (Unit 3.5.6) provides the required growth figures.

Further guidance on the use of the ITS model is available from the Department on request.

**A Worked Example**

Assume that data has been collected in 2003 for three income bands. It has been found that the average income in each of these bands is £9,000, £26,000 and £55,000 respectively. Mileage data for each income band was also collected and the average mileage in each band was calculated to be 10 miles, 10 miles and 19 miles respectively. For the overall sample the average income was calculated as £22,500 and the average mileage is 11 miles.

Using this data, we can apply the ITS model to calculate the values of time for the commuting journey purpose for each segment, as follows.

\[
VoT_{1st} = 1.26 \left( \frac{9}{35 \times 1.26} \right)^{0.358773} \left( \frac{10}{7.58} \right)^{0.421305} = 3.86
\]

\[
VoT_{2nd} = 1.26 \left( \frac{26}{35 \times 1.26} \right)^{0.358773} \left( \frac{10}{7.58} \right)^{0.421305} = 5.65
\]

\[
VoT_{3rd} = 1.26 \left( \frac{55}{35 \times 1.26} \right)^{0.358773} \left( \frac{19}{7.58} \right)^{0.421305} = 9.68
\]

\[
VoT_{Overall} = 1.26 \left( \frac{22.5}{35 \times 1.26} \right)^{0.358773} \left( \frac{11}{7.58} \right)^{0.421305} = 5.58
\]

The values are in market prices at 2003 prices. To convert pence per minute to pounds per hour simply multiply the values by 60 and divide by 100. So for the example, the values of time would equal £2.32, £3.39, £5.81 and £3.35 for the first, second, third segments and for the overall sample respectively.

**Local Values of Time for Work Trips**

Estimating values of time for working trips requires data on mileage and individual gross income, (note this is different to the income required for non-work trips), and the calculation of a mileage weighted income. Income should be collected for a large number of income.
bands and total mileage should be collected for each of those bands. A mileage-weighted income is then calculated by multiplying the average income of each band by the total mileage for that band. To then segment income in to three segments as above involves summing the mileage-weighted income over a segment and dividing by the total mileage for that segment.

11.4.12 Added to this is an estimate for the non-wage labour costs such as national insurance and pensions. The Department uses a 21.2% mark-up for this, based on the 2000 Labour Cost Survey. This figure is then divided by the annual hours worked; at a national level this is 1804 hours. This gives the perceived cost for the year used and as businesses perceive costs in the factor cost unit of account these values are also the resource costs. The market price can be derived by multiplying the perceived cost by the indirect tax correction factor, see Value of Time and Operating Costs (Unit 3.5.6).

11.4.13 Growth in the values should be treated in the same way as the nationally based values (see 11.3.6). Table 3 in Values of Time and Operating Costs (Unit 3.5.6) provides the required growth figures.

11.4.14 Further advice and guidance on calculating local values of time for work purposes is available from the Department on request.

11.5 Freight

11.5.1 Segmentation by income for freight has been investigated by the Department. In the context of urban areas, given the low proportion of heavy goods vehicles (HGVs), income segmentation is not considered an issue but vehicle type segmentation could still be appropriate.

11.5.2 The Department is still investigating the impact on inter-urban flows and will shortly be commissioning research leading to the release of new guidance on freight modelling and freight values of time.

11.5.3 Currently the Department has a single value of time of £10.18 (2002 market prices and values) for freight business time savings for use in appraisal. This value applies to all vehicle classes and drivers as well as passengers. The values only represent the value of driver’s time and it is considered that this might be overlooking other important aspects of freight time savings benefits. For instance there could be a value applicable to the load being carried, no adjustment is currently made for unloaded vehicles compared with loaded, and some consider there to be a value for the just in time delivery. All of these aspects are to be examined in the research to be commissioned in the summer.
12 Annex B – Modelling marginal social cost based prices

12.1 Introduction

12.1.1 This annex provides advice on the modelling of marginal social cost (MSC) based prices in highway assignment models. The advice given is based on modelling work carried out in the Department to modify the assignment model within the National Transport Model suite to estimate marginal social cost based prices at the national level. It may be necessary to make changes to the methods suggested here when implementing them in other assignment models. Analysts are encouraged to discuss implementation with the Department.

12.1.2 The annex is presented in two parts. The first provides a detailed specification of some of the calculations required. The second section outlines techniques that can be employed for the iterative calculation of MSC-based prices with highway assignment models.

12.1.3 In some cases, particularly for local pricing schemes, it may only be necessary to use the congestion element of marginal external costs in determining prices. This is discussed further in Designing Efficient Road Pricing Schemes (TAG Unit 3.12.1)

12.2 Section 1. Calculation of marginal social costs and prices

12.2.1 In order to determine the correct price for a link, the ‘marginal social cost’ associated with using the link needs to be calculated. The marginal social cost is defined as the sum of two components:

- the time and vehicle operating resource costs directly associated with driving the length of the link in prevailing traffic conditions (the marginal private resource cost, $U$), and

- the resource costs imposed on society, i.e. the change in the total delay caused to all others on the link, and total change in vehicle operating resource costs faced by others on the link (the marginal external resource cost, $X$) by a marginal vehicle.

\[
MSC_m^k = U_m^k + X_m^k
\]

where:
- $m$ is the vehicle type (work car, non-work car, LGV, OGV and so on)
- $MSC_m^k$ is the marginal social cost for a vehicle of type $m$ using a link $k$
- $U_m^k$ is the marginal private resource costs incurred by vehicle type $m$ using link $k$
- $X_m^k$ is the marginal external resource costs (total additional costs) imposed on society by the marginal vehicle using link $k$
12.2.2 The marginal private resource cost is not the same as the perceived cost used in transport modelling. It represents those costs borne directly by the user, *measured in terms of the resources consumed*. As such, it does not include taxes or other charges that are transfer payments. Thus, vehicle operating costs (fuel and non-fuel) should exclude fuel duty and VAT for all traveller types.

\[
U_m^k = t_m^k \bar{v}_m^k o_m^k + r_m^k
\]

*Equation 2*

where:
- \(t_m^k\) is the congested time taken for vehicle type \(m\) to travel along link \(k\)
- \(\bar{v}_m^k\) is the average value of time per traveller in vehicle type \(m\) on link \(k\)
- \(o_m^k\) is the average occupancy of vehicle type \(m\) on link \(k\)
- \(r_m^k\) is the vehicle operating resource costs for vehicle type \(m\) on link \(k\)

12.2.3 Where different traveller types (user classes) are distinguished to represent different trip purposes or income groups and/or where information on varying vehicle occupancies is available, Equation 2 can be rewritten as:

\[
U_m^k = t_m^k \left( \frac{\sum v_c P_{mc}^k}{V_m^k} \right) + r_m^k
\]

*Equation 2b*

and:
- \(v_c\) is the value of time of travellers of type \(c\)
- \(P_{mc}^k\) is the number of people of type \(c\) using vehicle type \(m\) on link \(k\)
- \(V_m^k\) is the number of vehicles of type \(m\) on link \(k\)

12.2.4 The marginal external resource costs can be broken down into three parts – the rise in the time spent travelling by other link users (\(X(T)\)); the change in the vehicle operating costs of other link users (\(X(F)\)); and other changes in external costs such as environmental externalities (\(X(O)\)).

12.2.5 The marginal external resource cost associated with the additional congestion and time delays on a link, \(X(T)\) is calculated from:

- the rate of change of link transit time from a unit increase in traffic volume (these derivatives can be based on the model’s speed-flow function or may be derived from model outputs);
- the volume and type of trips affected
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\[
X(T)^k = \sum_{mc} \left( \frac{\partial t_m^k}{\partial Q^k} P_{mc} v_c \right)
\]

Equation 3

where: 
\[\frac{\partial t_m^k}{\partial Q^k}\] is the rate of change of travel time \(t\) for vehicle type \(m\) per equivalent vehicle (pcu) \(Q\) on link \(k\)
\(P_{mc}\) is the volume of people of type \(c\) travelling in vehicle type \(m\) affected by change in time on link \(k\)
\(v_c\) is the value of time of persons of type \(c\)

12.2.6 Note that \(X(T)\) is the marginal external congestion cost, MECC, discussed in the Annex to Designing Effective Road Pricing Schemes (TAG Unit 3.12.1). The equation given there can be shown to be an approximation to Equation 3 given in the box above.

12.2.7 The marginal external resource cost associated with changed vehicle operating costs due to changed link speeds, \(X(F)\), is calculated from:

- rate of change of vehicle operating resource cost from a unit increase in traffic volume (these derivatives may be based on the vehicle operating cost functions used in the model, on the vehicle operating cost models in Values of Time and Operating Costs (Unit 3.5.6), or they may be derived from model outputs)
- volume of vehicles by vehicle type affected

12.2.8 In this case fuel consumption is related to flow through the impact of flow on link transit time.

\[
X(F)^k = \sum_m \left( V_m^k \frac{\partial r_m^k}{\partial Q^k} \right) = \sum_m V_m^k \left( \frac{\partial r_m^k}{\partial t_m^k} \right) \left( \frac{\partial t_m^k}{\partial Q^k} \right)
\]

Equation 4

where: \[\frac{\partial r_m^k}{\partial t_m^k}\] is the rate of change in vehicle operating resource cost for vehicle type \(m\) on link \(k\) per unit change in travel time along link \(k\) for vehicle type \(m\)

12.2.9 The marginal external costs associated with environmental / other externalities can be complex to calculate. For the purposes of modelling they could be approximated as an external cost per vehicle kilometre.
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\[ X(O)^k = \sum_m \left( e_m^K d^K \right) \]  
Equation 5

where:  
- \( K \) is the type of the link \( k \) being used  
- \( e_m^K \) is the environmental / other externality cost per kilometre imposed by a vehicle of type \( m \) on a link of type \( K \).  
- \( d^K \) is the length (km) of link \( k \)

12.2.10 The terms in equations 2, 3, 4 and 5 can be drawn together to give the full marginal social cost of a vehicle using a link. In circumstances where \( X(T) \), the marginal external congestion cost, is large, it may be satisfactory to omit the marginal external resource costs associated with changed vehicle operating costs (\( X(F) \)) and environmental and other externalities (\( X(O) \)). However, where marginal external congestion costs are not large, it is important to include these terms.

12.2.11 The ultimate aim of the price setting process should be to determine a set of link prices that, when added to the average perceived private cost in the absence of road pricing for a vehicle of a given type, is equal to the marginal social cost of it using the link. The average perceived private cost in the absence of road pricing, \( Y \), is a demand-weighted average of the costs (including any existing tolls) faced by the users of a given vehicle type on the link. The average perceived private costs should include indirect taxation.

\[ Y_m^k = t_m^k \sum_c \left( \frac{P_m^k v_c}{Y_m^k} \right) + p_m^k + c_m^k \]  
Equation 6

where:  
- \( Y_m^k \) is the average perceived private costs in the absence of road pricing for vehicle type \( m \) using link \( k \)  
- \( p_m^k \) is the perceived vehicle operating costs for vehicle type \( m \) on link \( k \)  
- \( c_m^k \) is any existing toll on link \( k \) incurred by vehicle type \( m \)

12.2.12 The perceived vehicle operating costs should vary by vehicle type depending on whether non-fuel costs and VAT are perceived - see Values of Time and Operating Costs (TAG Unit 3.5.6).

12.2.13 The additional price \( c_m^k \) required on a link is the difference between the marginal social cost and the average perceived private costs in the absence of road pricing.
12.2.14 Note that, if private costs are correctly perceived, then the marginal social cost based price is equal to the marginal external costs minus the existing tax element of vehicle operating costs \((p_m^k - r_m^k)\) and any existing tolls.

12.2.15 Once a price has been levied, the demand for use of the link will change, as will the private and social costs. Consequently the price calculation problem needs to be solved iteratively. Section 2 (below) presents modelling techniques that may be used to determine equilibrium prices.

