# Model Structures and Traveller Responses for Public Transport Schemes

## TAG Unit 3.11.1

January 2007

Department for Transport

Transport Analysis Guidance (TAG)

# Contents

# 1 Good practice in the design of forecasting models for major public transport schemes

## 1.1 Introduction

This TAG Unit provides guidance on the structure of appropriate forecasting tools for major public transport schemes, including appraisal. The unit approaches this question from three angles:

- the necessity of certain model components on the basis of the objectives and likely consequences of the scheme;
- good practice in the application of the full range of model components;
- the decision-making process for determining model structures, guided by examples of major public transport schemes.

This unit deals in detail with the processes and considerations relevant when determining an appropriate model structure (Section 2). In addition it provides advice on the design of the modelled area (Section 3) and the zoning system (Section 4).

It then looks in detail at the modelling of traveller responses (Section 5). This is followed by sections which address demand segmentation (Section 6), generalised cost (Section 7), convergence between demand and supply (Section 8), resource considerations (Section 9) and overall model validation (Section 10)

Finally there is a discussion of modelling park and ride schemes (Section 11) and of some examples of possible model structures in relation to examples of types of scheme (Section 12).

## 1.2 Relationship with other TAG units

It is recommended that this TAG Unit be read in conjunction with other Units on public transport modelling. *Road Traffic and Public Transport Assignment Modelling* (Unit 3.11.2) deals with assignment modelling and *Mode Choice Models: Bespoke and Transferred* (Unit 3.11.3) deals with bespoke choice model development and the potential for use of transferred models. There is also a linkage with *Forecasting and Sensitivity Tests for Public Transport Schemes* (TAG Units 3.11.4).

# 2 Model Structure

## 2.1 Key issues for Model Structure

When designing a demand forecasting model for major public transport schemes, the following issues must be considered when identifying an appropriate model structure.

The first requirements are (a) to specify what type of scheme it is that the model has to address and (b) to make clear what the scheme objectives are. Clearly, the schemes to which the models are applied vary but also the relevant issues may vary as a function of aspects of the scheme and the context in which it is planned.

In general, the first set of key issues is the changes in traveller behaviour, and hence in traffic flow, that the scheme is expected to produce, so that model components can be selected that can forecast those changes.

The second main group of issues concern the implementation of the component sub-models representing each of the relevant behavioural responses and how these sub-models link to other sub-models.

The third major issue in model design is to assess the impact of constraints imposed by availability of time, data and money, as well as the available skills. In many cases, particularly for schemes towards the lower end of the cost range, these constraints will be sufficiently stringent that they rule out the full development of certain significant model components and may even, in the extreme, lead to the conclusion that it is not feasible to develop an adequate model. In this case there must be a presumption against the taking forward of the proposed public transport scheme, and this situation should be discussed with the Department.

## 2.2 Types of Scheme

The most appropriate modelling approach will depend on the type of scheme being assessed. This advice covers public transport schemes such as, for example:

- urban light rail schemes;
- urban guided bus schemes;
- park-and-ride schemes; and
- bus priority strategies.

**Urban light rail schemes** are generally intended to provide both a better service for existing public transport users and a viable alternative for car users. Usually, an important part of the rationale for schemes of this nature is that they will attract significant numbers of car users to change mode.

In addition to encouraging travellers to change mode, there is evidence that travellers could also change their time of travel and their destination. The responses are likely to be complex and inter-related. For example, a trip by car to one destination outside the peak could be replaced by a trip by light rail to another destination in the peak.

Light rail schemes may operate partly on segregated tracks and partly in streets shared with other road traffic. It will usually be important to assess the travel time advantages of the light rail system over the congested road system as well as the delays to road traffic that would be caused by the priorities accorded to light rail. The balance between the extra congestion caused by the priorities over road traffic and the relief of road traffic congestion caused by transfers from car to light rail usually form a crucial part of the case for the light rail proposal.

These considerations suggest that, for the appraisal of an **urban light rail scheme**, a multi-modal transport model will be required, which includes all the main traveller responses and detailed network models. This will be especially true for city-wide networks.

The same kind of model may be required for an **urban guided bus scheme**, again particularly for a city-wide network. However, some guided bus schemes may be little more than a localised **bus priority** measure which requires guidance technology because of the limited lateral space available. In these circumstances, the benefits are likely to accrue mainly to existing bus passengers and a multi-modal model is unlikely to be justified. Bus priority schemes will generally impact on the amount of road-space or green time available to general traffic. Hence, there may be expected to be a need for highway assignment as well as public transport assignment. Where the bus priority schemes do not affect conditions for general traffic, the highway assignment component may be omitted.

**Park-and-ride schemes** are, by their very nature, intended to attract car users to use public transport. There is strong evidence, though, that a substantial proportion of the users of a park-and-ride scheme are likely to have used public transport for their entire journey prior to the provision of the park-and-ride scheme. City-wide strategies involving a number of sites are therefore likely to require a multi-modal transport model, which includes not only all the main traveller responses and detailed network models but also a model of the choice between car and park-and-ride, and between public transport and park-and-ride. Whether such a comprehensive approach is warranted for a single park-and-ride site will depend on its size and strategic importance.

## 2.3 Scheme Objectives

In addition to scheme type, any modelling approach will be influenced by the specific questions that need to be addressed. For more general demand forecasting tools the multitude of uses will generally lead to complex and expensive model forms, and supporting data collection. If such a model is already available, its suitability in the light of the objectives and likely other consequences of the public transport scheme under consideration should be investigated.

This advice is focused on the situation that no suitable model is in existence, and that the structure of a demand forecasting tool must be determined solely by the objectives and likely consequences of the scheme under immediate consideration and any further schemes likely to require appraisal in the near future. These objectives and consequences can vary widely, can be more or less difficult to quantify, and be mutually supportive or conflicting.

In all cases the individual scheme objectives will be driven by those of the New Approach to Appraisal, and the Appraisal Summary Table:

- Economy
- Safety
- Environment
- Accessibility
- Integration

Of particular relevance is the need for the model to be able to provide robust and relevant input to downstream quantitative appraisal packages such as TUBA for user benefits, and environmental or accessibility models.

The main quantifiable elements which feed into the determination of the extent to which a public transport scheme contributes to meeting these objectives are as follows:

- Public transport performance
- Mode split
- Car congestion
- Accidents
- Integration
- Reliability

- Quality
- Walking and Cycling
- Regeneration
- Access/attractiveness
- Pollution/noise

This list focuses on the more easily quantifiable elements of the overall objectives. This is because this advice relates to currently available modelling. However this does not imply that non-quantifiable impacts are not relevant to decision making. Clearly, the wider the scope of models available for scheme analysis, the better. Scheme promoters should develop modelling structures that can quantify the impacts of stated objectives to the greatest extent which is reasonable but should bear in mind the role of qualitative statements in assessment and any potential for modelled outputs to contribute to this.

In conclusion, before deciding on an appropriate structure for the demand forecasting model, both the main behavioural responses expected and the scheme objectives need to be considered as these set the modelling requirements to be addressed. The implications of both of these for modelling are discussed next.

## 2.4 Implications for Modelling

The first considerations are the implications of the expected traveller responses for model structure and for sub-models set out in paragraphs 2.4.2 to 2.4.6. The implications of scheme objectives are considered in paragraphs 2.4.7 to 2.4.20.

A major public transport scheme, if designed correctly, should obviously reduce the generalised costs of travel by public transport. However, a public transport scheme may additionally reduce the capacity of the road network, thereby increasing congestion and the generalised costs of travel for cars and goods vehicles. It may also reduce the demand using the road network, with the result that congestion and the generalised costs for cars and goods vehicles are reduced. The most complex models for the appraisal of public transport schemes therefore need to include sub-models of the responses of users of all motorised modes (ideally including goods vehicles), to changes in the generalised costs of travel by all motorised modes.

Advice on the general structures of the models suitable for the appraisal of different kinds of major public transport scheme has been discussed above. This current section offers advice on the forms of the sub-models which may be used to create those models.

In many respects, these sub-models and the modelling structure are no different from those that would be used in a multi-mode model for a multi-modal transport study or the appraisal of a high-impact road scheme in a congested urban area. However, there are aspects where a different emphasis in the model specification is appropriate in a model for public transport scheme appraisal. In this section, the focus is on the special aspects which are required for modelling public transport schemes, supported by references to advice elsewhere in TAG for guidance on standard sub-models which may be used in public transport models without special adaptation.

The main responses of travellers to changes in the generalised cost of using the transport system are:

- change in the number of trips, also referred to as ‘change in trip frequency’ ;
- change of mode, also referred to as ‘modal transfer’;

- change of destination, sometimes referred to as ‘trip redistribution’;
- change of time of travel; and
- change of route or service, also referred to as ‘reassignment’.

Advice on modelling each of these responses, among others, is covered in separate sub-sections of Section 5 below with the exception of change of route or service. Such change is handled at the assignment stage. For detailed advice on assignment models, reference should be made to *Road Traffic and Public Transport Assignment Modelling* (TAG Unit 3.11.2)

The implications of scheme objectives for model structure are considered by examining the types of model approach that would be suitable for assessing each of the main elements identified above as contributing to the extent to which a public transport scheme contributes to meeting the NATA and other objectives These are discussed in the following paragraphs and summarised in the Table in paragraph 2.5.3

Public transport performance and the travel times experienced by travellers are at the heart of most public transport schemes. For very simple schemes in a single corridor it is sufficient to quantify travel times by simple processes that would not generally be described as a model, e.g. through explicit changes at route or individual stage level. For schemes with any degree of complexity it is necessary to set up a public transport network model and to make an assignment using that network. Such an assignment would yield the required travel times and other performance or level of service measures. Given the frequency with which this objective occurs, and the need for public transport travel times to feed into many other model components, it is expected that a network and assignment will be a necessary part of almost any model system – a departure from this approach is possible, however, as discussed in the model structures in Section 11.

Mode split changes are an objective of many schemes, justifying the attention that this issue receives. Typically, a model of mode split will take some resources to set up but its operation is straightforward. It will require input of public transport and alternative mode (e.g. highway) travel times, so in addition to a public transport network model, a network model for private transport modes will be necessary, unless the scheme is so simple that levels of service for the modes can be calculated without recourse to a network.

Congestion reduction by a public transport scheme will require a forecast to be made of a change in mode split, and subsequent decongestion impacts on the road. Hence, if this is one of the scheme objectives it is best to set up a highway network and calibrate and run capacity-restraint assignments on it, taking care to include the major contributors to delay, such as junctions. If decongestion is a major scheme objective, the coarseness of area-wide speed-flow curves is unlikely to do justice to the detailed issues that are relevant at junctions or where public transport and private vehicles share limited road space. The impact of decongestion on bus traffic should be considered alongside its impact on cars.

Accident reduction as an objective of a public transport scheme relies on a modal shift, and the resultant reduction in the volume of car traffic; therefore this objective requires the same modelling mechanisms for quantification as car congestion modelling

Integration of the public transport system is a benefit that is cited frequently, but it is rarely quantified and methods for quantifying integration are not immediately apparent. However, approximate indicators may be obtained from public transport assignments (total number of transfers, wait and interchange time etc.) ( see *Road Traffic and Public Transport Assignment Modelling* (Unit 3.11.2).

Research interest in modelling reliability has been gaining momentum recently and a number of research teams have reported valuations of reliability changes. The two aspects requiring consideration are the valuation by travellers and the estimation (in the same terms) of reliability changes resulting from network or operational changes to the public transport system. Even before modelling reliability in detail becomes feasible with standard packages, the value of benefits resulting from increased reliability can be quantified separately.

If significant quality benefits are claimed as part of a scheme, then the value of these should be quantified on the basis of parameters determined from behavioural research in the target area or elsewhere.

