Department for Transport

TAG UNIT M1.1

Principles of Modelling and Forecasting

May 2024

Department for Transport

Transport Analysis Guidance (TAG)

https://www.gov.uk/transport-analysis-guidance-tag

This TAG Unit is guidance for the **Modelling Practitioner**

This TAG Unit is part of the family **M1 – Modelling Principles**

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

Transport Appraisal and Strategic Modelling (TASM) Division

Department for Transport
Zone 2/25 Great Minster House
33 Horseferry Road
London
SW1P 4DR
tasm@dft.gov.uk

Contents

1. Introduction

1.1 Scope of this unit

1.1.1 Transport investment is made in order to improve transport for the user, grow and level up the economy and to reduce the impact on the environment. Decisions will need to be made regarding which investment options in pursuit of these objectives should be implemented. These decisions should be informed by evidence of existing or anticipated future problems that have been identified, the effectiveness of viable options in addressing them, and the consequences of implementing each option. Evidence should be of adequate quality to make decisions, compiled using proportionate resources.

1.1.2 Transport models provide a means of providing quantitative evidence and insight to support such decisions. They do so by forecasting transport conditions in future years so that options for intervention may be compared and assessed. The transport system and how it is accessed by users is complex. Decisions concerning investment often need a level of assurance that mathematical models, based on strong empirical evidence, can at least in part provide.

1.1.3 Transport modelling is used for a range of applications within the transport sector. The modelling and forecasting guidance in TAG was originally established to enable practitioners to produce adequate evidence to support the business cases for major transport schemes. It also serves as a best practice guide for other projects or studies. In particular, strategic models of the nature described in TAG are valuable tools for developing policies and strategic and spatial plans at national, regional and local authority levels. Models help us to understand current and emerging issues (e.g. crowding or congestion), help to shape overall policy or strategy, and in the design or operational planning stage.

1.1.4 This TAG unit often refers to transport **appraisal**, which involves the application of models to derive the impacts of a specific set of proposals to ameliorate an identified transport problem. Appraisal is an analysis undertaken for the purpose of assessing potential value for money of such proposals to the public, deriving economic costs and benefits under a range of different scenarios. Models are often necessary in this process to provide the required quantification of impacts in future years. Guidance for the Technical Project Manager provides further information on the fundamentals of the transport appraisal process and how transport models can measure these impacts. Guidance for the Appraisal Practitioner informs practitioners of best practice in preparing the necessary outputs for the appraisal of transport schemes and policies.

1.1.5 Where possible, TAG attempts to emphasise that any model or wider analysis should be proportionate to the issue at hand. Simplifications may be made to the design of a model where it is judged that a more detailed specification would not add materially to the analysis to be worth the time and cost of doing so. For example, assessments of smaller schemes may make proportionate use of parts of the guidance or use simpler methods in proportion with the size of the scheme (e.g. a detailed model of a single junction rather than a larger model of a transport network).

1.1.6 The guidance in TAG is not intended to be a comprehensive textbook on modelling practice. The technical Guidance for the Modelling Practitioner is intended for analytical professionals to provide assurance and consistency with good practice concerning their model development approach.

1.1.7 This unit aims to help practitioners understand why modelling and forecasting are required and the principles behind the Department's guidance. Step-by-step guidance, along with the standards the Department expects, are given in the remainder of the Guidance for the Modelling Practitioner.

1.2 Structure of this unit

1.2.1 Section 2 explains why forecasting, modelling, and data collection are required to produce evidence for decision makers regarding transport schemes. Later sections explain the principles behind why the approach set out in TAG is recommended with regard to:

- data collection (section 3)
- modelling (section 4)
- forecasting (section 5)
- reporting (section 6)

2. Rationale for modelling and forecasting

2.1 Modelling

2.1.1 A transport model is a tool (usually an automated computer program) that converts readily available data and assumptions into a forecast of demand (number of trips) and supply (level of service / cost of travel) on the transport network. Transport models are therefore constrained by the availability of data, technical expertise, resources, and the outputs required.

2.1.2 Models themselves are underpinned by a large number of assumptions. In the case of transport models, they include:

- that the structure of the model is a sound representation of human behaviour and based on sound theoretical principles
- that any necessary simplifications within the model do not have a materially adverse effect on the required quality and assurance of the results with regards their ultimate use
- the numerical parameters used in the model, many of which cannot be observed directly and therefore need to be estimated using a sample of data and statistical principles (a process known as **calibration**).