12.2.16 This analysis assumes that fuel duty and VAT will continue to be levied as now and thus the resultant equilibrium prices may be positive or negative. In congested conditions, where the marginal external costs are large, prices will be positive. In un-congested conditions, where the marginal external costs are minimal, the prices will be negative. This phenomenon reflects the fact that fuel duty and VAT are taxes levied on a per litre basis, and are not intended to capture congestion externalities. Consequently in some instances average perceived private costs in the absence of pricing may exceed marginal external resource costs.

12.2.17 A discussion of the merits of fuel duty and EU tax regulations is clearly beyond the scope of this guidance note. However, in order to model an efficient distribution of traffic across the road network, it may be necessary to include negative prices. It should be remembered when analysing and presenting results that the resultant system of marginal social cost prices are a theoretical construct for use as a sensitivity test, rather than an explicit representation of the prices that would be imposed under a possible future national road pricing regime.

12.3 Section 2. Methods for achieving equilibrium prices

12.3.1 An iterative process is required to calculate equilibrium marginal social cost prices for a transport model, because application of prices within the model will cause the flows on links and, therefore, marginal social costs, to change. This section presents techniques that have been applied with the Department’s National Transport Model to address this iterative problem.

12.3.2 The processes discussed below focus on establishing an equilibrium, given a fixed level of demand. This can be achieved using an assignment model in isolation. However, it is expected that road pricing will have an impact on demand, so the iterative processes below...
must be embedded within a demand/supply structure that is itself iterated to an acceptable level of convergence.

12.3.3 Two distinct approaches to solving the problem have been used. The first, faster technique requires the modification of traffic assignment software to calculate prices as part of the assignment process. The second technique can be applied without such software modifications but requires the repeated running of assignment software to achieve equilibrium prices.

12.3.4 The problem of finding equilibrium prices lends itself to solution with the algorithms used by assignment software. Assignment software packages already employ iterative techniques to find equilibrium flows and speeds for the links within a network. With software modification the same algorithms can be employed to determine equilibrium flows, speeds and prices. The Department employed consultants to modify the assignment software used as part of the National Transport Model to internally calculate and apply marginal social cost based prices.

12.3.5 It should be noted from the algebraic exposition above that the aim is to provide a price for each vehicle class. The analysis recognises that each vehicle class will include user segments with different values of time. Thus, in equation 6, the equation giving the average private costs for a given vehicle type, link transit time is multiplied by a weighted average of the values of time for each user segment. Similarly, in equation 3, the equation giving the marginal external congestion cost, traffic flows for a given vehicle class are subdivided by user segment and each segment is multiplied by the value of time for that segment. It is important to ensure that this analysis is correctly implemented in modified assignment software. This can be ensured by calculating prices in units of money.

12.3.6 Once the price for a vehicle type has been calculated, its use in the assignment is straightforward. If the assignment is in generalised time terms, the price has to be divided by the value of time for the specific user segment. If generalised cost is being used, link transit times must be multiplied by the value of time for the specific user segment.

12.3.7 Note that a segmented 'system optimal' assignment routine that represents externalities in units of time will return a price for each user segment, reflecting the value of time for that user segment. While such prices may be considered to be 'more optimal' than those resulting from the approach set out above, they are (even more) impractical.

12.3.8 The second technique does not require the modification of modelling software but is considerably slower. For this second technique the assignment software needs to be run repeatedly within an iterative price setting structure.
To aid the description of the second technique, a new concept is introduced – marginal residual cost. The marginal residual cost (MRC) is the difference between the marginal social cost $MSC^k_{mi}$ and the average perceived private cost $Y^k_{mi}$ for a given vehicle type for a given iteration.

**Equation 8**

\[ MRC^k_{mi} = MSC^k_{mi} - Y^k_{mi} \]

where: \( i \) is the price-setting iteration number

In effect, the MRC is the amount by which the price needs to be adjusted to internalise the externalities at a given flow rate. The aim of the price setting algorithm should be to reach an equilibrium where the MRCs for all of the links in the network are equal to or close to zero.

Equation 9 may be used for calculating the price for the first price setting iteration. In effect, a price of two-thirds (or alternative dampening factor) of the marginal residual costs is applied as a first estimate of the equilibrium price.

**Equation 9**

\[ \tilde{c}^k_{mi} = \tilde{c}^k_{m(i-1)} + sMRC^k_{m(i-1)} \]

where: \( i \) is the price setting iteration number (iteration zero is the reference case)

\( s \) is a dampening factor to aid convergence in congested networks (a dampening factor of \( \frac{2}{3} \) was found to be effective for the National Transport Model analyses)

Once this model run is complete and the marginal residual costs for iteration 1 have been calculated, one of two approaches may be adopted to reach price equilibrium.

- Continue with the method expressed in Equation 9, where two thirds of the marginal residual costs from the last iteration are added to the price from the last iteration to calculate the price for the next, or
- Use Equation 10 to interpolate/extrapolate, from the previous two price setting iterations, the price at which marginal residual costs would be zero.

**Equation 10**

\[ \tilde{c}^k_{mi} = \tilde{c}^k_{m(i-1)} + \left( \tilde{c}^k_{m(i-1)} - \tilde{c}^k_{m(i-2)} \right) \left( \frac{MRC^k_{m(i-2)}}{MRC^k_{m(i-2)} - MRC^k_{m(i-1)}} \right) \]
13 Annex C – Core requirements for modelling road pricing

13.1 introduction

13.1.1 This annex summarises the core requirements for modelling. Analysts may adopt simpler or more complex approaches. Where this is the case, clear justifications for departure from these core requirements must be provided, based on the requirements of the study in hand. The guiding principle is that the model should be fit for purpose.

13.2 General

13.2.1 Properly formulated variable demand and traffic assignment models to refine the preferred options and to support the business case are a core requirement.

13.2.2 It is a core requirement for the morning and evening peak and the interpeak periods to be modelled.

13.3 Segmentation

13.3.1 The guidance on segmentation given in Variable Demand Modelling - Scope of the Model (TAG Unit 3.10.2) is a core requirement for modelling road pricing.

13.3.2 Use of the segmentation by income and associated values of time presented in Annex A is a core requirement for modelling unless more localised approaches are considered to be appropriate.

13.3.3 The core requirement for assignment segmentation is to ensure that the number of user classes is sufficient to represent the heterogeneity of values of time.

13.3.4 Segmentation of the demand model to reflect the variation in value of time with income is a core requirement for modelling for road pricing.

13.4 Assignment

13.4.1 It is a core requirement for highway assignment (choice of route) to be dealt with by means of conventional network procedures.

13.4.2 It is a core requirement to employ an adequate representation of the network containing the alternative routes, including the effective capacity of minor roads, and of the prevailing levels of traffic on these roads.
13.4.3 It is a core requirement to model junction delays (including flow metering and, where necessary, blocking back) at all junctions likely to be affected by diverted traffic and, where there is doubt, include more, rather than less, junction modelling.

13.4.4 A capacity restraint assignment mechanism is a core requirement.

13.5 Demand modelling

13.5.1 Detailed guidance on variable demand modelling is given in *Variable Demand Modelling*, (TAG Unit 3.10). This represents the core requirement for modelling for road pricing.

13.5.2 *Variable Demand Modelling – Convergence, Realism and Sensitivity* (TAG Unit 3.10.4) recommends the use of the ‘demand-supply gap’ statistic as a measure of convergence and provides guidance on what is an acceptable level of convergence. Convergence in line with this guidance is a core requirement.

13.5.3 If a tiered modelling approach is being considered, it is a core requirement that the demand estimated by the higher tier model and supply estimated by the detailed model meets the Department’s published guidelines for acceptable demand-supply convergence (see *Variable Demand Modelling – Convergence, Realism and Sensitivity* (TAG Unit 3.10.4)).
Use of TEMPRO data
TAG Unit 3.15.2

November 2008

Department for Transport

Transport Analysis Guidance (TAG)
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1. **Summary**

1.1.1. TEMPRO is a program that provides projections of growth over time for use in local and regional transport models. It presents projections of growth in planning data, car ownership, and resultant growth in trip-making by different modes of transport under a constant-cost assumption.

1.1.2. Part of the role of TEMPRO is to act as a nationally-consistent benchmark distribution of growth in planning data and trip ends (i.e., the constant-cost response of transport demand due to demographic changes). This benchmark allows consistency between different parts of the country when justifying transport proposals, as well as reducing the risk of optimism bias.

1.1.3. The TEMPRO software presents the output of the Department’s National Trip End Model (NTEM). This is the final step in a chain of processes that form the TEMPRO system (see Figure 1).

![Diagram of the process of generating TEMPRO forecasts](image)

**Figure 1:** The process of generating TEMPRO forecasts

1.1.4. The planning data, consisting of demographic forecasts from national data sources of population, households and employment, are derived for forecast years through the Scenario Generator. This forecasts future year demographics through use of accepted projections and a methodology that ensures data consistency. For more information concerning the derivation of these forecasts, see the ‘TEMPRO Planning Data Guidance Note’ (DfT, 2006).

1.1.5. The car ownership model produces forecasts of household car ownership through the input forecast population data as generated through the Scenario Generator. This gives the propensity of households to own private vehicles based on the demographic make up of the area, as well as factors such as the type of area and levels of income. A summary of the operation of the car ownership model is in Annex A.
1.1.6. Finally, the trip end model produces forecasts of trip ends by mode, time period and car ownership. This uses demographic forecasts from the Scenario Generator and car ownership forecasts from the Car Ownership Model. NTEM uses this information in order to give forecasts of growth in trip ends over time by using the propensity of different types of households to make trips by mode, purpose and time. A summary of the operation of the trip end model is in Annex B.

1.1.7. TEMPRO is recommended for use in the following circumstances:

1) As growth factors for trip matrices in multi-modal models;

2) To derive trip growth factors for use in highway-only models, either with a fixed matrix or a variable demand model;

3) As growth factors in elasticity-based rail models;

4) To derive local adjustment factors which modify growth from the National Transport Model (NTM), for applications where there is no transport model.

1.1.8. Section 5 of this note describes how the figures should be used in each case.

2. Introduction

2.1.1. The TEMPRO program provides projections of growth over time for use in local and regional transport models. It presents projections of growth in planning data and car ownership and resultant growth in trip-making by different modes of transport (under a constant-cost assumption). The data presented is from the National Trip End Model (NTEM), which is operated and maintained by ITEA division of the Department for Transport. This guidance supersedes the TEMPRO Guidance Note (April 2006) that accompanied TEMPRO 5.

2.1.2. TEMPRO version 5 has been designed on the basis that data for each region can be individually updated, without changes to the software. The intention is to move to a system where, as each region issues new regional planning guidance, or carries out a new consultation on likely patterns of development within the region, ITEA division will work with the Government Office and/or regional planning body to produce a new TEMPRO dataset for that region.

2.1.3. One consequence of this is that the version number for the software no longer serves to identify a set of data. In order to specify what growth assumptions have been used in a particular study, it is necessary to note the version numbers for the data.

2.1.4. The structure of this guidance is as follows:

- Section 3 provides a general introduction to the National Trip End Model. This section discusses the context, meaning, and status of the figures.
- Section 4 looks at the structure of this version of the NTEM.
- Section 5 explains how the forecasts should be used in transport modelling.
3. The National Trip End Model (NTEM)

3.1. Background

3.1.1. With the focus of transport planning shifting to give greater emphasis to the competition between modes, the National Trip End Model has been developed to be fully multi-modal. TEMPRO provides multi-modal modellers with a set of predictions of growth in travel demand at the level of trip ends.

3.1.2. NTEM is now a fully integrated part of the National Transport Model (NTM) framework currently being developed by the Department. The NTM produces traffic forecasts, currently incorporating a substantial amount of new modelling work. These forecasts are available from the DfT web site (see references). This includes expected growth rates by vehicle type, including goods vehicles, which may be used to apply growth to freight matrices.