Quantification of walk and cycle enhancements relies on quantification of the improvements that users of these modes might experience, then a model could be used to predict increased use of these modes. Sometimes walk and cycle times and distances are skimmed from a highway network model, but alternatively the impacts of the public transport schemes on slow mode levels of service may be calculated externally. To incorporate the impact of any improvements on the pedestrian and cyclist modal share requires the inclusion of relevant variables in the mode choice model. These also should be quantified on the basis of parameters determined from behavioural research in the target area or elsewhere.

Regeneration is often cited as a major objective. Quantification of success in meeting this objective is complex. Methods exist that estimate the impact of (public) transport improvements on land use development, with varying degrees of sophistication and success. These models require specialist skills, and significant resource inputs in terms of data, model development and application. The valuation of the benefits of land-use changes brought about by transport schemes is a separate issue, which has not been solved yet by the profession.

Accessibility models have been developed on behalf of the Department for Transport which can quantify changes in the accessibility to or from key locations. Alternatively, the accessibility measures which form the basis of land-use modelling could also represent accessibility. Both approaches require network models of both private and public transport as input.

Attractiveness may be related to accessibility but is not necessarily a description of the same effects. Attractiveness is likely to be a qualitative measure related to the physical design of facilities, similar to quality and equally difficult to quantify.

A quantified assessment of pollution and noise can be made on the basis of vehicle kilometres, using the same methods as are used for car congestion modelling. If external environmental models are used, these are fed by these same network models, making use of more local estimates of speeds, flow and traffic composition.

Other issues such as improved parking conditions and improved access for the mobility impaired do not lend themselves to quantitative modelling in the present state of the art. Quantification may be possible on an ad-hoc basis.

## 2.5 Summary

The structure of a model for appraising a public transport scheme will need to consider the following components, though as set out below, not all will be required in all cases.

- Land use and transport interaction
- car ownership forecasting;
- trip end forecasting and trip frequency;
- transport and land use interactions;
- mode choice;
- destination choice;
- time-of-day choice (i.e., in principle, departure time choice);
- public transport service and route choice, including the potential use of access modes such as park-and-ride and the use of multiple public transport sub-modes; and
- highway route choice (i.e. assignment), together with a model of emissions when necessary.

In making a forecast of the situation in a future year under do-minimum or reference case assumptions, all eight stages could play a role. In forecasting the effects of a scheme, however, only the last five stages would normally come into play, and not all of these would be always necessary. All the components and their interrelations are discussed in section 3.

The above considers a number of common public transport major scheme objectives, based on schemes in the current public domain. Model components that will generally be required for the forecasting and appraisal of the effects of such schemes, as summarised below:

| | **public transport assignment model** | **highway assignment model** | **mode choice model** | **Destination choice model** | **transport - land use interaction model** |
|---|---|---|---|---|---|
| **Public transport performance** | x | | ? | | |
| **Mode split** | x | x | x | | |
| **Car congestion** | x | x | x | | |
| **Accidents** | x | x | x | | |
| **Integration** | ? | | ? | | |
| **Reliability/quality** | ? | ? | ? | | |
| **Walk and cycle enhancements** | | | x[1] | | |
| **Regeneration** | x | x | | x | x |
| **Accessibility** | x | x | | x | ? |
| **Pollution/noise** | ? | x | | | |

*Note: car ownership models, trip generation and time of day models are likely to be required for reference case forecasting, but not specifically for assessing the scheme's impacts*

There are other scheme objectives that cannot be quantified as easily. Rather than ignoring or guessing these, an increased degree of quantification is necessary to the political acceptability of the appraisal process, to avoid damaging inconsistency between public opinion about the benefits of schemes

[1] In this case the mode choice model and, particularly, the trip frequency model must reflect the trips made by ALL modes which also makes it more reasonable to ignore the likely impact of network improvements on trip rates.

and the government's appraisal of those schemes. This implies that promoters need to explore the options for expanding the scope of models where this is feasible and cost effective.

# 3 Design of the Modelled Area

## 3.1 Introduction

The area subjected to detailed modelling for the appraisal of a new public transport scheme should be sufficiently large to encompass all significant influences of the scheme yet not so large that the resources required to develop the model and the computing time taken to run the model are impractical.

In general, the use of a cordon boundary to a modelled area should be avoided. By their nature, cordons involve fixing the points at which traffic and passenger movements enter and leave the modelled area and this can prevent the realistic modelling of choice of route by road and public transport service. The use of a cordon also means that, for trips with only one end inside the modelled area, the model will represent the costs of travel between cordon points and internal zones, that is, for only part of the complete journeys. The use of truncated costs will render some forms of demand model inappropriate whereas the use of end-to-end journey costs will allow the modeller greater freedom in the choice of demand model.

The preferred approach is for the area of influence of the proposed scheme to be modelled in detail and surrounded by an external area of less detailed modelling. The zoning system and networks should be continuous and cover both areas, with the level of detail being fine inside the area of influence and becoming progressively coarser as one moves away from the area of influence. Trips with both ends inside the area of influence, sometimes referred to as the 'fully modelled area', will normally be subject to all of the main traveller responses included in the model. Trips with one or both ends outside the fully modelled area can usually be modelled in a less complete fashion.

The design of the area which should be covered by a model for the appraisal of a public transport scheme can be greatly assisted by the use of an existing model, even if designed for another purpose. However, for an existing model to be of use, it must cover an area wider than the area likely to be influenced by the public transport scheme.

## 3.2 Model-Based Design

The key issues for the design of the fully modelled area are:

- the area over which road traffic might reassign in response to a change in road capacity caused by the allocation of priorities to the new public transport scheme or to a change in the level of road traffic congestion as a result of transfers from car to the new public transport scheme;

- the existing public transport services from which patronage could be extracted by the new service; and

- the area over which trips could redistribute in order to make use of the new public transport scheme.

Road traffic assignment models are the most common type of model likely to be available. These models can be used to test both a reduction in capacity and a reduction in demand to mimic approximately the nature and the notional impacts of the scheme. However, these models should not have fixed cordons as their boundaries as that can constrain route choice unrealistically.

In principle, the fully modelled area should be chosen to encompass all significant changes in delay and traffic flow. Changes in delay are important for the transport economic efficiency appraisal and changes in flow are important for the noise and local air quality appraisal.

In practice, it is hard to judge when a change in delay is either important or unimportant without conducting a series of economic appraisals with models of varying size. In most cases, such an exercise is unlikely to be warranted. The best way of avoiding having to judge when a delay change is important is to extend the fully modelled area to the point where the flow changes are no more than 2%. This approach would also ensure that all the noise and local air quality impacts are captured.

Section 6.5 of the Report on Modelling the Traffic Impacts of Highway Capacity Reductions, commissioned in 1997 jointly by London Transport and the Department for the Environment, Transport and the Regions discusses the dilemma of choosing an area which is either too small to capture all the effects or too large so that model convergence 'noise' becomes a problem.

Public transport passenger assignment models are much less common than road traffic assignment models. If such a model does exist, it would be instructive to code in a simple version of the proposed scheme and identify which of the existing services would suffer significant reductions in patronage. Again, the definition of 'significant' is problematic. A prudent approach would be to extend the fully modelled area of the new model so as to include all the services shown (by the existing model) to suffer more than 2% reductions in patronage.

Multi-mode transport models are also less common than road traffic assignment models. For them to be of use in designing the area to be covered by the new public transport model, they must contain a destination choice (distribution) model, as well as a mode choice procedure. A simple version of the proposed scheme should be coded up and the model run to assess the extent of the resulting changes in the trip matrices. Again, it is hard to judge when a change in a matrix cell is material, and a prudent approach would be to extend the fully modelled area of the new model so as to include all sections of road and public transport network which display a change of flow on a link that is greater than 2%.

It may be that the inclusion of all transport links that show a change in flow of greater than 2% would result in a model which is too large, either because it would take too long to run or because it would require too much data and effort to develop. Where a fully modelled area is proposed which is smaller than that ideally required from a theoretical point of view, the Department should be consulted at the model design stage.

## 3.3 Design without the Aid of a Model

The design of a fully modelled area without the aid of an existing model should be based on local knowledge, experience and judgement. It is important, therefore, that advice is sought from a modeller who is experienced in the modelling of major public transport schemes.

To assess the scope of the possible reassignment effects on the road system, the modeller should identify the roads which appear to offer realistic alternative routes for traffic on those roads that would be affected directly by the new scheme. A similar approach should be adopted to identify the existing public transport services that could be affected.

To assess the redistribution effects, the modeller should identify attractions outside the corridor of the new scheme, which appear to be similar in nature and scale to those which lie in the scheme corridor, and to or from which traffic could realistically redistribute.

It is possible that trips could redistribute between nearby urban areas as a result of changes to the transport system in one of the areas. While this effect may not be very large with some public transport schemes, such as a bus priority strategy confined to one corridor on the opposite side (of the area to be modelled) to the nearby area, it could be significant in the case of a city-wide light rail system if accompanied by either a park-and-ride site and/or a marked reallocation of road space and/or a strong parking or congestion charging traffic restraint scheme. Thus, the modeller may be faced with circumstances where the inclusion of nearby urban areas in the fully modelled area is desirable. In these cases, where it is not considered practical to include nearby urban areas in the fully modelled area, the Department should be consulted at the model design stage.

# 4 Design of the Zoning System

## 4.1 Introduction

General advice on the design of zoning systems for transport models can be found in *Modelling* (TAG Unit 3.1) and for road traffic models in *Variable Demand Modelling – Scope of the Model* (TAG Unit 3.10.2). Different considerations apply for models designed for the development and appraisal of public transport schemes, and this section explains the principles that should be followed.

## 4.2 Design Principles

This section starts by considering models in which the demand for the use of public transport is explicitly represented by means of matrices of public transport trips. Different considerations apply to road traffic models that may be used alone for the appraisal of some public transport schemes, such as bus priorities, and these are addressed secondly in this section.

The assumption in most practical models is that all travellers to and from each zone start or end their journeys at the notional centre of the zone, called the ‘centroid’ and they all encounter the distance, time and cost allocated to the ‘centroid connector’ which is a link between the centroid and the transport network being modelled. However, consideration should be given the mode of access (see paragraph 4.3.4).

In the real world, access to a public transport service is usually achieved by walking from an origin (such as an individual building) to a bus stop or light rail station. Walking speeds are low and walking time is valued, on average, at around twice the time spent riding in the public transport vehicle. Thus, the distances that people have to walk to access the public transport system can have a crucial influence on the use made of any particular public transport service. It follows that access links (zone centroid connectors) should, ideally, reflect the real world as accurately as possible and that, in principle, the zoning system should be as fine as possible.

In practice, there are two main factors which work against the use of small zones: the effects of the number of zones on model run times, and the implications for data collection and trip matrix accuracy of using small zones.

One of the key factors which determine the time taken for the model to run is the number of zones. Generally speaking, the run time will increase with the square of the number of zones. That said, computing power is increasing rapidly and this factor is less of a constraint than it used to be.

The amount of travel demand data that can be collected, and the proportion of travellers sampled, will be governed by practical considerations, the most dominant of which is likely to be the budget available. For any given number of trips surveyed, the accuracy of the resulting matrix cell values will be inversely proportional to a function of the number of cells. Thus, the smaller the zones, the more zones that the data will be spread across, the fewer the number of trip records in each matrix cell, and the less accurate will the trip estimates be in each cell, for any given level of survey expenditure. It is also likely that the resulting observed trip matrices will contain more cells containing zeros than should be the case.

Striking the right balance between issues of this kind – model accuracy, model run times, and survey budgets – is a difficult process for the design of any transport model. In the case of public transport models, however, primacy should be given to securing adequate model accuracy, and then working out the consequences for model run time and data collection. If the resulting model run times are considered impractical or the data collection requirements unaffordable, some compromise should then be made on the number of zones.