3.1.3. NTEM provides the demand growth inputs to the NTM, thus forming the starting point for national forecasting work, which is increasingly concerned with policy-sensitive forecasts. Publication of these inputs through TEMPRO allows local models to be developed on a fully consistent basis.

3.2. Trip ends & trip purposes

3.2.1. The NTEM model starts from the basis that each one-way trip by any mode has two trip ends. The model works by relating the number of trip ends in each zone to a range of demographic and land use factors, such as the number of households with cars in each zone and the number of people employed in each zone.

3.2.2. Trips are categorised as either home based (HB), having one end of the trip at the place of residence; or non-home based (NHB), having neither end of the trip at home. The purpose of the trip is determined by the destination purpose of the trip; except where the destination purpose is home in which case the origin purpose is used.

3.2.3. There are two alternative ways of describing the travel pattern:

- When travel patterns are constructed from roadside surveys the trips are logically described by the place the trip started and the place the trip finished, and the trip purpose of each end. This is usually known as an Origin-Destination (O/D) based trip pattern. Assignment models use this definition of the trip matrix.

- An alternative way of looking at the trip pattern is from the viewpoint of the factors that produce or attract trips, i.e. on a Production-Attraction (P/A) basis, with home generally being treated as the "producing" end, and work, retail etc as the "attracting" end. Trip production is usually defined as the home end of a home based trip or the origin of a non home based trip. Trip attraction on the other hand is defined as the non-home based end of a home based trip or the destination of a non home based trip. Changes in these P/A trip end forecasts over time or by scenario will lead to changes in the trip pattern. This definition of the trip matrix has normally been used in modelling travel demand.

3.2.4. The distinction between production/attraction and origin/destination matrices is most easily explained by the example of commuting trips from home. On an O/D
basis a commuter from the suburbs with a workplace in the city-centre completes one trip from suburb to centre in the morning and one trip from centre to suburb in the evening, say. On a P/A basis, the suburb 'generates' two commuter trips (there and back) and the centre 'attracts' two commuter trips. This distinction is most important when forecasting travel patterns in the future since, for instance, changes in workplace distribution may well be different from those in employee's residences. This can, in most circumstances, lead to different forecasts of trips depending on which of the two trip matrix definitions is used. When developing a four-stage model, it is standard practice to use P/As in the demand model and O/Ds in the supply model.

3.2.5. Figure 2 below gives another example of a commuter travelling to work in the morning, going to a shop and back to work in the afternoon and returning home in the evening. O/Ds and P/As are equivalent except for the return home-based work trip where the home end of the trip is the production end.

<table>
<thead>
<tr>
<th>Offpeak</th>
<th>AM peak</th>
<th>Interpeak</th>
<th>PM peak</th>
<th>Offpeak</th>
</tr>
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<tbody>
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</table>

**Figure 2:** Example of P-As and O-Ds for a sequence of trips

3.2.6. TEMPRO trip-ends are based on trip rates from the National Travel Survey (NTS) between 1988 and 1996, applied to projections of the household population. They therefore include all journeys made by people living in households in Britain, including trips where part of the journey is made by air.

3.2.7. There are 23 trip destination purposes identified by the NTS. These are aggregated in TEMPRO into 8 purposes, further split into HB and NHB trips. These categories are aimed at picking up a large part of the variation in destination land use, travel distance, and time of travel. The purpose categories in TEMPRO are as follows:

- Work
- Employers Business
- Education
- Shopping
- Personal Business
- Recreation / Social
- Visiting friends and relatives (NB: HB only)
holiday / day trip

3.2.8. In NTS, trips are only classified as to or from “visiting friends and relatives” if the journeys are to or from the home of the person(s) being visited. Thus a trip from “visiting friends and relatives” to another non-home purpose (such as going to work) has its production trip end at a place of residence. In the interests of locating such trips more accurately, TEMPRO treats this as a home-based trip, even though it is not from the home of the traveller himself/herself. Trips to visit friends and relatives are accordingly not divided into HB and NHB.

3.2.9. Trips to or from holiday bases are typically long distance and although few in number contribute significantly to the trip kilometres occurring each year. From NTS, 13.5% of holiday trips are in the 200 miles plus distance band. They also occur at different times of the week to most other purposes and so in transport models are treated as separate. The holiday trips are similar in nature to “day out” trips, and were thus combined with day trips to form a single category.

3.2.10. The home based employer’s business trip category is identified separately since although they are a small proportion of the total, their modal split and trip length characteristics are significantly different from journeys to work.

3.2.11. Non home based trips account for a relatively small proportion (less than 15%) of all journeys made.

3.2.12. To reiterate, the convention adopted in NTEM is that for home based purposes, one production and attraction tripend gives rise to one return journey (two origins and two destinations). For non home based purposes, one production and attraction give rise to a one-way journey (one origin and one destination). Annex B gives more detail on how P-A tripends in TEMPRO 5 have been converted to O-D tripends, including different methods of time period allocation.

3.3. Scope

3.3.1. The number of trips produced in each NTEM zone will depend on the number of people living there. Also the number of trips attracted to a particular zone will bear some relationship to employment in the zone, among other factors. Zones where employment or population are growing rapidly will, other things being equal, experience a high rate of trip end growth. NTEM is a forecast of trip ends by purpose, mode and time of day, based on these sorts of relationships.

3.3.2. TEMPRO tripends are based on National Travel Survey (NTS) trip rates applied to projections of the GB household population. The total therefore includes all journeys made by people living in households in Britain. For each trip purpose the total number of trip attractions is controlled to be equal to the number of productions at the level of “balancing areas”. These areas are derived from the 2001 Census and represent areas when in-commuting and out-commuting is reasonably self-contained to within a certain level of tolerance. The TEMPRO Planning Data Guidance Note contains more detailed information in the context of TEMPRO.

3.3.3. Analysis of the 1988-96 NTS data has looked at the change in travel patterns through time in terms of the yearly number of trips, of travel time and of passenger kilometres per person in GB. The findings show that distance travelled has increased quite rapidly, while travel time and number of trips per person have both grown quite slowly and at similar rates. The number of trips (by all modes) made does not vary enormously either over the years, or between areas of the country. Accordingly, it is not expected that trip rates per person will increase to any significant degree into the future.
3.3.4. The NTEM adopts people as the unit for trip making rather than households. However, the population is segmented into categories based on the characteristics of the households in which they reside as well as characteristics of the individual. The traveller type disaggregation used internally within the model includes the following, although the outputs are not available at this level of detail:

- age (under 16, 16-64, 65+)
- gender
- employment status (for 16-64 age group)
- household car availability
- household size (number of adults)

3.3.5. A constant trip rate is adopted for each of the disaggregate categories in the NTEM model. Projected total trips still increase over time, due to population growth and shifts in the distribution of population between categories (including car ownership bands). This modelling assumption of constant trip rate is only valid when all trips, including short walks, are counted in the model.

3.4. Mode

3.4.1. NTS distinguishes 19 alternative modes of travel. These have been combined to give six modes in TEMPRO as follows:

- Walk (includes NTS “short walk” trips)
- Bicycle
- Car drivers (includes motorbike and van driver)
- Car passengers (including taxi)
- Bus (including coaches)
- Rail (including underground and light rail systems)

3.4.2. Car drivers are separated from car passengers because they were found to differ significantly both by trip purpose and by the gender of the travellers.

3.4.3. NTEM estimates trip productions for each trip purpose, zone and traveller type. These estimates are further split into time periods and modes, based on a set of factors derived from the NTS data. For further information, refer to Annex B.

4. Structure of NTEM

4.1. Introduction

4.1.1. There are three stages to the TEMPRO projections, namely:

1) Planning data (Scenario Generator)
2) Car ownership (National Car Ownership Model)
3) Trip-ends (National Trip End Model)

4.1.2. Each of the three stages works at the level of NTEM zones – a system of around 2,500 zones covering Great Britain. These zones nest within local authority areas, splitting these areas into different area types, based on settlement size and population density.

4.1.3. The planning data used in NTEM are policy based forecasts of:

- population by age group
- households
- workforce
- jobs

4.1.4. The key definitions are as follows:

- A household is “one person living alone, or a group of people who share common housekeeping or a living room”. This definition is the same as is used in the 2001 Census, and in DCLG’s published household projections. Note that numbers of households are similar but not identical to numbers of dwellings.

- NTEM population figures are population in households, i.e. excluding the institutional population – elderly people in nursing homes, students and student nurses in halls of residence, etc.

- The workforce in a zone are those members of the resident household population aged between 16 and 64 inclusive who are in either full-time or part-time employment, including self-employed, HM forces and government-supported trainees.

- Zonal employment is the number of jobs in a zone, including full-time and part-time, including self-employed, HM forces and government-supported trainees.

4.1.5. The total number of jobs is not equal to the total workforce, because some of the jobs are filled by:

- The 65+ age group
- The institutional population (e.g. soldiers in barracks)
- Double-jobbers – those who hold down more than one (usually part-time) job.

4.1.6. From this detailed planning data set, the car ownership model further splits households according to their projected car ownership. The model draws on Family Expenditure Survey data over a number of years. This household-based model thus picks up both cross-sectional and time-series effects. From this study, the primary factors influencing car ownership are:

- A strong time trend, proxied by national growth in licence-holding
- Household income
- Household location (on a rural/urban scale)
Household structure (number of adults, whether all retired, number of children)

4.1.7. More recent work on this model has introduced responsiveness to car purchase and use costs and a company car effect. This model is described in Annex A.

4.1.8. The car ownership model outputs the number of persons in each of 88 car ownership/person type categories for each zone in each forecast year. The trip end model then applies to each of these a constant NTS-derived trip rate, for trips by all modes, for each trip purpose. These trip productions are then further segmented by "default mode" (using base year 1998 mode shares) and by time period, using a combination of NTS and 1991 Census journey-to-work data. These default mode splits represent a reference case that uses the base year mode split at the national level, rather than observed mode splits in particular areas.

4.1.9. Trip attractions are controlled to trip productions over a series of "balancing areas", with trip attractions being distributed in line with appropriate land use indicators. For example, figures on retail employment are used as the indicator variable for shopping trips. Annex B provides more details.

5. Application of TEMPRO growth factors

5.1. Introduction

5.1.1. This section provides guidance on how the figures in TEMPRO should be used in local forecasting. The key point is that these figures are not forecasts, they are "reference case" inputs to transport modelling, forecasting what is likely to happen if the base costs remain the same. The nature of this reference case is set out below. It is then up to the modeller to adjust the numbers to allow for the differences between the reference case assumptions and what they predict will happen.

5.1.2. This advice does not cover single-mode forecasting models for modes other than highway travel. Modellers wishing to use TEMPRO figures for this purpose should refer to *Forecasting and Sensitivity Tests for Public Transport Schemes* (TAG Unit 3.15.3) for public transport modes and *Rail Passenger Demand Forecasting Methodology* (TAG Unit 3.15.4) for guidance on using TEMPRO as growth factors in elasticity-based rail models.

5.1.3. Three distinct uses are identified, each covered in this guidance in turn:

- For multi-modal models;
- For highway-only models;
- For estimating highway traffic growth factors in the absence of a model.

5.2. TEMPRO growth factors are a reference case

5.2.1. For any movement where there is a choice of modes, the proportion of travellers choosing each mode ('modal split') is liable to change over time. Within a trip-end modelling framework, there are three possible reasons for such change:
a) Changes in the generalised cost of travel for the different modes (whether money cost, parking availability, speed, journey quality, or other factors).

b) Changes in the disutility that people attach to different elements of generalised cost, even when those elements do not appear to change. The principal effect here is that as people get richer, a fixed real money cost has a diminishing effect as a deterrent to travel. But this category also potentially includes the impact of changes in “taste”. For example, if cycling becomes increasingly fashionable, then the disutility of spending time on a bicycle may reduce, even if all the measurable characteristics of cycling remain unchanged.

c) Changes in demographic totals, which will have an effect even if the behaviour of each category of people and the costs that they face remain the same. For example, if elderly people make more use of bus than the general population, then an increase in the proportion of elderly people would be expected, other things being equal, to lead to increasing bus use.