Some major public transport schemes, such as a light rail system for a city, can represent very significant levels of expenditure, even when viewed in the national context. It is important, therefore, that their appraisal is conducted to a level of accuracy sufficient for robust decisions to be taken. One temptation that should be avoided is to allow the zoning system for the public transport model to be distorted from the ideal by partially adapting a zoning system designed for some other model. The zoning systems appropriate for road traffic modelling and public transport modelling may be quite different and the former should not unduly influence the latter in the case of models for the appraisal of major public schemes.

It is possible, within a single public transport model, to employ different zoning systems for the public transport assignment sub-model, the road traffic assignment sub-model, and the demand sub-models. The primary constraint is that all the more detailed zoning systems should be subsets of the more aggregate zoning systems. In general, though, best practice is to use the same zoning system for all sub-models and for that zoning system to be dictated by the needs of the public transport assignment sub-model.

The above advice relates to zoning systems for public transport models which are to include matrices of trips by public transport passengers, as required for the appraisal of most public transport schemes. There are some public transport schemes, however, which may be appraised satisfactorily using a road traffic assignment model alone, such as a bus priority scheme. In these cases, the advice on the design of the zoning system for a road traffic model given in *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) should be followed.

## 4.3 Detailed Considerations

Zones for public transport models should:

- be consistent with the boundaries of the National Trip End Model (NTEM) zones used in the Department's TEMPRO data base, as information from this data base is likely to play an important role in the development and/or use of the model;
- be consistent with Census Output Areas as planning data at this level of detail may be available and useful for forecasting;
- be homogeneous in the land-uses they contain;
- not span barriers to movement such as rivers, main roads or railway lines;
- allow areas of new development to be distinguished, because trips to and from these zones may need to be treated separately in the forecasting process;
- avoid grouping together areas with different levels of access to the public transport system; and
- avoid grouping together areas which are served by different public transport services.

In general terms, there are two kinds of zone to be considered:

- zones through which a public transport service either does pass now or may pass with the new scheme; and
- zones that are not within normal walking distances from an existing or future public transport service.

Zones in the first category should be focused on stops or stations. They should generally be sufficiently small for it to be realistic to expect people to walk from anywhere in the zone to the nearest public transport stop or station. This distance can be assumed to be less that a one kilometre radius in urban areas. Generally, there should be one zone of this kind for each stop or station, although, in central areas where bus stops are frequent, it may be acceptable for there to be more than one stop in any individual zone. This guidance applies not only to existing services but also to the new scheme to be appraised. Thus, it is important to have some idea, at the model design stage, of where the stops and stations for the new services could be located.

In zones in the second category, the expectation is that people would not normally access the public transport system by walking. People accessing facilities in these zones are much less likely to use public transport than people in the first category of zone and, as a consequence, the modelling of these zones can be more approximate, that is, the sizes of these zones can be geared to highway modelling which are often larger.

Thought should be given to the way in which people would access the existing and future public transport services from each zone. For zones which are close to public transport services (the first category in paragraph 4.3.2), walking would be the obvious choice, and the centroid connectors should be coded with an average walking speed. For zones well away from any public transport service (part of the second category in paragraph 4.3.2), it will be clear that, for users of these zones to access public transport, they would generally have to use a car. For zones which lie between these two extremes (also part of the second category in paragraph 4.3.2), some people would walk, some would cycle and some would use a car.

It may be important for the accuracy of the forecasts of patronage on the existing and new public transport services that these various access costs are realistically represented in the model. This issue relates to the network element of the public transport passenger assignment model and the reader should see *Road Traffic and Public Transport Assignment Modelling* (TAG Unit 3.11.2) for further advice.

# 5 Models of Traveller Responses

## 5.1 Introduction

In designing model structures, the key focus will be the need for cost-effectiveness. In this context, cost-effectiveness means obtaining the most robust possible appraisal with the minimum outlay (and within the real-time constraints of the planning process). This implies balancing the need for accurate estimation of the key behavioural responses and the parameters governing those, exploiting existing resources, against the budget constraints.

A choice can be made by the model developers between trip-based and tour-based approaches. In general, a tour-based approach can be considered to give higher quality representation of behaviour in several of the components of the model system, but they are, at the present time, generally restricted to large scale strategic models. If available they could be used to provide inputs to more locally based models.

## 5.2 Hierarchy of Responses

Once it has been decided which traveller responses to include in the model, the order or hierarchy in which those responses operate must follow certain rules. The sequence of the responses will affect the output elasticities from the model and the scale and pattern of demand by mode. The appropriate sequence of responses should be determined by analysis of local data. *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) provides advice on how the sub-model hierarchy should be determined.

## 5.3 Land use and transport interactions

In virtually all models, the impact of land use on transport is a standard component of the modelling procedure. Here we refer to the feedback of transport schemes on land use development.

Undertaking a land use transport interaction model is costly, data-hungry and time-consuming. For some cases, however, the impact of the scheme on regeneration is expected to be substantial, so that regeneration needs to be considered as an important part of scheme appraisal. In these cases, despite the cost and time required for land-use transport interaction modelling, this option should be carefully considered

Where such expenditure is not defensible, an alternative approach is to extract measures of accessibility from the transport model and use these to inform expert judgement. In cases where an objective of the scheme is simply to improve accessibility these measures are in principle sufficient in themselves, but they can also give sufficient information for an expert to assess what land use changes are likely. The exact formulation of accessibility measures is an issue on which land-use modellers can advise.

Thus, it is the Department's view that:

- that land-use transport interaction modelling be undertaken only when it is such an important part of the justification of the scheme that the substantial cost and time requirements are justified. This should be discussed in advance with the Department before any decision is taken to implement such a model

- that the use of accessibility measures to inform expert judgement be considered as an alternative;

- that accessibility measures of the same type be used to quantify accessibility improvements when these are part of the case for a scheme.

## 5.4 Car ownership forecasting

Changes in car ownership are not part of the expected impacts of major public transport schemes. Nevertheless, if a scheme is to be appraised over a period of several years, it is reasonable to expect that car ownership will be different from the current level. As car ownership and availability are crucial to determining the level of public transport usage, it is important that reasonable forecasts are made of changes, to form the appropriate background to predicting scheme impacts.

The Department provides car ownership forecasts as part of the TEMPRO database and these can be used as input to a model system. These forecasts are based on a national model and are provided for the TEMPRO zone system (about 300 zones nationally. The overall level of car ownership given in TEMPRO may be adjusted to meet local conditions only when there are good reasons for doing so and when good local information is available. If local data are used, a sensitivity test with TEMPRO data should also carried out.

## 5.5 Trip Generation/Frequency

'Trip generation' should not be confused with 'generated traffic'. 'Generated traffic' is a term that is often used to describe the extra demand that arises on both the road and public transport systems in response to the provision of new capacity. Commonly, the term is used to describe all the responses which travellers could make, sometimes including change of route or service as well as the other demand responses. Change in trip frequency, is one element of 'generated traffic', the main other elements being change of mode, destination and time of travel.

Trip generation/frequency, as defined in *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3), involves two 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**).

Trip frequency may be thought of as, mainly, the transfer between the slow modes of walk and cycle and the mechanised modes. Thus, if the number of trips estimated from the planning data includes trips made by the slow modes, the trip frequency response is often zero. If, on the other hand, only mechanised mode trips are estimated from the planning data, the trip frequency response may be non-zero for some trip purposes.

The usual form of a trip frequency sub-model is a relatively simple elasticity formulation. Reference should be made to *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) for further advice on the form of this sub-model.

In a multi-mode model (as would be used for a city-wide light rail scheme, for example), the trip frequency sub-model would apply, logically, at the total motorised mode level, but separately by trip purpose and car ownership or availability group. The use of different elasticities for different levels of car ownership or availability would result in different trip frequency effects on the car and public transport modes.

It is unlikely that data will be available to enable trip frequency elasticities to be estimated locally. In any event, the currently available evidence suggests that the trip frequency effects are markedly less important than the mode, destination and time of day effects (See *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3)). The available resources are therefore better directed towards those sub-models rather than the trip frequency sub-model. In general, trip frequency elasticities should be imported rather than estimated.

*Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) provides advice on elasticities for the trip frequency response which are applicable to all mechanised modes combined. While these total mechanised mode elasticities are given separately for the various trip purposes, there is no distinction made by car ownership or availability group. The implicit assumption there is that the elasticity is used to factor existing numbers of mechanised trips, the majority of which are made by car available households.

In the development of models for the appraisal of public transport schemes, the total mechanised mode elasticities should be applied separately by purpose but, initially, without distinction according to car ownership or availability. As explained in Section 9 below, it may be necessary to adjust some model parameters to ensure that the demand elasticities implied by the overall model accord with established values. If adjustments of this kind are necessary, one option that could be considered is to differentiate the trip frequency elasticities by car ownership or availability. The modeller may therefore opt to conduct tests of the sensitivity of the forecasts to alternative elasticities that vary by car ownership or availability.

However, if slow mode trip ends are generated and walking and cycling incorporated in the mode choice model, the necessity for including a trip frequency response is greatly reduced and, although choice modelling remains an attractive way to model trip frequency, the consequent accessibility complication in the model can usually be avoided. For a scheme affecting public transport, which generally carries a small minority of total traffic (when car and walk trips are also considered), the impact on total travel is likely to be small.

Forecasting attractions, i.e. the number of trips arriving at each destination, can also be delegated to TEMPRO. If a local model is required, it is greatly preferable that attractions should be forecast as part of the destination choice model, to avoid biases that can occur when attraction variables are correlated with accessibility.

## 5.6 Change of Mode

The way in which mode choice is handled in a public transport model may differ according to the nature of the existing public transport system and the type of new scheme. Advice on the overall model structures appropriate to different types of public transport scheme in different circumstances has been discussed above. More detailed advice on mode choice modelling is provided in *Mode Choice Models: Bespoke and Transferred* (TAG Unit 3.11.3).

In some instances, the most appropriate model structure will involve a main mode choice model that splits trips between car and public transport as a whole, with the allocation of public transport passengers to the various public transport sub-modes being made at the assignment stage. In other cases, a mode choice sub-model may be used to split the total mode trips between all motorised modes, leaving the individual mode trip matrices to be assigned individually to their corresponding networks. The issues involved in reaching a decision on the best approach are discussed later in this section.

The detail of the mode choice sub-model may also vary according to the nature of the passengers being served. For example, air passengers respond differently from the average traveller. People's propensity to use public transport to and from an airport may vary markedly according to whether they are travelling on business or leisure and whether they are away from their home area. For a mode choice sub-model designed to appraise a link to an airport, therefore, the demand needs to be segmented in a different way to that used for the modelling of general travel in an urban area. Demand segmentation is discussed in Section 7.

An initial structural issue is how mode choice and destination choice should relate to each other. In practice, satisfactory models have been developed which show structures with mode choice 'below', 'above' or 'joint' with destination choice. In theory, how the models relate to each other depends on the relative accuracy of measurement of generalised cost differences influencing the two choices and issues such as zone size and the quality of the transport networks will therefore influence the structure. This issue is thus best left to analysis of local data.

In any case, it is essential that the models of mode and destination choice be properly linked. Since both models are usually of a form closely related to logit models, the appropriate linking 'composite cost' measure will be the logsum which gives a measure of the cost in the 'upper' model as a result of the choices which are to be made in the 'lower' model. For example, if mode choice is modelled 'below' destination choice, the composite cost gives a measure of the separation of zones, taking account of the modes which are available for travel between them.

Further, the coefficient of composite cost must have a value which lies in a specific range – depending on the exact model structure, but usually between 0 and 1 – which ensures that the responses of the model are not obviously wrong. For example, if such a constraint were not met, it might be possible that an improvement to public transport in a corridor could increase total traffic in the corridor by so much that car journeys were also predicted to increase.