5.2.2. The above comprehensive modelling framework is not affected by the existence of a target or declared policy for modal shift. Such a policy can only be effective if it leads to a change in costs or in perception of costs. Although it is important to ensure that models are consistent with observed trends, any observed trend in modal split is likely to be in essence some combination of these three factors.

5.2.3. TEMPRO models only the impact of (c), the demographic factors. They can be expressed as being a reference case at constant generalised cost and constant value of time, while allowing for the expected changes in car ownership as people become richer. It is then for local models to take account of:

- Generalised cost changes by each mode;
- Other impact of rising incomes - represented as increasing travellers’ value of time over time, leading to longer trips and a shift towards the more expensive modes;
- Any local policy action to influence travellers’ “taste” for different modes.

5.3. TEMPRO for multi-modal models

5.3.1. Multi-modal models can be classified as “strategic” or “detailed”. For this purpose, a strategic model is one where it is sufficient for the demand model to operate at the NTEM zone level, possibly with a proportion of demand being allocated to finer zones for assignment purposes. Conversely, a detailed model requires zonal trip ends or trip end growth which takes account of the differences between the characteristics of zones that are more disaggregate compared to NTEM zones. These zonal characteristics will be, for example, planning data, car ownership, base mode share, etc.

5.3.2. In the case of a strategic model, TEMPRO figures can be applied directly, as set out below. For detailed models, possible approaches include disaggregation methods or application of the National Car Ownership and Trip End models at the finer zone level. Contact ITEA division if this approach is contemplated.

5.3.3. Trip ends (either all-modes or by mode) may be an input to the matrix-building process. But note that (as in paragraph 4.1.8) the TEMPRO mode split is an NTS-based average by area type and person type, and does not reflect the particular characteristics of each individual local area.
5.3.4. The main use of TEMPRO is in forecasting. A typical multi-modal model will have base year trip matrices for car travel and for one or more public transport modes, with the public transport matrices segmented into car-available and non-car-available households (the non-car-available households assumed to be captive to public transport).

5.3.5. TEMPRO-based growth factors by mode and car availability should be applied to each matrix, to get to a future year reference case position. This represents what the future demand would be if there were no changes in the relative cost of each mode and no effects of income (beyond its effects on car ownership, which are included in TEMPRO). This reference case is the starting point from which the variable demand model runs an iterative process to reach an equilibrium position between demand and supply. This forms the core without-intervention case. See Forecasting Using Transport Models (TAG Unit 3.15.1).

5.3.6. All multi-modal models are designed to deal with changes in generalised cost, but the full impact of income growth on modal choice and on trip length is not always included. For further information on such cost issues, including values of time, refer to TAG Unit 3.15.1.

5.4. TEMPRO and highway-only models

5.4.1. The second possible application of growth factors is in the case of a relatively simple highway-only model that has fixed trip matrices. Where a scheme is of sufficient size or scope and shows evidence of potential congestion, a variable demand modelling approach should be used as recommended in VDM Preliminary Assessment Procedures (TAG Unit 3.10.1). This is because fixed trip models are not designed to deal with variable demand responses.

5.4.2. Where variable demand effects are considered insignificant for a scheme – ie suppression or induction of traffic is determined as negligible - the fixed matrix approach may be applied. This essentially is the application of TEMPRO growth factors to determine a future year fixed trip matrix, where the ‘without-intervention’ and ‘with-intervention’ matrices are identical.

The fixed demand approach

5.4.3. The TEMPRO factors used in fixed demand highway-only models is a reference case at base year cost. This means that changes in value of time and vehicle operating costs over time need to be accounted for. It should be noted that global changes in highway costs - such as those resulting from fuel cost changes or income growth - affect all car journeys.

5.4.4. With this in mind, the growth factors that are applied to base year trips to obtain the future year reference case need to incorporate all changes over time other than rerouting since trip frequency and modal split effects are not issues of concern in this situation. It is therefore appropriate, as an interim method, to use TEMPRO car driver trip-ends applied to row and column totals, with an additional global traffic growth factor representing the impact of income growth and fuel cost change. Note that the income and fuel price factors must only be applied in a highway-only model with a fixed trip matrix. Any model that accounts for variable demand invalidates their use since in these cases variable demand is being modelled explicitly.

5.4.5. Appropriate adjustment factors representing fuel cost and income effects are presented in Table 1.
Table 1: Fuel price and income forecast adjustment factors

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<th>Year</th>
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5.4.6. The standard method of applying trip-end growth factors is by multiplying base year trip matrix row and column totals by TEMPRO growth factors and then Furnessing the base year matrix to these totals. Since the Furness procedure only converges when row and column totals each have the same number of trips, the two estimates of the total trips in the matrix (one from the rows, one from the columns) need to be reconciled. This may be done by simply taking the average of the two estimates, and controlling both row and column totals to this total. Alternatively, if the matrix is held in production-attraction form, the productions may be deemed more reliable. This is because production trip rates are more accurate and household numbers more stable than employment numbers.

5.4.7. Where Furnessing the whole matrix is not possible because some movements (external – external) are not fully observed, the standard method is to Furness the fully-observed (internal – internal) movements and growth the remainder by the mean of the relevant row and column growth factors.
5.4.8. Forecasting assumptions underlying the fuel and income factors are:

- Car vehicle kilometres increase proportionately to income per car owning household with elasticity of 0.2 (or equivalently to GDP per household with elasticity of 0.16). Note that the TEMPRO tripends take account of the expected impact of income on car-ownership, so this elasticity figure excludes the effect of income on car stock, to avoid double-counting.

- Fuel price, vehicle fuel efficiency and market share of diesel in accordance with WebTAG Unit 3.5.6, although some recent fluctuations in fuel price have been smoothed.

- Elasticity of car vehicle kilometre per car to fuel cost of -0.25 (note that the current TEMPRO tripends do not take account of the impact of fuel cost on car ownership, so this elasticity includes the effect of fuel cost on car stock).

5.4.9. In summary, using a fixed trip matrix approach, the analyst must undertake the following in order to provide a future year trip matrix:

- Define the reference case by applying TEMPRO car driver trip end growth factors to the base year trip matrix;

- Apply global growth factors to represent the impact of income growth and fuel cost change;

- Furness the result to produce the future year trip matrix.

5.4.10. For modelling other vehicle types in highway models, growth factors from the NTM should be used. These should be adjusted by the TEMPRO ratio of growth in the study area to national growth (method as in para 5.5.2), to reflect differential change in economic activity in different parts of the country.

5.5. Using TEMPRO without a formal model

5.5.1. As the tripends alone do not incorporate the changes in fuel cost and VOT over time, TEMPRO growth in car trips is not suitable for direct use as a growth factor to be applied to traffic (vehicle kilometres). Where such a traffic growth factor is required in the absence of a traffic model, the Department's published forecast from the NTM should be used as the basis, with local adjustments as set out below. NTM forecasts are available from the Department’s web site at:

Example:

A matrix is required to be growthed up from 2000 to 2010.

TEMPRO growth should be supplemented with:

Overall income adjustment factor = 1.056 / 1.029 = 1.026

Overall fuel cost adjustment factor = 0.957 / 0.928 = 1.031

Therefore the initial growth factor for each origin and destination trip end of the matrix should be:

TEMPRO tripend growth * 1.026 * 1.031
The NTM forecasts give traffic growth by region, road type and whether the area is built up or not. TEMPRO factors should be used to tailor this published traffic forecast to local circumstances. This is done as follows:

- Calculate a growth factor indicating how car driver tripends for the local area in that time period compares to average day regional car driver tripend growth (both from TEMPRO)
- Apply this factor to the NTM traffic growth for the particular road type

Example:

Estimating AM peak period traffic growth from 2003 to 2010 on an uncongested rural trunk dual-carriageway road which in the judgement of the user primarily serves the Somerset area.

NTM growth on rural trunk roads in South West = 1.2

TEMPRO AM peak period car driver trip end growth for Somerset = 1.084 (average of origins and destinations)

TEMPRO average day car driver trip end growth for the South West = 1.096 (origins or destinations – same at Regional level)

Adjusted local peak period growth factor = \( \frac{1.2 \times 1.084}{1.096} = 1.187 \)

Note that it is the responsibility of the user to ensure that this simple approximation is appropriate for the particular location that they have in mind. For example, whereas it may be suitable to use zonal growth in trip rates to scale traffic for a local minor road, it may be more appropriate to use a more aggregate level of geography when estimating growth for strategic motorways or trunk roads.

5.6. Uncertainty

5.6.1. Multi-modal studies are used to appraise a wide range of transport measures (or packages of transport measures) against the multiple criteria set out in the New Approach to Appraisal. It is crucial that the recommendations of a model or scheme appraisal need to be robust to all elements of uncertainty in the assumptions and forecasts made. Guidance on the treatment of uncertainty can be found in *The Treatment of Uncertainty in Model Forecasting* (TAG Unit 3.15.5).

5.6.2. Formally accounting for uncertainty in modelling involves the systematic development of a ‘most likely’ do-nothing scenario and will often involve as a minimum some sensitivity testing of ‘optimistic’ and pessimistic’ scenarios. This allows the provision of a range of outcomes that consider the potential effects of uncertainty within the model. This gives decision-makers an idea of risk – the risk that a new facility will be under-used (and thus uneconomic) or over-used (and thus congested). Appropriate optimistic and pessimistic assumptions need to be drawn up in consultation with local planning authorities.
5.6.3. There are various sources of uncertainty. Those which have been shown in the past to be most significant are:

a) national economic uncertainty as to future levels of GDP growth and fuel price, both of which have a substantial impact on rates of traffic growth (at least in the short term)

b) political or commercial uncertainty as to whether individual large developments, or other transport projects than those being appraised, will go ahead

c) local economic or planning uncertainty, e.g. as to the success of local regeneration initiatives.

5.6.4. Quantifying political and local uncertainty issues (b and c) can only be undertaken using detailed local information. Analysis of the uncertainty in the NTM - component (a) – suggests that an appropriate allowance for this is to look at a range about the central forecast of ±2.5% for forecasts one year ahead, rising with the square root of the number of years to ±15% for forecasts 36 years ahead (ie 5% four years ahead, 7.5% nine years ahead, 10% sixteen years ahead, 12.5% twenty five years ahead).

5.6.5. Ideally, the study will be able to report that the recommended proposals are robust to this range of assumptions. Conversely, it may identify that the case for a particular transport measure is dependent on some other proposal, or on a particular local or national demographic or economic outcome. This type of information is exactly what decision-makers need to know.

5.6.6. The assumptions about uncertainty in traffic will affect the assessment of environmental impact such as noise, local air quality and emissions. Modellers should liaise closely with those carrying out environmental assessment to ensure that all are employing consistent assumptions about land use and so on, and to ensure that traffic uncertainty is fully reflected in the uncertainty about environmental impact.

5.7. **TEMPRO growth factors & developments**

5.7.1. NTEM aims to set out a robust “reference case” growth scenario for input to transport models. It should not be read as assuming the success or failure of any current or proposed policy initiative, land-use development, or infrastructure project. Where such policies or projects are likely to have a numerically significant impact on the case for a transport project, the project appraisal will need to take these into account.

5.7.2. Where a particular development proposal is likely to have a significant impact on demand for transport on one of the roads or rail services where transport measures are being considered, this should be allowed for by explicit modelling of trips associated with that development. Methods adopted for doing this need where possible to be consistent with those set out in the Transport Assessment for the development. It is important to ensure that modal split assumptions are realistic in the context of current planning policy guidance. The growth factors applied to non-development trips may then have to be adjusted downwards, to avoid double-counting of trips within the model.