Within the public transport system there may be a range of 'sub-modes':

- different public transport technologies, i.e. bus, light rail, heavy rail;
- different access modes to public transport, i.e. walk, cycle, taxi, car (park-and-ride or 'kiss-and-ride').

Further there will be many trip options that involve combinations of public transport technologies. Choices within these sub-modes can be modelled either by choice models of the form used for the main mode choice, i.e. almost always logit models, or they can be handled in the assignment procedure. This is an important decision for the design of a model and requires careful consideration.

A logit-based approach to choice modelling is more stable and transparent, and therefore capable of inspiring greater confidence, than an assignment-based approach. A choice model approach can also be supported by empirical evidence more easily. However, in instances where there are predicted to be significant numbers of mixed mode trips using a significant number of mode combinations, a logit-based approach can be cumbersome.

A logit-based approach is also preferable for situations

- where travellers who are indistinguishable with respect to measured variables are likely to choose different alternatives in significant numbers, i.e. the split is not close to zero–one;
- where sub-mode split can only be explained by the incorporation of a constant representing the net effect of unmeasured variables in influencing the choice between sub-modes;
- where there are serious difficulties in calculating fares for trips using a mixture of sub-modes – as these can be directly incorporated in a choice model;
- where the model includes representation of car access to public transport, because there are many household-related reasons for using or not using a car that are not clearly represented in current models. Further, assignment packages generally have difficulty with the processing needed to deal with mixed car and public transport journeys. The car access component should of course be assigned to the car network.

For the choice among 'pure' public transport alternatives, however, the issue is not so clear and local circumstances, including software capability, will be decisive. A key issue for consideration is deriving appropriate 'composite cost' measures for use in the main mode choice model. This is discussed in section 6 below.

The analyst should be aware that, even if the sub-mode choices are modelled through a choice model, the public transport assignment must produce the required skimmed time and cost values for each of the alternatives, for example by bus and train separately. Particular care must be taken that, for the sake of consistency, the assignment should reproduce the (sub)-modal splits calculated in the choice model, which may require manipulation of networks and linkages – so-called biased networks

Thus, to summarise, it is important that

- proper linkages must be established between mode and destination choice models;
- linkages are more easily established if both models are, or are transformed to, the logit form;
- a logit form should also be used if it is necessary to model park-and-ride;
- the appropriate logsum variable should then be input from the park-and-ride model to the main mode choice model;
- the decision between choice modelling or assignment for the choice among public transport submodes depends on the local circumstances and software; when a choice model is used it should be of the logit form and a proper logsum linkage should be made with the main mode choice model;
- choice among public transport routes should be represented in the assignment software and not in a separate choice model;
- the specification of composite cost for the models based on assignment is difficult and depends on software capability (this is the subject of separate analysis in section X).

## 5.7 Change of Trip Destination (distribution)

Advice on the formulation of 'destination choice' or 'trip distribution' sub-models can be found in *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3). The forms used in models for public transport scheme appraisal should, in general, estimate the incremental changes in trip patterns which would occur in response to an incremental change in generalised cost; that is, they should be of a 'gravity' formulation rather than a Furness procedure.

In a multi-mode model for public transport scheme appraisal, the detailed form of the distribution sub-model depends on its position in the sub-model hierarchy. If the distribution sub-model is less sensitive than mode choice, it should distribute trip generations by car ownership or car availability to a combined set of trip attractions. If the distribution sub-model is more sensitive than mode choice, it should distribute trip generations by mode to a combined set of trip attractions. Whatever its position, the distribution sub-model should be applied separately by trip purpose.

Distribution sub-models may be either singly or doubly-constrained (see *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3)). Doubly-constrained sub-models are appropriate for trip purposes where at the modelled area level a **predetermined** number of trip productions are expected to continue to be in balance with a **predetermined** number of trip attractions. Home-based journey to work is one example of such a purpose where, at the modelled area level, one would expect the total number of jobs to be approximately the same as the total number of employed residents (after making allowances for inbound and outbound commuting across the modelled area boundary). For other trip purposes, a singly-constrained model is usually more appropriate. An example purpose would be shopping, where the number of travellers wishing to make a trip is largely **predetermined**, whereas the number of people that can be accommodated in any zone is, generally, flexible and unrestricted over the time scales being modelled.

The Department will usually expect that the distribution model is calibrated by trip purpose against local data and used to predict incremental changes from a mainly observed base year matrix. In the event that insufficient locally-collected data are available for estimation of the model lambda (spread, sensitivity or scaling) parameters, values may be imported from other models. *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) provides advice on lambda values by trip purpose, car ownership or availability, and time of day.

For models in which the distribution sub-model is more sensitive than mode choice, the same lambda value should be used, initially, for both car and public transport modes. As explained in Section 9 below, it may be necessary to adjust some model parameters to ensure that the demand elasticities implied by the overall model accord with established values. If adjustments of this kind are necessary, one option, which could be considered, is to differentiate the destination choice model parameters by calibration area and/or mode. The modeller may opt to conduct tests of the sensitivity of the forecasts to alternative lambda values which vary by mode.

If lambda values are imported from another model, the modeller should ensure that the chosen values are consistent with those provided in *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3). If the imported values differ significantly from the values given in Unit 3.10.3, the Department will expect to see a convincing justification for the preferred values.

While changes in destination choice are not usually claimed as intended scheme impacts for major public transport investments, it is clear that when regeneration or accessibility benefits are claimed, these will imply a change in travel patterns with more trips attracted to and generated from the improved areas.

If a local model for trip attractions is to be set up, this should be done in conjunction with the model of destination choice to avoid the potential for bias which occurs when attraction variables are correlated with accessibility. For example, *ceteris paribus*, town centre shops will attract more trips (particularly from those without cars) than out-of-town shopping centres because of the greater accessibility of the town centre. If attractions were modelled separately, this difference could be attributed to some feature of the zone containing the shops, rather than the networks connecting it to the rest of the area.

## 5.8 Change of Time of Travel

It is usually necessary to make assignments for separate time periods so that a processing step is required to split the matrices, even if the splits use the constant factors under base and forecast scenarios

Splits should be made between peak and off-peak conditions. In some cases it will be necessary to distinguish between morning and evening peaks and/or between daytime and evening off-peak. The peak period definitions should be chosen to relate to the operating practices, in particular frequencies and fares, which are current in the local area.

Public transport schemes do not usually seek to change the distribution of demand over the day. Time of travel choice models are most needed, and the effort to develop them most justified, where conditions on the road system, and therefore the relative disadvantage of public transport, varies markedly by time period, and where significantly different fares and/or service levels would apply at different times of the day.

In practice, time of travel modelling is under-developed and not easy to apply successfully. *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) provides some advice on the model formulation which may be used to represent time of travel choice, along with some illustrative parameter values

The Department’s general presumption is that a time of travel choice sub-model should be included where crowding on public transport is a major issue or if there are significant differences between peak and inter-peak public transport fares or between peak and inter-peak costs for road traffic (such as might arise with a differential parking or congestion charging scheme). However, because of the potential difficulties involved, the need for a time of travel choice sub-model should be discussed with the Department at the model design stage.

## 5.9 Public transport assignment

It is noted above that a public transport assignment will form part of almost all scheme appraisal models. The importance of this element is reflected by its discussion in *Road Traffic and Public Transport Assignment Modelling*) (TAG Unit 3.11.2.

### 5.10 Highway assignment

Many major public transport schemes aim at reducing road congestion and hence an important aim of a suitable model should be the quantification of this impact. This is also discussed in *Road Traffic and Public Transport Assignment Modelling* (TAG 3.11.2)

# 6 Demand Segmentation

## 6.1 Introduction

In a public transport model, the travel demand will usually be split into a number of 'segments' to enable the model to distinguish between different types of traveller making different kinds of trip who will react to changes in the transport system in different ways. All trips within a segment are treated in the same way and so it is desirable for the traveller and trip types within each segment to be as similar as possible. However, the more segments that the demand is split into, the greater will be the data requirements, the resources necessary to develop the model, and the time taken to run the model.

## 6.2 Segmentation for Demand Models

Advice on the segmentation of demand, by household type and traveller type, value of time, trip purpose and modes, applicable to demand sub-models is provided in *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3). This advice is also applicable to models developed for the appraisal of public transport schemes, with further segmentation that is discussed below and applies particularly for the public transport models.

*Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) also points out that demand segmentation by car ownership or availability is important for mode choice sub-models. Mode choice sub-models are usually an essential component of models developed for the appraisal of major city-wide public transport schemes and segmentation of the travel demand by car ownership or availability will be necessary for those models.

An important influence on the use of public transport by those with a car available is whether or not they also have access to a convenient parking space. Consideration should therefore be given to segmenting the home-based work demand by the availability of a parking space at the workplace.

Segmentation of demand according to the type of ticket or fare concession may also offer a significant improvement in model accuracy. Travellers who pay for each trip they make will pay more than travellers buying season tickets or travel passes. Travellers buying travel passes are often able to make unlimited journeys for the single payment that they make and may therefore make more journeys than they would if they purchased their tickets for each journey individually. Many senior citizens, school children and students are able to take advantage of fare concessions and may travel more than they would if they did not have the concessions. Consideration should therefore be given to the extent to which demand should be segmented by ticket type and/or fare concession.

Travellers using a public transport link to an airport have special characteristics which need to be reflected in the model. First, the distinction must be made between air passengers and airport workers. The propensity of air passengers to use public transport to access the airport depends strongly on whether they are travelling on business or leisure and whether they are in the home area or away from home. The use that airport workers can make of a public transport service is limited by the availability of services which fit in with their shift patterns.

The Department's general expectation is that, at the model design stage, the available demand data will be analysed in order to identify the separate markets for the new public transport scheme. The principle which should be followed is that, as far as possible, all elements of demand that are distinct in their characteristics and significant in their magnitude should be treated separately in the demand model.

### 6.3 Segmentation for Public Transport Assignment Models

Segmentation of the demand at the assignment stage is only necessary if different groups of travellers have attributes that may influence their choice of service or route. The following two attributes may be of relevance:

- the type of ticket purchased; and
- the degree of familiarity with the services available.

Travellers who purchase their tickets individually may be less familiar with the services on offer and therefore may not always take the best route through the network. Conversely, those who buy travel passes are likely to know more about the public transport system and may be more unconstrained in the routes they choose.

The computer run times for public transport assignment models can be a significant element of the total run time of a multi-stage model for the appraisal of a public transport scheme. Increasing the demand segments at the assignment stage may therefore have substantial implications for the overall model run times. There are other considerations too, such as the need for relatively fine zoning systems and service detail that will cause longer run times. The balance between these aspects of an assignment model should be considered carefully. The Department's general advice is to give primacy to the fineness of the zoning system and the network detail and to resort to segmentation of the demand at the assignment stage only if it can be shown that doing so would significantly improve otherwise unacceptable results.

# 7 Generalised Costs

## 7.1 Introduction

Advice on the formulation of generalised costs for private car users is provided in *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3). Advice on the formulation of generalised costs for public transport users is provided in *Road Traffic and Public Transport Assignment Modelling* (TAG Unit 3.11.2)

## 7.2 Generalised cost components

Generalised costs are used in the identification of paths and in determining the assignment of passenger flows to the paths. It is a combination of a number of different attributes of a path with each attribute being given its own weight or coefficient. The coefficients convert components to common units and are specified to reflect the relative importance of these for travellers. The attributes that can be included in the generalised cost vary between PT models. They will normally be a subset of the following list:

- access time (from trip origin to PT stop, by relevant modes),
- egress time (from PT stop to trip destination, by relevant modes),
- walk transfer time (between PT stops),
- origin wait time (time spent waiting for first service on path),
- transfer wait time (time spent waiting for subsequent services),
- in vehicle time (may vary by mode/vehicle type),
- fare,
- transfer penalty (based on number of transfers times a penalty which may depend on the circumstances of the interchange),
- distance,
- overcrowding,
- reliability.