5.7.3. Note that nowhere in the derivation of TEMPRO planning data is there an explicit assumption that particular developments do or do not go ahead. The identification of developments to model explicitly should depend on their local impact on the area of interest, not on any preconceived idea of whether the development is (perhaps implicitly) included in the existing growth factor.
5.7.4. Similarly, the correction of growth rates to avoid double-counting should be informed by a view as to the plausible overall population, household or employment growth in the zone, not by a local argument as to whether or not the development can be seen as “additional” in terms of the derivation of the TEMPRO figures.

5.7.5. Either because of this need to make adjustments for explicitly-modelled developments, or in constructing a low or high growth scenario, modellers may need to derive tripends relating to planning data assumptions other than those in TEMPRO. The following paragraph indicates how this can best be done.

5.7.6. The TEMPRO growth in household-related trips should be used as the basic building-block in calculating differential growth rates in development and other areas. That rate is the product of growth in number of households and growth in trips per household. Thus to a good approximation, any change in household numbers in a particular zone leads to a pro rata change in numbers of household-related trips. Similarly with employment. Based on an average mix of trip purposes, a reasonable rule of thumb is to assume that half of the trips or traffic are generated by/related to employment, and half to households. This assumption is built into the “alternative planning data” facility within the TEMPRO software, which calculates the first-order changes in trip growth likely to result from changes in planning inputs.
5.7.7. Part of the role of TEMPRO is to act as a nationally-consistent benchmark distribution of growth in planning data. Without such a benchmark, it would for example be easy to end up in a situation where every area of the country justified transport proposals on the basis of above-average employment growth. Given the need for model assumptions to be acceptable to local stakeholders, the Department does not insist that the central case in every study should be consistent with TEMPRO planning data.

5.7.8. However, as part of the process of sensitivity tests, one model run should be undertaken on the basis of planning assumptions consistent with TEMPRO at study area level (or the level of the Government Office region if this is smaller). This model run may need to be additional to the high, low and central cases discussed above. It is needed to allow those taking decisions on funding of proposals from different regions to assess the extent to which model results are dependent on departures from the benchmark planning assumptions.
5.8. **TEMPRO growth factors & airports**

5.8.1. Given the rapid recent growth in air travel, if the study area includes a major airport then it will probably be necessary to give particular attention to airport trips. One of the issues raised is the extent to which there is overlap between the number of trips in TEMPRO and projected airport use figures.

5.8.2. In the base year, trips connected with airport employment should already be adequately represented in TEMPRO.

5.8.3. TEMPRO does not currently include trip-ends representing the airport end of surface access trips by air passengers, or accompanying "weepers & greeters". All trips (including air travellers and their escorts) are included in the trip production totals, but their attraction ends are distributed according to the trip purpose. So that, for example, any holiday trips abroad by air, and relevant escort trips, appear in the TEMPRO base year trip-end figures as trips to GB holiday destinations.

5.8.4. Thus if trip-end totals are being used to estimate a base year matrix for the study area, an additional element representing surface access trips by air passengers and escorts to/from the airport in question should be added to the TEMPRO-consistent non-air matrix. This needs to be accompanied by a correction factor, restoring the TEMPRO trip totals over the whole of the catchment area of the airport.

5.8.5. Similar considerations apply when using TEMPRO and local adjustments to growth up an existing matrix to represent a future year. As always, modelling needs to be appropriate to the questions that the study is addressing. Studies that are specifically looking at the pattern of airport access trips, or where air travel is used by significant numbers of people for travel within the study area, may need a more detailed approach. But for many studies, the following approximation should be adequate.

5.8.6. Trips associated with increases in airport employment should be dealt with in the same way as any other major development. Local authorities should be consulted to assess what is a reasonable future year employment total for the relevant zone with the development in place. This should be compared with TEMPRO employment. If it is different, the TEMPRO trip-ends over a wider appropriate area should be redistributed, in accordance with the difference between this with-development view of the likely pattern of employment and the employment distribution in TEMPRO. The area over which this redistribution takes place needs to be appropriate to the type and scale of development, but should not extend beyond the Government Office Region without consulting the Government Offices for the other regions affected.

5.8.7. For trips associated with increases in numbers of air travellers, a simple assumption is that for every outbound air traveller with a trip production in the study area there is an inbound air traveller with a trip attraction in the study area. So that for each increase of two air passenger movements, the number of non-airport trip-ends remains constant, and the number of airport trip-ends (which are trip-ends in terms of surface travel, but intermediate change-of-mode points in the journeys of the travellers involved) increases by two. This might be thought of as one business trip from Stoke to Manchester city centre being replaced by one business trip from Stoke to Foreign Parts plus one trip by a foreign businessman to Manchester city centre (similar examples could be constructed for other trip purposes).

5.8.8. This simple approach assumes that growth in air travel replaces trips which are wholly within the catchment area of the airport (although they may involve external
zones in terms of a particular study). It also assumes that incoming travellers are as likely to travel by car (hired or otherwise) as outgoing travellers. A more complex and realistic approach might take a view as to the proportion of the growth in air trips to/from each region of Britain, and the extent to which these involve replacements for long-distance surface trips (and other modal shift effects) rather than increasing trip length (redistribution) associated with "globalisation" of the economy. As always, the complexity of the modelling needs to be appropriate to the scope of the study.

5.9. **Copyright statement**

5.9.1. All TEMPRO figures are Crown copyright, but may be freely reproduced provided that the source is acknowledged.

5.9.2. TEMPRO planning data projections are derived from Census data, which is Crown copyright and reproduced with the permission of the Controller of HMSO. Census output incorporates safeguards against the possible identification of any particular person or household. Users shall not use this material to attempt to obtain or derive information relating specifically to an identifiable individual or household, nor claim to have obtained or derived such information.

5.9.3. The Department for Transport is not a supplier of Census data, and does not guarantee that any particular number in TEMPRO is identical to the Census figure. Anyone wishing to reproduce Census data should obtain it from ONS or from a licensed distributor.

6. **Further Information**

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<td>TEMPRO user guide</td>
<td>TEMPRO download site <a href="http://www.tempro.org.uk">www.tempro.org.uk</a></td>
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<td>The National Car Ownership Model</td>
<td>NATCOP technical note</td>
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7. References


1. Documents and forecasts referenced are current at the time of the release of this Unit (December 2007). These may be subsequently updated and found at the referenced location on the DfT’s web site.

8. Document Provenance

This Document was produced in April 2008 to provide guidance on the use of the TEMPRO data sets. This replaces the TEMPRO Guidance Note of April 2006 that was available from the TEMPRO download site.

Technical queries and comments on this TAG Unit should be referred to:

Integrated Transport Economic Appraisal (ITEA) Division
Department for Transport
Zone 3/06 Great Minster House
76 Marsham Street
London
SW1P 4DR
itea@dft.gsi.gov.uk
Tel 020 7944 6176
Fax 020 7944 2198
Annex A: The National Car Ownership Model

Summary

The National Car Ownership Model (NATCOP) calculates the probability of households owning 0, 1, 2 and 3 or more cars for a given forecast year. This information is important in transport modelling, since household car ownership fundamentally affects the demand for travel of persons within each household. This is used in transport models to segment travellers into more detailed user classes in order to more accurately model travel behaviour and mode shift responses. Output from NATCOP is also fed into the National Trip End Model (NTEM) as part of the TEMPRO system. This affects the number and purpose of trips within that model when applied to trip rates by person type.

Car ownership within this model is determined by a combination of:

- Demography (household structure, age, etc)
- Income and the national economic background
- Type of area
- Other car-related factors (i.e., license holding, rates of company car ownership, etc)

The demographic data in the TEMPRO system is derived via the Scenario Generator and is fed directly into NATCOP by means of a target file. Other input assumptions such as income (growth) and GDP is taken from standard data sources used by the Department. Figure 1 shows the basic process involved in the generation of car ownership forecasts.

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**Figure 1: Generation of car ownership forecasts**

The model outputs the following information, all at the NTEM zone level:

- Households with 0, 1, 2 and 3+ cars;
- Households by number of adults and number of cars owned;
• Adults and children in households by number of adults and cars owned.

**Detailed background**

This car ownership model uses information on household income, household-type (defined by the number and age structure of residents) and area-type (loosely defined by population density) to derive a probability that a given household will own 0, 1 or 2+ vehicles.

Two separate models are calibrated on pooled cross sectional Family Expenditure Survey data at the household level. The first shows the probability that a household will own at least one vehicle \( P_{1+} \) and the second shows the conditional probability that a household will own two or more vehicles \( P_{2+|1+} \).

\[
P_{1+} = \frac{S_{1h}}{1 + \exp(-LP_{1+})}
\]

\[
P_{2+|1+} = \frac{S_{2h}}{1 + \exp(-LP_{2+|1+})}
\]

and

\[
P_{2+} = (P_{1+}) \cdot (P_{2+|1+})
\]

\[
P_1 = (P_{1+}) - (P_{2+})
\]

\[
P_0 = 1 - P_1
\]

\( S \) is the saturation level (an assumed maximum number of cars per household) and \( LP \) is termed the ‘linear predictor’. This predictor is the linear combination of explanatory variables used during the estimation process.

Originally, both household car ownership models were calibrated using standard logistic regression techniques involving the multi-stage process shown below:

\[
LP_1 = d + d_t + (f + b_h) \log(G_t Y)
\]

\[
LP_2 = LP_1 + d' + (b_a + f') \log(G_t Y)
\]

\[
LP_3 = k + (b + b_h + b_a) \log(G_t Y)
\]

\[
LP = k + k'(LPA_t) + (b + b_h + b_a) \log(G_t e_a Y)
\]

In the first instance \( LP_1 \) is taken as a function of a constant \( d \), a year specific constant \( d_t \) and household income \( Y \) segregated by household category \( h \). \( G_t \) is the annual growth over the base period in income in period \( t \).

Next, the ‘residuals’ of the \( LP_1 \) model are explained in \( LP_2 \) as a function of a new constant \( d' \) and household income segregated by area-type \( a \).

Models \( LP_1 \) and \( LP_2 \) are then combined (without re-calibration) to form \( LP_3 \), where \( b = f + f' \) and \( k = d + d_t + d' \). \( LP_3 \) was not estimated directly over the period 1971 to 1991 since area type factors were unavailable in 1976 and 1981.

Further modifications are made to the model to derive \( LP \). Here the constant \( k_t \) in \( LP_3 \) is adjusted by the number of licences per adult to \( k + k'(LPA_t) \).

In order to replicate the base market shares in different areas, base income \( Y \) in the final model (\( LP \)) is adjusted by \( e_a \) in each area-type until base market shares are correct.
Following a review of the NATCOP models carried out by ITS in 1999 (Whelan, 1999) a new functional form for the linear predictor that could be estimated simultaneously rather than by the multi-stage process above was developed. The functional form of the modified linear predictor is shown in equation 10 below.

$$LP = k + k' + t(LPA) + (b + b' + b_h + b_a) \log(Y)$$  \hspace{1cm} (10)

Where:

- $k$ is a constant
- $k'$ revised constant for 1976 and 1981.
- $t$ is a time trend coefficient that is attached to LPA
- $LPA$ is licenses-per-adult
- $b$ is the coefficient on the log of income term
- $b'$ is a revised coefficient for income for 1976 and 1981
- $b_h$ a modifying parameter based on household category
- $b_a$ a modifying parameter based on area type
- $Y$ income (this has not been adjusted to take account of differences between regions)

Note that $k'$ and $b'$ relate to the years 1976 and 1981. They are included to capture the impact of omitting area type impacts in those years and are not required for forecasting.

In the past it was suggested that the provision of company cars had relatively little impact on 1+ car ownership because it was said "the household involved would have at least one car anyway". Whilst this is a reasonable assumption to make, omitting reference to company cars within an ownership model ignores the possibility that "households with a company car are more likely to own a second car than are comparable households whose first car is privately purchased".