As far as possible, attribute weights should be consistent between assignment and choice modelling.

Travellers' perceptions of the different public transport modes may vary. For example, some people may prefer to travel on trains because they can more easily make use of the travelling time for other activities, such as work. Other people may prefer to use surface level modes as opposed to underground systems. Others may prefer to use a mode with a high chance of a seat (such as a bus) rather than a mode with a smaller seating capacity (such as an urban tram with a high standing proportion).

In mode choice sub-models which split trips between all the public transport modes available, the relative attractiveness of the different public transport modes can be represented in the modal constants calibrated for each mode. However, in models which split trips between car and public transport as a whole (sometimes referred to as 'main mode choice'), any distinctions between the various public transport modes will need to be reflected by means of either mode-specific willingness to pay fares or mode-specific values of in-vehicle time.

Assignment packages deal with these components at differing levels of sophistication. However, the following recommendations can be made regarding the key components.

## 7.3 Fares

Fares need not be included in the assignment, provided that they do not influence route choice; matrices of fares can be added to the generalised cost after the assignment and before passing cost matrices to a demand model or appraisal package. Where fares can influence route choice then it is essential to include them in the assignment. It is accepted that the complexity of some fare systems may prevent them from being represented exactly in the assignment model, but the model representation needs to be 'acceptable'. Acceptability can be gauged from whether the assignment model validates or not (see *Road Traffic and Public Transport Assignment Modelling* (TAG 3.11.2) for validation criteria).

Fares may not be important for holders of some kinds of travel passes, in which case they would need to be assigned as a separate user class. This is in addition to any other segmentation (e.g. by purpose or car availability) that might otherwise be required by demand modelling or appraisal.

The relative willingness to pay fares for existing modes and any new mode may be derived by means of a stated preference experiment. In experiments of this kind, great care must be taken to present the modes in an even-handed manner. For example, existing modes should not be presented to the respondent as old and out-of-date while new modes are presented as modern and state-of-the-art. The emphasis should be on those attributes of the existing and new modes which are likely to influence people's preferences and these attributes should be presented in as unbiased a manner as possible. For advice on stated preference surveys, see *Mode Choice Models: Bespoke and Transferred* (TAG Unit 3.11.3)

## 7.4 Mode Specific Values of In-Vehicle Time

In some instances, factors may be applied to the in-vehicle times that reflect people's preferences for the various modes. This is most likely to be relevant where the influence of fare on the choice of routes and services is likely to be quite weak and, as a result, the fare term may be excluded from the generalised cost formulation used at the assignment stage. These in-vehicle time factors may be interpreted as mode-specific values of in-vehicle time. Thus, instead of an in-vehicle value of time of unity being used, as might be used in models for multi-mode transport studies, non-unity values of in-vehicle time are used to represent the inherent, relative attractiveness of the various modes.

In-vehicle time factors or mode-specific values of time are best obtained from a properly designed and conducted stated preference experiment. An alternative method sometimes used is to calibrate in-vehicle run time factors, by a process of trial and error, during the assignment model development. However, this is a less precise way of identifying correctly the relative attractiveness of the alternative modes and a properly designed and conducted stated preference survey is to be preferred.

## 7.5 Waiting times

It is important to distinguish between the wait at the first stop on the path and the wait at subsequent stops. Passengers have some control over when they arrive at the first stop on the path, but their arrival time at subsequent stops is under less control.

For service headways up to around 10-15 minutes it is acceptable to estimate waiting time using half the headway for the first and subsequent waits (but see the next paragraph). For longer headways, this assumption is not valid and it will therefore be necessary to use some kind of wait curve to cap the wait time at the first stop.

It should be noted that when services are irregular (either planned or a result of poor punctuality), half the mean headway is actually an underestimate of the mean waiting time, for both the first and subsequent waits. In this situation it is worth considering using wait curves where the waiting time is greater than half the headway. Reduced waiting times for a given headway can be used to model the effect of improved reliability, although it can be hard to quantify.

In any case, waiting time should be calculated using the *relevant* set of routes which serve the traveller's destination. Determining this set is a complicated function of the assignment software and may require careful consideration by the user.

## 7.6 Crowding

The introduction of crowding has significant practical problems for PT assignment, namely the need for assignment to be an iterative procedure with a consequent impact on run times, the need to achieve convergence, and the need to calibrate overcrowding curves. For these reasons crowding should only be modelled where it is likely to have a significant effect on traveller behaviour or where an effect on crowding is one of the objectives of the scheme.

Where crowding is not modelled it is still important to monitor volume to capacity ratios when forecasting to determine whether crowding will become a problem in the future.

## 7.7 Effect of road congestion

For submodes that run on-street (mainly bus, but some LRT schemes) it is important that journey times in the PT assignment model are consistent with the level of traffic congestion. This will require some linkage of on-street PT mode link times in the PT network to assigned journey times from a highway assignment model.

In congested urban situations it may not be appropriate to take bus times from a published timetable. In any case this will not be possible when forecasting and a link to a highway assignment model will be necessary to estimate PT on-street journey times for forecast years.

# 8 Convergence between Demand and Supply in Public Transport Models

## 8.1 Introduction

When the supply of transport is changed, as would be the case with a new public transport scheme, the demand for travel will also change. ‘Convergence’ is the term used to describe the process of finding the equilibrium position in which the costs used by the demand model equal those predicted by the supply models. The accuracy of the transport economic efficiency appraisal is highly dependent on the accuracy with which the equilibrium position can be determined.

The complexity and range of the demand responses needs to vary with the nature of the scheme, as demonstrated by the following examples.

- A city-wide light rail scheme would be expected to cause significant changes in the scale and pattern of demand by mode. In this case, a fully-specified multi-mode model would be required and it would be necessary to find the balance between the supply of, and demand for, both public and private modes.

- The provision of a new public transport service to serve an area of low car ownership already served by public transport would not be expected to attract much traffic from cars. The expectation is that it would derive most of its patronage by extraction from the existing services, although there could be some additional public transport demand attracted from walking or cycling in response to the overall capacity increase. In this instance, the public transport model need consist of only an assignment model coupled to a procedure for estimating the generated demand for public transport.

The convergence procedures needs to vary according to the type of model, as may be seen by considering the examples above:

- The multi-mode model described in the first case above will require the most sophisticated kind of procedure for finding the equilibrium between the demand for, and supply of capacity on, all modes.

- The single mode model described in the second case would **only** require a procedure for finding the equilibrium between the demand for, and supply of, public transport, **if** the additional demand were to change the generalised costs of travel through over-crowding. Convergence is therefore required between the over-crowding and assignment routines, but there would not be any need for a convergence procedure between highway and public transport forecasts in these cases.

## 8.2 Procedures for Finding Equilibrium

*Variable Demand Modelling – Convergence Realism and Sensitivity* (TAG Unit 3.10.4) provides advice on methods for seeking convergence between demand and supply in multi-mode models.

The Department has commissioned the development of software called DIADEM, which can be used to implement the demand sub-models discussed earlier in this current Unit, and which will find the equilibrium point between demand and supply in an efficient manner.

The algorithms for seeking equilibrium which are available in DIADEM are more efficient than the methods that are generally available in other software packages. *Variable Demand Modelling – Convergence Realism and Sensitivity* (TAG Unit 3.10.4) offers advice on simpler and less efficient methods which may be used with most software packages.

At present, DIADEM will operate only with a CONTRAM or a SATURN road traffic assignment models. The intention is to develop the software to enable it to work with other assignment models. DIADEM has yet to be used to create a multi-mode transport model, with the full range of demand responses and with both road and public transport supply (assignment) models. At present DIADEM assumes that PT costs remain fixed. Until the software has been fully developed and some experience of using it has been gained, there would be some risk in applying it to a live appraisal of a complex public transport scheme. Against that risk must be set the advantage of being able to use the efficient convergence procedures available in DIADEM.

The need to achieve convergence accurately is clear when the appraisal is concerned with policies which could cause a major reduction in or transfer of demand. Even major public transport schemes are unlikely to cause either major increases in the overall demand for travel by all modes or major transfers from car to public transport. The scale of the transfer from car to public transport is likely to be modest in most cases and may be difficult to detect clearly against the residual ‘noise’ or residual convergence errors in even a well-converged road traffic assignment model. It is likely that, in most cases, the need for efficiency in the convergence of the road traffic assignment model will be significantly greater than the need for efficiency in the convergence of the demand and supply models, as the former could be significantly harder to converge than the latter, bearing in mind the likely scale of convergence problem in each case.

Balancing these considerations, the Department’s general advice is as follows. Until DIADEM has been developed, the advice in *Variable Demand Modelling –*

*Key Processes* (TAG Unit 3.10.3) on non-DIADEM methods of achieving convergence should be followed. When DIADEM is fully operational and proven for public transport modelling, its use should be considered, taking account of the superior convergence procedures that it **may** offer over other software.

Unless crowding is explicitly modelled, public transport assignment models are not solved iteratively, so convergence is not an issue. Where the public transport assignment model represents crowding, and hence requires iteration, we suggest that convergence is monitored in the same way as in highways assignment (see DMRB Volume 12), and that similar convergence criteria are used.

Convergence of the full model system, i.e. iteration between demand and supply, or in other words between the demand response components and (public transport and highway) assignment, should be monitored using the guidelines developed in DIADEM; if necessary the convergence algorithms designed in DIADEM should be incorporated in the model system to aid in achieving required levels of convergence.

# 9 Validation of the Overall Demand and Supply Models

## 9.1 Introduction

Section 2 of this Unit refers the reader to *Variable Demand Modelling – Key Processes* (TAG Unit 3.10.3) for advice on the formulation of sub-models of the various traveller responses. Advice is also provided on the estimation of model parameter (sensitivity, spread or scaling) values (or sources for these parameter values in cases where estimation is not feasible), and on the calibration of modal and area-specific constants.

*Road Traffic and Public Transport Assignment Modelling* (TAG Unit 3.11.2) refers the reader to advice on the validation of road traffic assignment models and provides advice on the validation of public transport passenger assignment models.

Following this advice should yield a well-constructed and validated model. However, it is important that the model, in forecasting mode, displays output elasticities which are in line with experience and, where available, empirical evidence. This section explains how the validation of the overall demand and supply models should be achieved.

## 9.2 Overall Model Validation

*Variable Demand Modelling – Convergence Realism and Sensitivity* (TAG Unit 3.10.4) explains, under the heading 'Realism testing', that it is desirable to check the elasticity of demand output or implied by the model with respect to:

- car journey times;
- car fuel price;
- public transport fares; and
- parking charges.

For the appraisal of a public transport scheme using a multi-mode transport model, the Department will normally expect to see a satisfactory validation in all four aspects.

*Variable Demand Modelling - Convergence Realism and Sensitivity* (TAG Unit 3.10.4) provides advice on the range of elasticities with which the modelled elasticities should conform. The range of trip-kilometre elasticities shown in Table 1 have been used to validate a number of multi-modal models and may also be useful.

**Table 1: Expected Short and Long-Term Trip Kilometre Elasticities**

| | High | Central | Low |
|---|---|---|---|
| **Car fuel (cost/km after allowing for vehicle fuel efficiency changes)** | | | |
| 1 year | -0.28 | -0.125 | -0.07 |
| 5 years | -0.32 | -0.2 | -0.13 |
| 10 years or longer | -0.48 | -0.3 | -0.19 |
| **Bus fares** | | | |
| 1 year | -0.65 | -0.3 | -0.16 |
| 5 years | -0.96 | -0.6 | -0.38 |
| 10 years or longer | -1.12 | -0.7 | -0.44 |

If the elasticities derived from the model output do not accord with the target ranges, the model parameters should **not** be used for the scheme development appraisal. Instead, the model parameters should be adjusted until acceptable output elasticities are achieved. Adjustments to imported parameters should be made before adjustments are made to parameters estimated from local data. Any adjustments made should respect the adopted hierarchy of traveller responses.