Because the FES data set does not contain information on the ownership status of the household vehicle fleet it was necessary extract data from the 1991 National Travel Survey to test this hypothesis. The new ownership models, calibrated on a joint FES/NTS data set have the same structure as the existing NATCOP models but include an additional variable to account for the company car issue. Further modifications to the form of the linear predictor are also needed to take account of differences in the definitions of area type in the two data sets. The modified "linear predictor" is shown below:

$$LP = k_{FES} + k_{NTS} + t(LPA) + (b + b_h + b_{FES} + b_{NTS}) \log(Y) + gCC_{NTS}$$  \hspace{1cm} (11)

Where:

- $k_{FES}$ is a constant where FES data is used
- $k_{NTS}$ is a constant where NTS data is used
- $t$ is a time trend coefficient that is attached to LPA
- $LPA$ is licenses-per-adult
- $b$ is the coefficient on the log of income term
- $b_h$ a modifying parameter based on household category
- $b_{FES}$ a modifying parameter based on area type definitions in the FES database
- $b_{NTS}$ a modifying parameter based on area type definitions in the NTS database
Y income
g is the coefficient on the company car dummy
CC_{NTS} is a company car dummy variable.

A company car dummy variable is included in the P_{2+1} model and is set equal to 1 if one of
the household’s stock of vehicles is provided by a company, else it is 0. This variable is also
included in the P_{3+2+1} model together with an additional company vehicle dummy which it is
set equal to 1 if two of the household’s stock of vehicles is provided by a company, else it is 0.

In general, the new car ownership model has been enhanced to incorporate:

- sensitivity to ownership and use costs;
- sensitivity to changes in the level of company cars;
- variation in saturation levels by area and household type;
- employment effects; and
- multi car households (3+)

The new models are applied using a new methodology known as prototypical sampling. This
is explained further below. This method allows the application of the ownership models to
each NTEM zone taking into consideration changes in demographic characteristics for each
forecast zone.

The parameters used in the car ownership model are shown in Table 1, where household
types and area types are as follows:

| HH1 | One adult, not retired |
| HH2 | One adult, retired |
| HH3 | One adult, with children |
| HH4 | Two adults, retired |
| HH5 | Two adults, no children |
| HH6 | Two adults, with children |
| HH7 | Three adults, no children |
| HH8 | Three adults, with children |
| Area1 | Greater London |
| Area2 | Metropolitan Districts |
| Area3 | Districts with density greater than 7.9 persons per hectare |
| Area4 | Districts with density between 2.22 and 7.9 persons per hectare |
| Area5 | Districts with density less than 2.22 persons per hectare |

The main input into the car ownership model are average household income growth which
takes into account the predicted increase in GDP, factors which represent increase in licence
holding and a purchasing cost index which represent the predicted cost of owning a car over
time.
| Table 1: Recommended Models for Forecasting (income in 1991 absolute levels) |
|-----------------------------|------------------|------------------|
|                            | P1+              | P2+|1+              | P3+|2+|1+              |
| K (ASC)                    | -3.110 (32.2)    | -1.003 (6.8)     | -0.5980 (1.7)    |
| T (LPA)                    | 2.384 (16.6)     | 2.131 (10.0)     | 1.020 (1.8)      |
| b (Income)                 | 0.00022118 (20.1)| 0.00004616 (3.8) | 0.0             |
| HH1                         | 0.0              | 0.0              | 0.0             |
| HH2                         | -0.00009691 (11.5)| 0.0            | 0.0             |
| HH3                         | -0.0004532 (5.2)  | 0.0              | 0.0             |
| HH4                         | 0.00004732 (3.8)  | 0.00006713 (6.2) | 0.0             |
| HH5                         | -0.00001791 (0.2) | 0.0003448 (2.8)  | 0.0             |
| HH6                         | 0.0001229 (1.5)   | 0.0002877 (2.3)  | 0.0             |
| HH7                         | -0.00005118 (6.3) | 0.00005942 (4.7) | 0.00004300 (11.0)|
| HH8                         | -0.00007167 (8.7) | 0.00005764 (4.2) | 0.0003433 (8.6) |
| Area1                       | 0.0              | 0.0              | 0.0             |
| Area2                       | -0.000008401 (1.1)| 0.0            | 0.0             |
| Area3                       | 0.0000016 (2.1)   | 0.00001073 (3.4) | 0.000008786 (2.5)|
| Area4                       | 0.00007461 (8.5)  | 0.00001910 (4.7) | 0.00001173 (3.4) |
| Area5                       | 0.0001049 (10.3)  | 0.0002090 (4.9)  | 0.000009421 (2.3)|
| Company Car 1               | N.A.             | 1.631 (7.9)      | 0.3657 (1.7)    |
| Company Car 2               | N.A.             | N.A.             | 0.9742 (2.6)    |
| Employment (numbers)        | 0.1666 (7.0)     | 0.2283 (7.9)     | 0.4238 (8.5)    |
| Purchase Cost               | -0.003235        | -0.02549         | -0.02517        |
| Running Cost                | -0.000568        | -0.003926        | -0.004283       |
| Implied Saturation Area 1, HH 1-3 | 0.6862        | N.A.             | N.A.            |
| Implied Saturation Area 1, HH 4 | 0.7698        | N.A.             | N.A.            |
| Implied Saturation Area 1, HH 5-8 | 0.9202        | N.A.             | N.A.            |
| Implied Saturation Area 2-5, HH 1-3 | 0.8751        | N.A.             | N.A.            |
| Implied Saturation Area 2-5, HH 4 | 0.9283        | N.A.             | N.A.            |
| Implied Saturation Area 2-5, HH 5-8 | 0.9705        | N.A.             | N.A.            |
| Implied Saturation Area 1, HH 1-4 | N.A.          | 0.2929           | N.A.            |
| Implied Saturation Area 1, HH 5 | N.A.          | 0.6410           | N.A.            |
| Implied Saturation Area 1, HH 6-7 | N.A.          | 0.7601           | N.A.            |
| Implied Saturation Area 1, HH 8 | N.A.          | 0.6623           | N.A.            |
| Implied Saturation Area 2-3, HH 1-4 | N.A.          | 0.2844           | N.A.            |
| Implied Saturation Area 2-3, HH 5 | N.A.          | 0.7480           | N.A.            |
| Implied Saturation Area 2-3, HH 6-7 | N.A.          | 0.8632           | N.A.            |
| Implied Saturation Area 2-3, HH 8 | N.A.          | 0.7736           | N.A.            |
| Implied Saturation Area 4-5, HH 1-4 | N.A.          | 0.3511           | N.A.            |
| Implied Saturation Area 4-5, HH 5 | N.A.          | 0.8158           | N.A.            |
| Implied Saturation Area 4-5, HH 6-7 | N.A.          | 0.9333           | N.A.            |
| Implied Saturation Area 4-5, HH 8 | N.A.          | 0.8885           | N.A.            |
| Global Saturation           | N.A.            | N.A.             | 0.7946          |
| Final Log Likelihood        | -21003.9758     | -12919.0592      | -2938.6253      |
| No Obs                      | 46137           | 28472            | 7838            |
Forecasting method

Introduction

The objective of this section is to detail both the methodology and practical application of prototypical sample enumeration techniques to forecasting car ownership at NTEM zone level using the NATCOP car ownership models.

Basis of the procedure

The objective of disaggregate modelling as applied to travel demand forecasting is to explain the choices made by individual decision-makers. This approach has proved very successful as a basis for the development of models and through the technique of sample enumeration, disaggregate models have also been used successfully for short-term forecasting. However, because straightforward applications of sample enumeration do not take account of the changing nature of the population (e.g. the general “greying” of the population), longer-term forecasting is not possible. To fill this gap, the technique of prototypical sample enumeration has been developed.

Disaggregate Models and Sample Enumeration

A key characteristic of disaggregate modelling is the statistical approach that it inherently takes to the analysis of data. This approach recognises that it is not possible to predict correctly how each individual (or household) in a population will behave, but this does not prevent information being obtained on the variables that influence – rather than determine – behaviour. The model for each individual is then formulated as

\[
\Pr \{ c_i=k \mid K_i, S_i \} = p_i(K_i, S_i) \tag{12}
\]

giving the probability that the choice \( c_i \) of individual \( i \), whose characteristics are \( S_i \), will be alternative \( k \) from the choice set \( K_i \) (which has availability and characteristics specific to individual \( i \)). It is a primary objective of the modelling then to specify how the alternatives in \( K \) are described and which characteristics \( S \) are relevant. A further important task in the modelling is to determine the form of \( p \) and estimate the values of unknown parameters that appear in it.

In order to make useful forecasts a means must be found to aggregate, to derive from a model predicting the behaviour of individuals a forecast of the behaviour of an entire population. An important point is that it is not correct simply to set \( K \) and \( S \) to the average population values and apply equation (12) as if the entire population behaved like a mass of identical average individuals: this overstates the response to changes, an effect known as aggregation bias which has long been recognised (e.g. Daly, 1976, Gunn, 1984). Similarly, the model (12) cannot be used directly to calculate elasticities, again this leads to an overstatement of responsiveness.

A technique that does not have this disadvantage is sample enumeration. Essentially, sample enumeration simply applies the model (1) to each member of a sample in turn. Then, if the sample is representative, the sum of the forecasts for each individual is the unbiased forecast for the whole population. Formally, the expected demand \( Q_k \) for an alternative \( k \) is given by

\[
Q_k = \sum_i w_i \cdot p_i(K_i, S_i) \tag{13}
\]

where \( w_i \) is the expansion factor or weight attached to individual \( i \) in the sample in order to make its sum representative of the population. Very often, the sample used for forecasting is the same sample used for model estimation, while the weights \( w \) are determined by the sampling process used.
The advantages of sample enumeration using the basic equation (13) are its simplicity and convenience. The forecasts are unbiased. It is important to note that the procedure of sample enumeration is entirely independent of the form of the model that is used for forecasting: logit, linear, whatever model is used can be applied in this way.

The primary disadvantage of sample enumeration is that a representative sample may not be available, perhaps because the model is being transferred in time or space. In particular this will always be true when a forecast is required over any considerable period, so that a base-year sample can no longer be considered representative.

The conclusion is that the advantages of sample enumeration are substantial in some circumstances and therefore that it would be advantageous to be able to apply the technique more widely. A means was therefore required for generating representative samples for circumstances different in space or time from those for which real samples are available.

**Prototypical Sampling**

The most obvious way to produce samples representative of future conditions is to generate an artificial population which has, as far as is known, the characteristics of the future population. However, the forecasts that are generally available – e.g. from planning authorities – typically refer to aggregate statistics such as age-sex population distribution, rather than the composition of individual households. A method is therefore required for generating a sample of households that is internally consistent, i.e. that it ‘looks like’ a typical population, while also achieving consistency with such aggregate statistics as are available.

The objective of the method is thus to use an existing household sample to produce a sample that is or will be representative of one or more target areas. The key method used for adjusting the samples is the adjustment of the expansion weights present on the survey records (the FES does not include expansion weights all households are weighted by the total population divided by the sample size). The following section discusses the possible ways in which these weights can be adjusted.

**Optimisation**

There are two sets of procedures that have been used in practice to produce prototypical samples: Iterative Proportional Fitting (IPF) and Quadratic Optimisation. Both methods rely on the availability of a detailed sample of households that is not directly representative of a specific target area or year. The detailed sample may refer to another area (larger, smaller or elsewhere), another year or both. The objective of the procedure is to create samples that are representative of target areas, given data for those target areas that is much less detailed in character.

The construction of prototypical samples by the quadratic optimisation method (‘QUAD’) rests on the recognition that the data for the target area and the base sample may be inconsistent. That is, the method balances the need to meet the target area marginal totals against the wish to retain the detailed relationships between the frequencies of different household types indicated by the base sample. Weights can be given to the relative divergences: in this sense QUAD is a generalisation of the IPF method, which gives exact matches to the marginal totals but sacrifices faithfulness to the original detailed sample.

A further difference between most applications of QUAD and the IPF method explained by Beckman et al. is that QUAD constructs its detailed samples by weighting or re-weighting the records of the base sample, rather than by drawing from the base sample with fixed probabilities. This difference has the minor advantage that the rounding errors found in IPF are eliminated, but its more important advantage is that it avoids the additional step of drawing the sample. The output is thus a sample whose size is predetermined and independent of the target area; the fit to the target area is achieved by the weighting.

Re-weighting is applied to all of the households in each of a series of categories, pre-defined to cover the main dimensions of interest for the prediction of travel behaviour. The categories
are defined with respect to variables such as household size, numbers of adults, number of
workers and the age of the household head.

QUAD is called quadratic optimisation because it can be specified in the form of optimisation
with respect to the new frequencies \( \phi_c \) of households of each category \( c \) of a quadratic
function for each target area, i.e. (following Daly and Gunn, 1985),

\[
\phi = \arg\min (Q), \quad Q = \sum_t w_t \cdot (z_t - \sum_c \phi_c \cdot x_{tc})^2 + \sum_c (\phi_c - f_c)^2
\]  \hspace{1cm} (14)

and

\[
w_t \quad \text{is the weight attached to the importance of meeting target } t;
\]

\[
z_t \quad \text{is the value per household of target statistic } t \text{ in the current area;}
\]

\[
x_{tc} \quad \text{is the average amount of target variable } t \text{ for a household in category } c;
\]

\[\text{hence } (\sum_c \phi_c x_{tc}) \text{ is the predicted total of statistic } t;\]

\[
f_c \quad \text{is the frequency of household category } c \text{ in the base sample.}
\]

The first term in \( Q \) clearly represents the error in not meeting the target marginal totals for
each variable \( z_t \), while the second term represents the divergence from the current distribution
of households over the categories. The weights \( w_t \) are introduced so that differential
importance can be given to meeting each of the different targets or that the balance between
consistency with targets and consistency with base population can be adjusted. In fact, in
most applications it has been found satisfactory to set all the \( w_t \) to 1. Setting large values of
\( w_t \) would cause QUAD to find a distribution of households that matched the target totals very
well at the expense of substantial departures from the original distribution, i.e. a solution like
that given by IPF.

Note that all terms of \( Q \) are on a per-household basis.

The simple form of \( Q \) makes it in principle easy to optimise. Given any starting value of \( \phi \), the
global minimum of \( Q \) is always at the value \( \phi^* \) given by

\[
\phi^* = \phi - Q'(\phi) \cdot Q''(\phi)^{-1}
\]  \hspace{1cm} (15)

where \( Q' \) and \( Q'' \) are the first and second derivatives respectively of \( Q \) with respect to \( \phi \), i.e.
Newton's calculation, which converges directly for a function which is exactly quadratic such
as \( Q \). The calculation is particularly easy if the starting value is taken at \( \phi = 0 \).

However, reality requires that constraints be imposed on the values of \( \phi \), e.g. that \( \phi \geq 0 \), and
there is no guarantee that Newton's calculation will give such a result. The procedure that can
be used in this case is then an iterative calculation, in four steps as follows.

1. Specify minimum values \( \phi_{min} \) for \( \phi \) and set \( \phi_0 = \phi_{min} \) and \( i = 0 \).
2. Perform Newton's calculation as in equation (4) above deriving
\( \phi_{i+1} = \phi_i - Q'(\phi_i) \cdot Q''(\phi_i)^{-1} \).
3. Check whether all free values of \( \phi_i \geq \phi_{min} \) and that \( Q' \geq 0 \) for all constrained values of
\( \phi \); if so, terminate.
4. Otherwise adjust any \( \phi \) values that are less than \( \phi_{min} \) to \( \phi_{min} \); free any \( \phi \) values which
are constrained and for which \( Q' < 0 \); set \( i = i+1 \) and repeat from Step 2.

This algorithm can be proved to converge to the overall optimum in a finite number of steps,
because the set of constraints \( \phi \geq \phi_{min} \) form a convex set while the function \( Q \) is concave.
Each iteration of the algorithm gives a reduction in the value of $Q$. This theoretical result is however of limited value, because the number of steps might be quite large. If the number of categories is of the order of 50, as is commonly the case, the maximum number of steps could theoretically be $2^{50}$, approximately $10^{15}$. In practice, the number of steps turns out to be very limited: typically convergence is achieved in 5 or 6 iterations.

The values $\phi_{\text{min}}$ can in principle be chosen to be any (non-negative) limits that seem sensible, such as 10% of the frequency of each household category in the base sample. Their function is to prevent unusual, perhaps erroneous, target data from generating an impossible – or nearly impossible – future population distribution.
Annex B: The National Trip End Model

Summary

The National Trip End Model (NTEM) produces estimates of person travel by all modes (including walk and cycle) for each zone in Great Britain, of which there are approximately 2,500. The model outputs trip productions and trip attractions in each zone (collectively known as tripends), which may be separated by mode, journey purpose, household car ownership category and time period.

The model produces a picture of the distribution of tripends based on land use and demographic forecasts that are produced through the TEMPRO system, namely the Scenario Generator and the National Car Ownership model. In principle the model bases the propensity to travel by different modes and for different purposes by the type of people that live in any particular area. As a final step, trip productions and attractions are reconciled over spatial units known as balancing areas. This ensures that the number of trip productions and attractions are equal across these areas. Refer to Figure 1 for a diagram of how the model works.

Trip end outputs from NTEM are used extensively in transport models. These allow the derivation of future year trip matrices, based on the forecast growth in tripends at suitable levels of disaggregation. Growth in tripends may also be used in scheme appraisals where no formal model exists by being a representation of traffic growth when combined with the National Road Traffic Forecasts (NRTF).

The NTEM uses base tables of trip rates, mode split and time period profiles derived from 1988-96 NTS data. This is applied to forecast year population and employment levels in order to produce the tripends. Previous research has shown that trip rates by area type and person type do not vary significantly over time and hence these are kept as constant assumptions.

Notation

It is useful to define a set of notation, which is used for the specification of all components of the tripend model and software. The notation is as follows:

- \( P_{ipamd} \): trip productions in ward \( i \), by trip purpose \( p \), traveller type \( s \), mode \( m \) and time/day \( d \)
- \( W_{ipamd} \): trip attraction weights in ward \( i \), by trip purpose \( p \), mode \( m \) and time/day \( d \)
- \( A_{ipamd} \): trip attractions in ward \( i \), by trip purpose \( p \), mode \( m \) and time/day \( d \)
- \( X_i^s, X_i^e, X_i^k \): land use indicators \( s \), \( e \) and \( k \), in ward \( i \)
- \( \alpha_{per} \): weekly trip attraction rates for trip purpose \( p \), and land use employment/population indicator \( e \) and area type \( r \)
- \( \hat{\alpha}_{pmkr} \): trip attraction factors for trip purpose \( p \), mode \( m \), and land use modal indicator \( k \) and area type \( r \)
- \( \beta_{psr} \): weekly trip production rates for trip purpose \( p \), traveller type \( s \), and area type \( r \)
- \( \gamma_{pmi(p’m)i} \): weekly NHB trip production rates for trip purpose \( p \) and mode \( m \), associated with HB trip purpose \( p’ \) and mode \( m’ \)
- \( \rho_{mdpsr} \): proportion of trips by mode \( m \) and time \( d \), given trip purpose \( p \), traveller type \( s \), and area type \( r \).
Use of TEMPRO data

The set of factors which identify the likelihood of a return trip being by purpose $p_r$ at time $d_r$, for each outward trip by purpose $p_o$ at time $d_o$ by traveller type $s$. These are used to get from productions and attractions to origins and destinations.

Each ward $i$ in GB, is defined as the set of frozen 1991 Census wards and is uniquely identified by a ward_id code as used by the Office for National Statistics (ONS).

In addition each district $I$, within GB is located within a balancing area $B$, thus $i \in I \in B$. It is also useful to consider the sets of dimensions being modelled as follows:

- $H$ the set of home-based trip purposes $p$ being modelled
- $N$ the set of non home-based trip purposes $p$ being modelled
- $P$ the set of trip purposes $p$ being modelled, $\{P\} = \{H\} + \{N\}$
- $S$ the set of traveller types $s$ being modelled
- $D$ the set of time periods / days $d$ being modelled
- $M$ the set of modes $m$ being modelled

**Model Structure**

Figure 1 shows the stages of the calculations within the tripend model. The calculations at each stage are relatively simple, although the quantity of data to be processed is reasonably large.

The first stage of the process is the estimation of trip productions as outlined at the top left of the diagram. The productions then need to be split into the modelled time periods, and by mode of travel. This is followed by the estimation of trip attraction weights as shown at the top right of the diagram, which will themselves then be split by time period and mode. In order to obtain an equal number of trip productions and attractions by a given purpose and mode at any one time, the numbers of attractions need to be calculated using a balancing procedure. The following sections outline the calculations involved at each stage.
Figure 1: Model framework for tripend forecasts

Estimation of trip productions by ward

Two sets of trip productions need to be estimated for each ward in GB: home-based (HB) and non home-based (NHB). These two types of trip productions are actually generated using different data and are covered separately below.
HB trip productions

HB trip productions are segmented by:

trip purpose - 8 categories, \( p \in H \)

and traveller type - categories distinguishing person and household characteristics, \( s \in S \).

This is achieved quite simply by applying a set of trip production parameters for each purpose \( p \), traveller type \( s \), and area type \( r \), derived from the NTS to a set of demographic data segmented by traveller type and the area type of each ward \( i \).

Hence for each purpose and each person type, calculate:

\[
P^p_s = B^{psr}X^s_i
\]

where ward \( i \) lies in area type \( r \) and \( X^s_i \) is the number of persons of traveller type \( s \) in ward \( i \) and \( p \in H \). The output from this stage is a set of weekly HB trip productions for each ward by purpose and traveller type.

NHB trip productions

NHB trip productions are less straightforward to estimate as they are associated with a variety of activities and the purpose definition applied to a NHB trip is that associated with the attraction. The NHB trip productions in a ward \( i \), has therefore been directly related to the total HB trip attractions to that ward. Ideally it would be related to all trip attractions. However doing so would make the procedure iterative in nature which would ideally be avoided given the scale of the model. Following this approach should not significantly reduce the quality of the results obtained.

The modal dimension is included here, to take account that NHB car driver trip productions are largely generated by HB attractions that previously arrived by that same mode.

Thus the NHB trip productions are estimated as:

\[
P^p_{pm} = \sum A^p_{pm'} \gamma^{pm_{pm'}} \text{ where } p \in N, p' \in H \text{ and } m, m' \in M
\]

This stage of the estimation process cannot therefore be completed, until the HB trip attractions have been calculated.

Segment trip productions by time period and mode

Having obtained estimates of trip productions for each purpose, ward and traveller type, these need to be segmented into time periods and modes. Since the modal split of trips by a given purpose was found to vary by time of day, a set of factors to split by mode and time were required based on NTS data.

Time periods represent both times of day, and days of the week. Since in the case of HB trip productions, approximately two trips are created (one from home and later one back to home), the time associated with a production has been defined as the time associated with first journey, ie the trip from the production end to the attraction end. This means that the
number of HB trip productions in the evening peak is the number of journeys starting from home at this time and not those returning from work, school etc. For NHB trips only one journey occurs for each production and attraction, so the time period is a more straightforward concept.