# 10 Resource Considerations

## 10.1 Introduction

The main limitations imposed on modelling for major public transport scheme appraisal are those of the resources available to the analysis team:

- existing models,
- data,
- time,
- money and
- skills available.

Of course, the balance between the resources can be changed, for example new data can be collected, costing time and money, or skills can be bought in. However, a realistic inventory of the resources available at the outset of an appraisal project is essential to a realistic choice of modelling method and structure.

## 10.2 Existing models

In some cases, models or model components exist which have been used for previous or ongoing studies. Of course, if these models are satisfactory for public transport scheme appraisal they should be used, but even if they are not suitable for all aspects of the study they may be able to supply some of the necessary sub-models. In particular highway assignment models may be found from this source.

Existing models may also be associated with relevant data sources which may be useful even when the models are not.

To identify which model components are of value to the study, the scheme objectives should be reviewed. Any component must be assessed to ensure that it meets the criteria for validation, as set out elsewhere in *Road Traffic and Public Transport Assignment Modelling* (TAG 3.11.2)

It is recommended that:

- before commencing the model design for the appraisal of a major public transport scheme an inventory of existing models is made;
- each model considered is assessed on: the structure of the overall model and its components; the age and quality of the underlying data; and adherence to quality criteria for calibration and validation set out in *Road Traffic and Public Transport Assignment Modelling* (TAG 3.11.2).

## 10.3 Data resources

When considering the modelling structure to be used for a new study it is advisable to obtain information about existing data before committing resources to new data collection. While some existing data may not be useable because of its age or specific defects, other data may be exploited at least in a limited way – and limited new surveys can be used to check the validity of larger, older datasets.

The advantage of exploiting existing data is not only in the potential cost saving. Additionally, the burden on the public and the long-term impact of 'survey fatigue' can be reduced, hopefully improving response rates, while a degree of consistency with past transport planning is maintained. That being said, the quality and accessibility of older data sets often imposes an additional burden on the study team. In particular, documentation of older data is often inadequate and staff are no longer in post who could answer questions about it.

Design of data collection is discussed elsewhere *Mode Choice Models: Bespoke and Transferred* (TAG Unit 3.11.3). Nevertheless, certain issues of model structure have consequences for data collection and these are now discussed.

**Home interview** revealed preference (RP) surveys are expensive, even when carried out by telephone. Surveys of this form are the natural procedure for obtaining information on household behaviour in moving home, car ownership and travel frequency. Thus if these model components form part of the structure of the model, it will be necessary to collect data from home interviews or to rely entirely on models transferred from elsewhere. Home interviews are prone to response bias, and care must be taken to avoid this.

**Stated preference (SP) surveys** are the natural procedure when dealing with new alternatives, such as new modes, or when new variables, such as new levels of comfort or information systems are being considered. SP can also provide a valuable support for modelling choice among existing modes, sub-modes or routes. But RP data should also be collected as a support for SP wherever possible. SP is generally a poor means for addressing travel frequency or destination choice.

**'En route' surveys**, such as roadside interviews or intercept interviews on public transport modes are a cheap and effective means of collecting large quantities of data of limited detail. In particular they can form the basis for estimates of matrices of base-year travel flows. This form of data is naturally best used to support the modelling of destination choice (possibly through the analysis of base matrices) and choice among existing modes, sub-modes and routes. Counts are of course basic to the transport planning process and are often available from existing work.

The advice of the Department is:

- that before any data collection is commenced a thorough inventory is made of existing data sources, its applicability and limitations;

- that if car ownership or trip frequency is a necessary component in the model structure, household interviews are considered;

- that stated preference surveys are valuable if new modes or new variables are part of the scheme under consideration: they also can provide valuable support for modelling choice among existing modes, sub-modes or routes;

- SP surveys should always be supported by RP data (existing or new);

- that en-route surveys are most suitable for the modelling of destination choice, and for base year matrix estimation;

- finally, the data collection required for a study may also impose requirements in terms of time, money and skills.

## 10.4 Time required

Data collection, model development and application and the further processes of reporting and consultation require amounts of time that can be estimated. These estimates should be respected – it is better to obtain model results that have been properly considered and discussed than rushed results that may prove to be incorrect or based on inappropriate assumptions but which meet an imposed timetable.

Where time constraints are an issue, the modeller has two options.

- Design a simpler modelling structure, with lower data requirements and reduced model development time. In such cases the implications of these simplifications for the model's outcomes (and ultimately the robustness of the appraisal) must be discussed with the DfT before implementation – note here that sensitivity tests can help identify whether more detailed modelling is required.

- Stick to the ideal modelling structure and associated data requirements and development times, and accept the increased risk of missing deadlines. The modeller should endeavour to quantify these risks – they may be unacceptable so that the only reasonable outcome is not to use a model at all.

## 10.5 Money budgets

The issues concerning money are very similar to those concerning time. Although it is better to get a right but expensive answer than a cheap but wrong one, ultimately, if the model required to analyse the impacts of a proposed scheme cannot be developed and applied within the money (or time) budgets available, the exercise may have to be abandoned. Once again, it is better to avoid spurious accuracy.

Both money and time may be saved by reducing the level of ambition of the model, e.g. by removing expensive components such as land-use modelling or highway assignment. A reduced scope of modelling is to be preferred to inaccurate modelling of specific model components. Naturally, the incompleteness of the model should be acknowledged in any presentation and this is easier to do when clear elements are omitted. However, the danger of inconsistency between appraisal on quantified aspects and public assessment on other aspects is then relevant.

### 10.6 Skill requirements

Finally, it is worth noting that model structures may be restricted by the need to employ staff with specific skills. For example, the conduct of credible SP surveys requires a degree of professionalism and experience which is not always appreciated. Two other aspects of the modelling process require particular skills which are not widely available.

First, when model structures expand to include multiple aspects of behaviour, it is necessary to incorporate proper linkages between the sub-models to ensure that credible results are always produced by the model. For instance, when an improvement is made in a specific public transport service, the sensitivity of transfers between services, across modes and across corridors must be related in the ‘right’ way. Specialised modelling staff may therefore be needed to ensure the appropriate behaviour of complicated models.

Second, when multiple existing and new, SP or RP, data sources may be used, econometric skills may be required to estimate the important model parameters, giving appropriate weight to each of the data sources.

It is in principle possible to hire in skills of these types but this imposes a cost requirement and may also require time for the contracting process. Hiring in temporary or consultant staff also reduces the local knowledge of the model system.

Thus it may be preferable to restrict the ambition of the model system because of the skill requirement. The dangers of such a reduction in ambition have been noted. However, reductions in complexity, as opposed to reductions in scope, bring lesser dangers of failure to quantify the scheme aspects that the public consider important.

## 11 Major Public Transport Scheme Examples

Whereas in section 2 the decision-making process for appropriate model structures is described as a ‘bottom-up’ process considering the scheme’s objectives, this section takes a ‘top-down’ approach, identifying a number of possible model structures and discussing the types of scheme for which these structures might be appropriate.

Ideally, both processes would come up with similar structures. This two-pronged approach should aid in the identification of structures and components that are out of the ordinary, driven by peculiarities of the scheme under investigation or its study environment.

In each case, the order: trip distribution (destination choice), modal split and time-of-day choice has been presented. In specific cases, as discussed in section 3, the order might be varied to suit local circumstances but the figures have not been adjusted to show these variations to avoid excessive complexity. Also, as discussed in section 3, not all three components may be necessary for modelling scheme impacts, although they may be essential in determining future reference case forecasts[2].

Major extensions of a public transport system, particularly LRT, could be expected to have impacts not only on travelling behaviour, but also on regeneration and land use changes over a wide area. The model structure in Figure 1, showing the most complete model system at the maximum extent would be appropriate.[3]

Figure 2 indicates the simplifications that could be obtained by omitting the land-use component, but retaining an output of accessibility measures that might form an input to an expert group. This model system would be appropriate for a scheme making major improvements in a corridor, and also if resource constraints would make the explicit modelling of the feedback of transport changes to land use developments too onerous.

Where resource constraints are more stringent still, the use of TEMPRO rather than locally derived data could reduce the timescale and data requirements significantly, and simplify the model structure. Figure 3 illustrates the use of TEMPRO data, shown as being used for both trip generations and attractions, although it could be used for one or the other independently. The approach would be suitable for a major scheme at network or corridor level, but any regeneration effects would be excluded and would need to be assessed and quantified separately.

Figure 4 omits trip generation/frequency[4] and distribution, working with a fixed matrix (of all trips including if possible slow modes). Such a model structure would be suitable for cases where modal split changes are the key desired and expected impacts, with no impact on the overall level or structure in demand. This structure might be suitable for improvements in a single line, between two existing generators, for example a city centre to airport access study. These applications could include the introduction of new modes.

Figure 5 omits the time-of-day step in the modelling, leaving only mode split and assignment. This is a simplification of the previous structure that might be appropriate in less urbanised contexts, where peaking would be less pronounced.

Bus priority schemes will generally impact on the amount of road-space or green time available to general traffic. Hence, there may be expected to be a need for highway assignment as well as public transport assignment. In certain cases mode choice could be omitted, leading to the model structure in Figure 6. This structure could also be of use in assessing the impact of quality bus corridors

Where the bus priority schemes do not affect conditions for general traffic, the highway assignment component may be omitted, leading to the structure in Figure

[2] Time-of-day choice is shown explicitly with a feed-back from the assignments. In most cases, however, time-of-day choice will probably use fixed factors and the feed-back mechanism will not operate. In those cases the model structure could be simplified to show the feed-back going to the mode choice model.

[3] In the Figures, dashed lines show connections that may or may not be present, while connections indicated by solid lines should always be present.

[4] Trip generation in the following diagrams should be read as Trip Generation/Frequency

7, showing the very simple minimal model with the assignment of a public transport matrix only.

Note that these are examples, and that careful assessment of the local conditions, the scheme's design details and limitations in resources may lead to different structures. For example, where a highway assignment model is already in place and the timetable for assessment tight, bus priority measures could be assessed without further development of a public transport assignment model, obviating the need for passenger surveys and model development and validation. However, in the presentation of the modelling work the assumptions made should be made explicit, and if possible a quantified assessment should be made of the possible implications of the simplification on appraisal results.

Similarly, interchange schemes could be assessed purely on their impacts on public transport generalised costs, i.e. using the structure in Figure 7. However, the construction of interchanges would generally include significant changes in the network lay-out for general traffic as well, so that a highway assignment model might be required. Depending on the magnitude of the changes in generalised costs for all modes due to the interchange, a mode choice component may or may not be appropriate.

None of the diagrams shows a linkage between congestion on the highway network and speeds of public transport (primarily buses) using that network. Such a linkage should be included wherever the impact is expected to be significant.

**Figure 1:** Complete Model

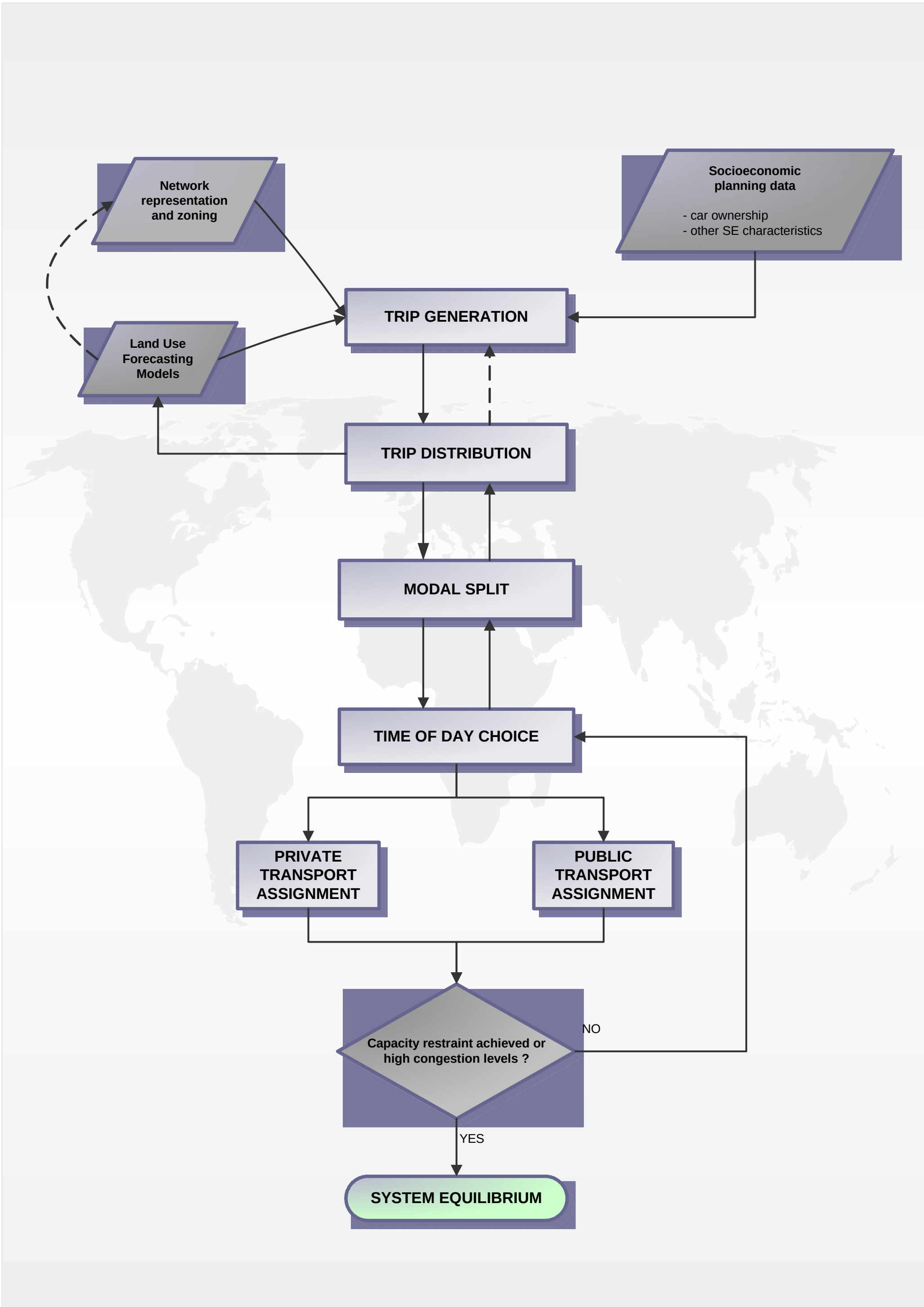

**Figure 2:** Omitting Land Use

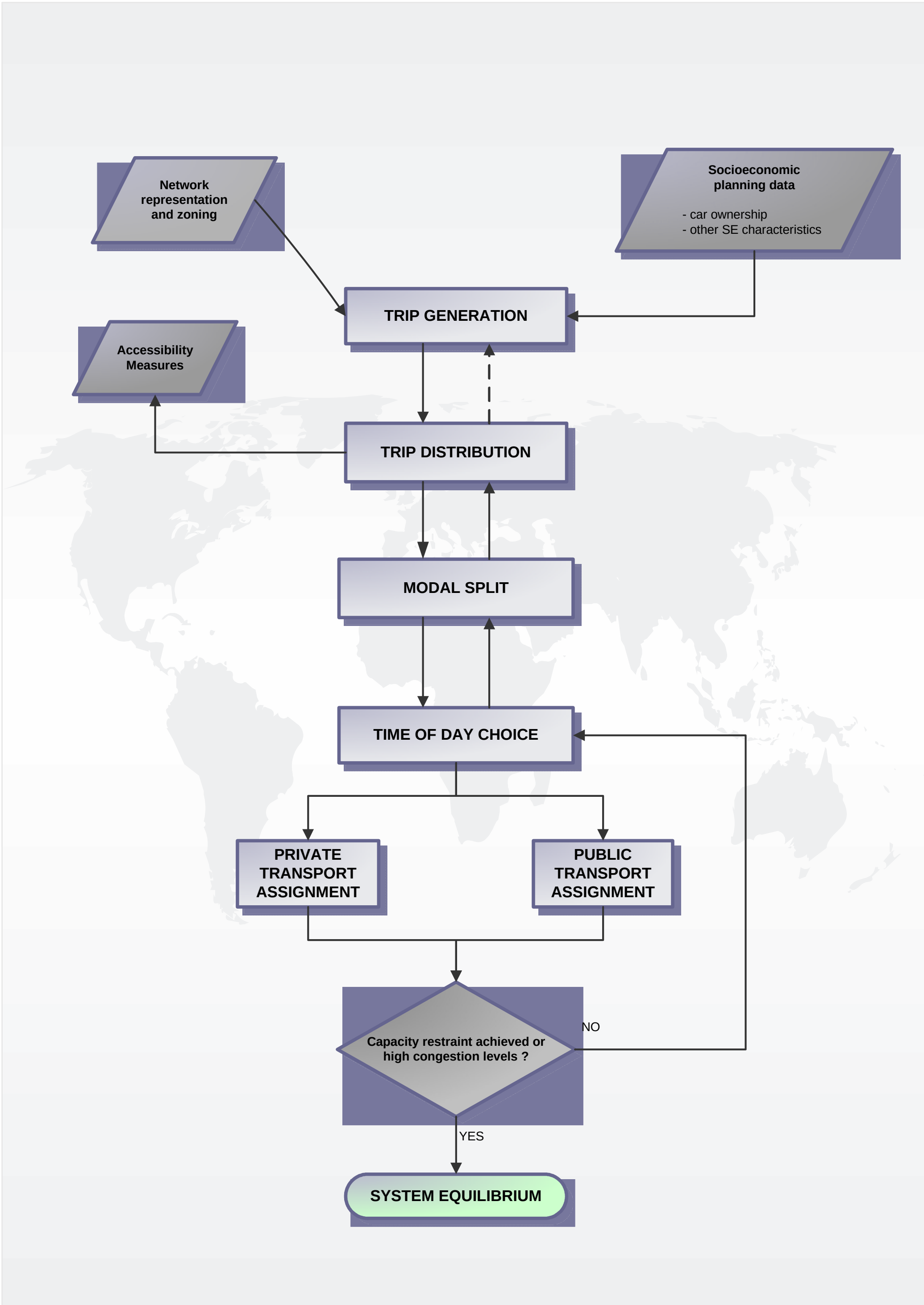

**Figure 3:** Reliance on TEMPRO

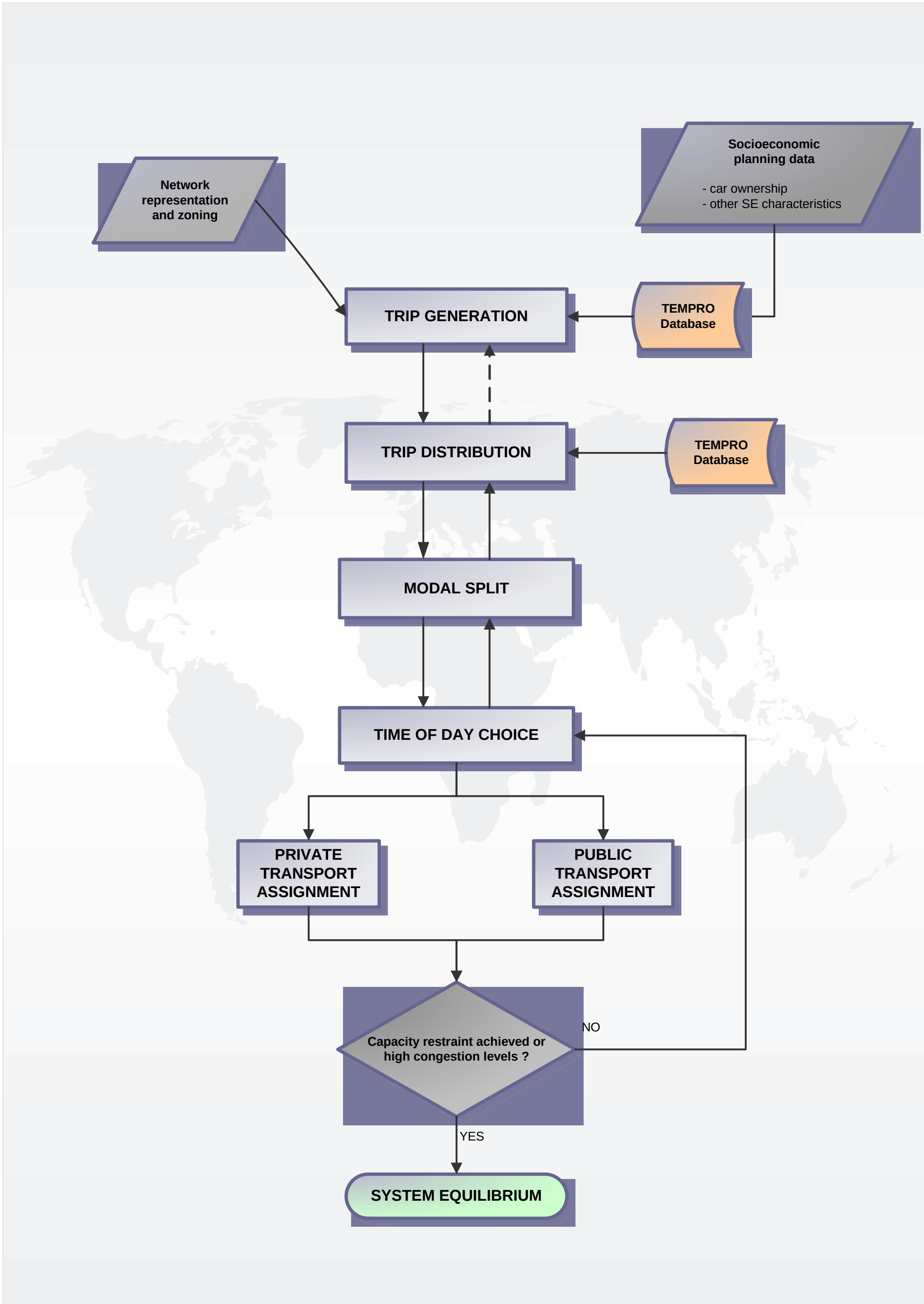

**Figure 4:** Fixed Matrix

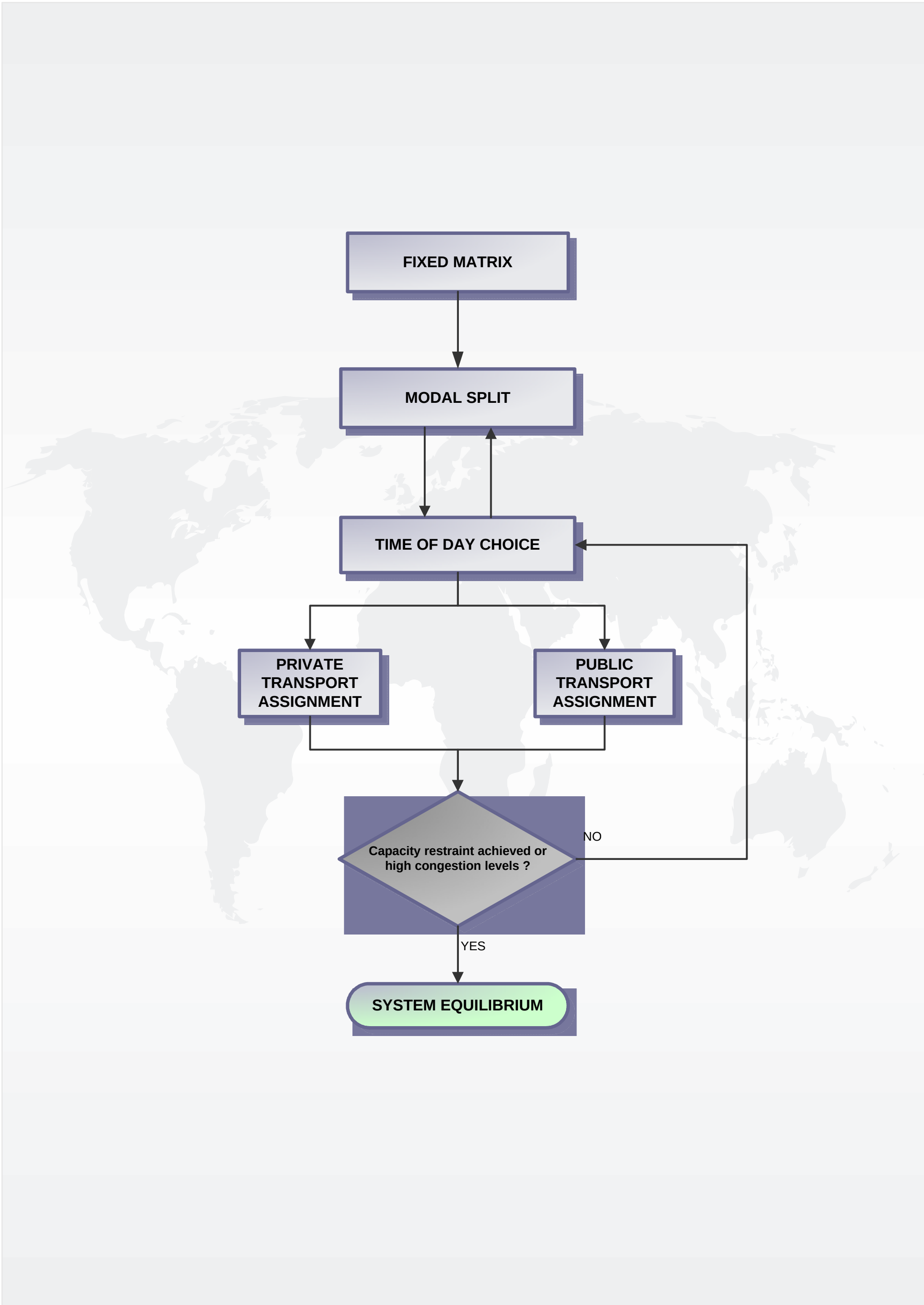

**Figure 5:** All Day Model

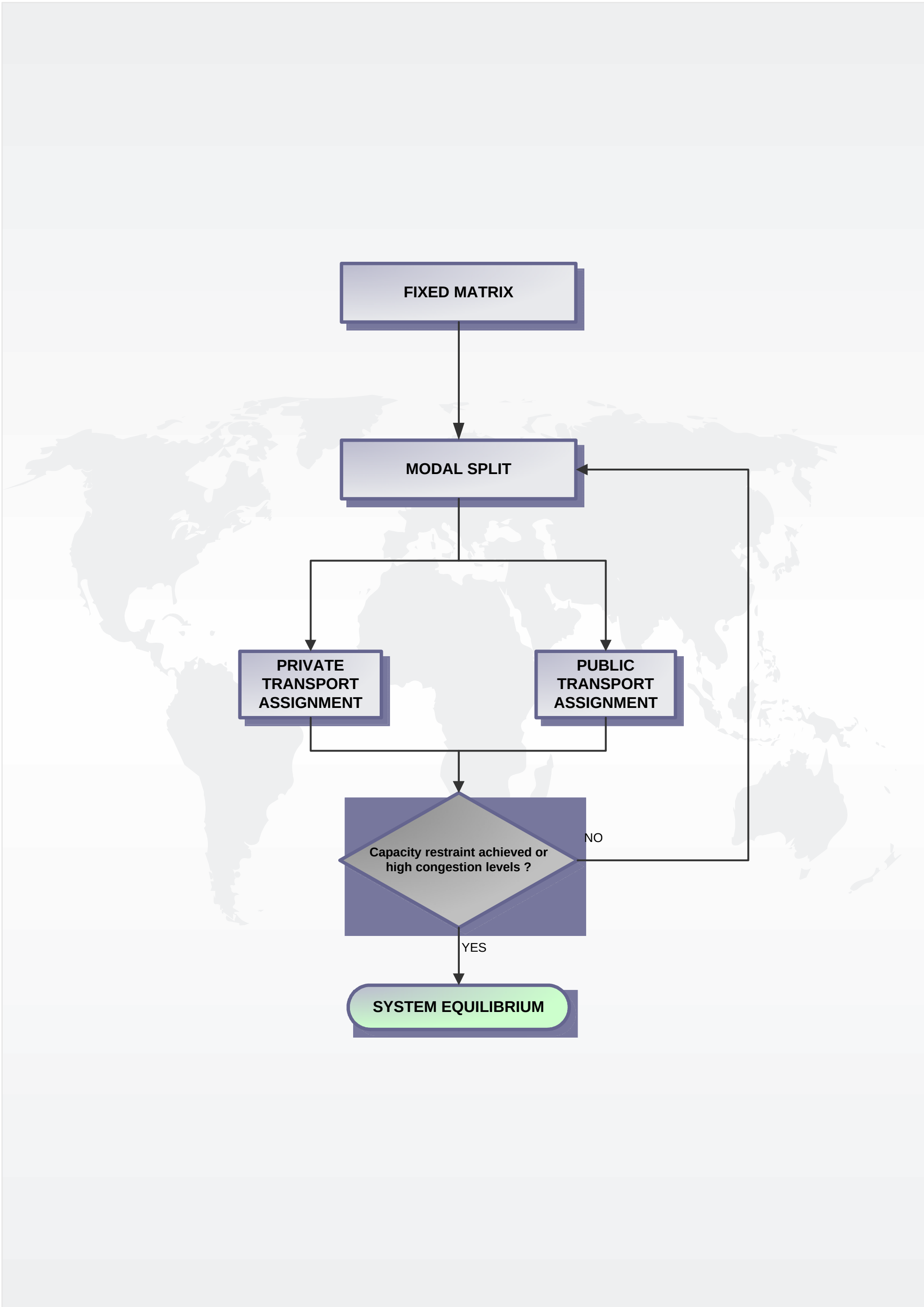

**Figure 6:** Road and PT Assignment Only

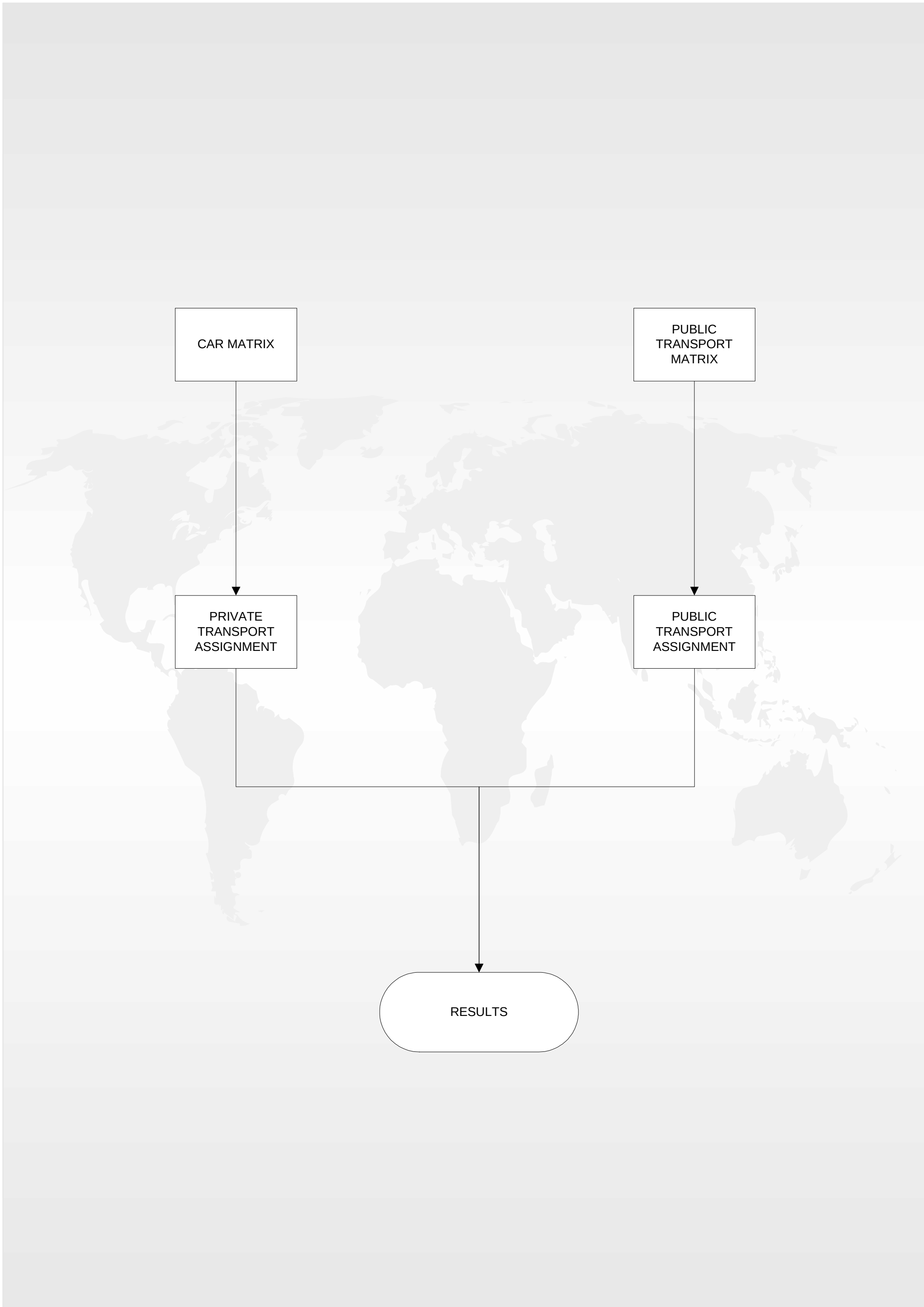


**Figure 7:** Minimal Model

# 12 Further Information

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

| For information on: | See: | TAG Unit number: |
|---|---|---|
| Appraisal of major schemes in Local Transport Plans | *Major Schemes in Local Transport Plans* | 1.4 |
| A general overview of modelling | *Summary Advice on Modelling* | 2.4 |
| An overview of variable demand modelling, primarily for highway schemes | *Variable Demand Modelling* | 2.9 |
| Detailed general modelling guidance | *Modelling* | 3.1 |
| Detailed advice on the appraisal of major schemes in Local Transport Plans | *Detailed Guidance on Major Scheme Appraisal in Local Transport Plans* | 3.9 |
| Detailed advice on variable demand modelling, primarily for highway schemes | *Variable Demand Modelling – Key Processes* | 3.10.3 |
| Detailed advice on the models for public transport schemes | *Public Transport Forecasting and Modelling* | 3.11.2<br>3.11.3<br>3.11.4 |

# 13 References

Design Manual for Roads and Bridges 12

# 14 Document Provenance

TAG Units 2.10 and 3.11 replace Major Scheme Appraisal in Local Transport Plans Part 3: Detailed Guidance on Forecasting Models for Major Public Transport Schemes.

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

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