The segmentation into time periods is based on a set of proportions derived from NTS. Thus:

\[ P_{i}^{pmd} = \rho^{md|por} P_{i}^{ps} \quad \text{where} \quad p \in H \quad \text{for home-based trip productions} \quad (3a) \]

\[ P_{i}^{pmd} = \rho^{dip|por} P_{i}^{pw} \quad \text{where} \quad p \in N \quad \text{for non home-based trip productions} \quad (3b) \]

where the sum over all modes \( m \) and time periods \( d \) gives the complete set of trip productions, so

\[ \sum_{md} \rho^{md|por} = 1 \quad \text{if} \quad p \in H, \quad \text{or} \quad \sum_{md} \rho^{dip|por} = 1 \quad \text{if} \quad p \in N \quad (4) \]

**Trip attraction weights**

Using a similar approach to the estimation of HB trip productions, trip attraction weights need to be estimated for each of the trip purposes being modelled for both HB and NHB trip attractions. For this stage there is no attraction data by traveller type, and possibly only limited information on the area type in which the ward is located (eg for Central London). However there is more information in the form of land use indicators \( e \) and \( k \), attracting trips by purpose and mode to a given ward \( i \) in a region of type \( r \). These attractors are used in one of two ways.

Firstly a set of **zonal weights** is defined for the purpose of **dividing the total trips** within the balancing area **among the different wards**. This function for estimating attraction weights takes the form shown in equation (5)

\[ W_{i}^{p} = \sum_{e} \alpha^{por} X_{i}^{e} \quad (5) \]

The land use indicators \( e \) applicable to each trip purpose \( p \) vary, and consist of a combination of data on the employment / population in the ward.

A second set of **modal weights** is defined for the purpose of **dividing the trips within a ward by mode**. This function for estimating attraction weights takes the form shown in equation (6). This is equivalent to the logit model form with the variables transformed.

\[ \hat{W}_{i}^{pm} = \prod_{k} X_{i}^{k} \frac{\sum_{m} \left( \prod_{k} X_{i}^{k} \right)}{\sum_{m} \left( \prod_{k} X_{i}^{k} \right)} \quad (6) \]

The land use indicators \( k \) applicable to each mode \( m \) vary, and consist of a combination of data on the observed modal split pattern from the SWS 1991 Census tables for journeys to work, the ward’s proximity to key transport nodes such as rail stations, density of employment etc.

**Definition of the time period of a trip**

The time of day / day of week split is that associated with the outward journey of a home-based production and attraction. In order that matrices for transport modelling can be
generated at later stages in the forecasting framework, the definition of the time period associated with both the production and the attraction must be the same. The number of productions and attractions should then be in balance for each particular purpose \( p \), mode \( m \) and time \( d \) combination. Thus long trips which start in one time period and end in another must only be associated with one, either the start time or the end time, or possibly the mid time. Analysis showed that when considering time periods of 3 hours or more, as in this study, it makes little difference whether the journey start or end time is used. As the timing of journeys is often determined by the required arrival time, this was adopted as the more appropriate variable to use.

### Balancing process to obtain trip attractions

The data available for estimating trip productions is more comprehensive and reliable than for trip attractions. Thus the estimates of trip productions are expected to be fairly accurate based on the data available. For trip attractions however, the patterns can be predicted using land use indicators but the attraction rates are less robust. The method being used therefore relies on the trip productions to provide the quantity of trip attractions by time period, and uses the trip attraction weights to allocate these trip ends to wards by mode. As already mentioned the number of trip productions should equal the number of trip attractions for a given “Balancing Area” in each time period. A set of Balancing Areas has been defined by ITEA using Census journey to work data. This is listed in appendix E. There are currently 50 Balancing Areas within GB which for now will be used for all purposes. The calculation of trip attractions will therefore be carried out for each Balancing Area \( B \) in turn as shown in equation (7).

\[
A_{i}^{pmd} = \left[ \sum_{i \in B^r, p \in S} P_{i}^{pmd} \right] \frac{W_{i}^{p} \tilde{W}_{i}^{p} G_{B}^{m|pd}}{\sum_{i \in B^r} W_{i}^{p} \tilde{W}_{i}^{p} G_{B}^{m|pd}} \text{ where } i \in B \tag{7}
\]

Here the form of equation (7) was devised to meet the following requirements

(a) within the Balancing Area the total trip attractions for each mode \( m \) will match the previously calculated modal trip productions, for every combination of purpose \( p \) and time period \( d \)

(b) between each ward the number of trips attracted will be in proportion to the zonal weights

(c) within each ward the number of trips attracted will be in proportion to the modal weights

To meet the requirement (a) above the modal adjustment factor is updated iteratively in each iteration \( n \) as

\[
G_{B}^{m|pd} = 1 \quad G_{Bel}^{m|pd} = \frac{\left[ \sum_{i \in B, p \in S} P_{i}^{pmd} \right]}{\sum_{i \in B} A_{i}^{pmd}} \tag{8}
\]

### Conversion to origins and destinations

Having obtained estimates of productions and attractions, it is useful to be able to provide estimates of actual trip origins and destinations. For NHB trips, the number of origins is the same as the productions and the destinations are the same as the attractions.

\[
O_{i}^{pmd} = P_{i}^{pmd} \quad \text{and} \quad D_{i}^{pmd} = A_{i}^{pmd} \tag{9}
\]

For home based (HB) trips the conversion is not so simple. For every trip from home, there will be another back home. From analysis of the NTS data it appears that the mode used for
trips from home and back to home are highly likely to be the same. However, there is no reason for the trip purpose to be the same. For example a trip from home to work, may be followed by a trip from work to the shops and then from the shops back home. In terms of productions and attractions this would be recorded as a HBW production and attraction, and a NHB shopping production and attraction. However in terms of origins and destinations, this would be a HBW origin and destination, a NHB shopping origin and destination and a HB shopping origin and destination. Table D1 below shows the average number of P-A and O-D tripends by car driver mode in Great Britain in 1991 on a weekday.

Table 1: Numbers of P-A and O-D tripends in Great Britain by car driver mode (in thousands)

<table>
<thead>
<tr>
<th></th>
<th>Production</th>
<th>Attraction</th>
<th>Origin</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Based trips</td>
<td>27,379</td>
<td>27,379</td>
<td>54,674</td>
<td>54,674</td>
</tr>
<tr>
<td>Non Home Based trips</td>
<td>7,937</td>
<td>7,937</td>
<td>7,937</td>
<td>7,937</td>
</tr>
</tbody>
</table>

This conversion of P-A trips to O-D tripends is further complicated by the time period in which the journeys take place. The time period associated with the trip productions and attractions is the time period of the outward journey. It is not possible to determine the time of the return HB journey directly from the time period of the productions or attractions. The return journey will occur either during the same time period or a later period in the same day. For the purposes of this project, it has been assumed that all travellers return home before the AM peak the following day.

Although the relationship between P-A and O-D tripends is likely to vary by traveller type, this dimension has not been incorporated within the model specification. Including such a dimension would have significantly increased both the resource and running time requirements of the tripend model requiring many additional intermediate model results to be stored, without leading to a significantly improved model.

Using subscripts $o$ and $r$ to denote outward (ie from home) and return (ie to home) trips respectively, the number of origins and destinations by purpose $p$, mode $m$ and time $d$ associated with each ward are:

$$O_{io}^{pmd} = O_{io}^{pmd} + O_{ir}^{pmd} \quad \text{and} \quad D_{io}^{pmd} = D_{io}^{pmd} + D_{ir}^{pmd}$$

In the same manner as for NHB trips, the tripends for the outward journey can be directly associated with the productions and attractions of the same purpose, mode and time.

$$O_{io}^{pmd} = P_{i}^{pmd} \quad \text{and} \quad D_{io}^{pmd} = A_{i}^{pmd}$$

For the return trips the origins will be associated with attractions (eg Work, shopping); while the destinations are associated with the productions (Home). Thus:

$$O_{ir}^{pmd} = f\left(A_{i}^{PmD}\right) \quad \text{and} \quad D_{ir}^{pmd} = f\left(P_{i}^{PmD}\right)$$

where $f$ is a simple function.

In practice, using the NTS database, a set of probabilities $\phi_{p,d,i,p,r}^{o}$ can be calculated which identify the likelihood of a traveller making a return trip being by purpose $p_{r}$ at time $d_{r}$, for each outward trip by purpose $p_{o}$ at time $d_{o}$. 

\[\text{Table 1: Numbers of P-A and O-D tripends in Great Britain by car driver mode (in thousands)}\]
Thus:

\[ O_{pr}^{pmd} = f \left( A_{pmd}^{PmdD} \right) = \sum_{p,d} \phi_{p,d,p,d}\ A_{pmd}^{PmdD} = \sum_{p,d} \phi_{p,d,p,d}\ D_{lo}^{pmd} \]

(13)

where \( \sum_{p,d} \phi_{p,d,p,d} = 1 \)

(13a)

and

\[ D_{pr}^{pmd} = f \left( P_{PmdD}^{Pmd} \right) = \sum_{p,d} \phi_{p,d,p,d}\ P_{PmdD}^{Pmd} = \sum_{p,d} \phi_{p,d,p,d}\ O_{lo}^{pmd} \]

(14)

where \( \sum_{p,d} \phi_{p,d,p,d} = 1 \)

(14a)

It should be noted that following this approach does not necessarily result, for a given purpose, in two origins and two destinations being created for each production and attraction. Similarly the number of trip origins for a given purpose will not necessarily be twice the number of trip productions for the same purpose.

However, the equation (14a) does ensure overall consistency in residence (eg production) zones which is what is required. Summing both sides of the equation (14) over the set of return purposes and time periods, \( p, d \), shows that the right hand side, which is the total origins from a zone, equals the total destinations to that zone. A similar consistency condition is achieved at the attraction zone end by the equation (13a).

The return factors in formulae (13) and (14) were applied equally to every mode, since there did not appear to be major differences between the outward and return modal shares, once all trips have been summed together.

Definitions of segmentation

A summary of the categories within the model is provided here for reference.

Trip purpose

P1  HB Work
P2  HB Employers Business (EB)
P3  HB Education
P4  HB Shopping
P5  HB Personal Business (PB)
P6  HB Recreation / Social
P7  HB Visiting friends & relatives (for HB trips only)
P8  HB Holiday / Day trip
P11 NHB Work
P12 NHB Employers Business (EB)
P13 NHB Education
P14 NHB Shopping
P15 NHB Personal Business (PB)
P16 NHB Recreation / Social
P18 NHB Holiday / Day trip
Time of day / day of week

D1 Weekday AM peak period (0700 - 0959)
D2 Weekday Inter peak period (1000 - 1559)
D3 Weekday PM peak period (1600 - 1859)
D4 Weekday Early or Late (0000 - 0659) and (1900 - 2359)
D5 Saturdays (all times of day)
D6 Sundays (all times of day)

Mode

M1 Walk
M2 Cycle
M3 Car driver
M4 Car passenger
M5 Bus
M6 Rail (including underground)

Area type

Area types have been defined to be as consistent as possible with those proposed for NRTF, while making the best use of the NTS data (definitions).

A1 Inner London
A2 Outer London
A3 Metropolitan areas
A4 Urban Big (> 250k)
A5 Urban Large (100k to 250k)
A6 Urban Medium (25k to 100k)
A7 Urban Small
A8 Rural

Zonal attraction weights

E01 All Jobs
E02 Households
E03 Primary & Secondary schools
E04 Higher Education
E05 Adult education
E06 Hotels, camp sites etc
E07 Retail trade
E08 Health / Medical
E09 Services (business, other, postal/courier) & equipment rental
E10 Industry, construction and transport
E11 Restaurants and bars
E12 Recreation and sport
E13 Agriculture and fishing
E14 Business
E15 Holiday accommodation and second residences

Traveller type

Traveller types are defined as a combination of person type and household type. The person types being distinguished are:

Children (0 to 15)
males in full time employment (16 to 64)
males in part time employment (16 to 64)
male students (16 to 64)
males not employed / students (16 to 64) - Unemployed plus other Inactive
male 65+
females in full time employment (16 to 64)
females in part time employment (16 to 64)
female students (16 to 64)
female not employed / students (16 to 64) - Unemployed plus other Inactive
female 65+

While the household types to be distinguished are based on the number of adults and car availability:

1 adult households with no car
1 adult households with one or more cars
2 adult households with no car
2 adult households with one car
2 adult households with two or more cars
3+ adult households with no car
3+ adult households with one car
3+ adult households with two or more cars