2.1.3 Transport models are rooted in the economics concept of demand and supply. On the demand side, the number of potential users is a consideration of not just population, but the types of trips people make, for different purposes and due to the characteristics of households and individuals (for example households with children will have greater demand for travel to education and household car ownership directly influences demand for travel by car). This demand needs to use the transport network – the supply side - to access activities. The characteristics of the network determine the quality, cost and time of travel, which users consider in their travel choices (for example, greater use of a highway leads to congestion and longer journeys). The above assumptions are important in constructing realistic models that may consider the interactions of all these parts.

2.1.4 Before using models for analytical work, the analyst should specify the capabilities required from the model. Where models are developed for scheme appraisal purposes, a recommended way to do this is through the appraisal specification process at the beginning of the project, described in The Transport Appraisal Process. The production of an Appraisal Specification Report is a useful record of the agreements on the scope of the appraisal and model, including those reached with relevant stakeholders, in particular, between scheme promoters and sponsors. This tailors the modelling approach to the scheme and problems in direct scope and the necessary level of detail for a successful appraisal, including what assumptions or aggregations in the model will be acceptable.

2.1.5 In some circumstances cost savings may be achieved by using an existing model, but a model constructed for one project cannot necessarily be used for another, even if it covers the correct geographical area. This may be for numerous reasons, for example a lack of appropriate detail in user segmentation, or a weaker representation of the transport network than is required in the specific area being examined. The Guidance for the Modelling Practitioner (see TAG units M2.1, M3.1, and M3.2) gives some advice on how to judge the validity of using existing models in different applications, or how one may transfer parameters or data to a new model to save time and resources in the model development process.

2.1.6 There is a risk the model may not be realistic or sensible due to the error around the model parameters used, or limitations in the extent to which the model can represent relevant human behaviour. Therefore, before using any model, it is essential to check that it produces credible outputs consistent with observed behaviour. This is usually done by constructing a model **base year** (either the current year or a recent year, depending on the data available), and:

- comparing the outputs (after it is run) with data independent from its construction (**validation**)
- checking that its response to changes in inputs is realistic, based on results from empirical evidence (**realism testing**)
- checking that the model responds appropriately to all its main inputs (**sensitivity testing**)

2.1.7 Both the calibration and validation processes described above can create a requirement for bespoke data collection, discussed in section 3.

2.1.8 Building transport models is often a complex process requiring a range of skills to work with data and relevant software. The models can take a long time to run and generate a large quantity of data, and even the best models are imperfect representations of reality. Therefore, the construction and use of models should be **proportionate**, and analysts who prepare models should be aware of their **limitations**, communicating the risks that such limitations create. Given the limits of resources available for modelling, analysts should consider the trade-off between developing the model (in terms of its accuracy and functionality) and carrying out additional forecasting work to test for sensitivity and uncertainty. Each TAG modelling unit provides practitioners with guidance on model development stages and also the range of checks and reviews that are typically undertaken.

2.1.9 To aid in the efficient and proportionate development of transport models, the Department has built a range of software tools available for practitioners covering both transport modelling and appraisal:

- **TEMPro** – Trip End Model Presentation Program – software allowing users to view the National Trip End Model (NTEM) dataset providing forecasts of trip ends and associated documentation.
- **DIADEM** – Dynamic Integrated Assignment and Demand modelling – software enabling users to quickly set up variable demand models in accordance with TAG unit M2.1 Variable Demand Modelling.
- **TUBA** – Transport User Benefits Appraisal – provides a standard method for calculating user benefits and some other impacts for direct use in appraisal by using the demand and cost matrices from transport models.
- **COBALT** – Cost-Benefit Analysis Light Touch – provides an efficient way of calculating accidents from transport model outputs.
- **WITA** – Wider Impacts Transport Appraisal – provides a standard method for calculating wider economic impacts (i.e. agglomeration) from transport model outputs.

- **The TAG Data Book** – provides a library of data and parameters one may use in the construction of models and key data for use in forecasting (e.g. future year GDP).

- **AMAT** – The Active Mode Appraisal Toolkit provides a proportionately simple approach to estimating the demand for walking and cycling for related infrastructure and demand management interventions.

2.1.10 TAG provides a number of recommendations in terms of reporting for each model component. This helps to provide evidence of the performance of models and provide a framework for practitioners to establish the suitability of the developed models for the analyses being undertaken. It is expected that all models used for decision making purposes and particularly business cases are fully documented. Further information on the reporting requirements can be found in section 6 of this unit.

2.2 Forecasting

2.2.1 Assessment of any intervention (transport or otherwise) requires an appreciation of expected impacts that may occur as a result. Being in the future, these impacts cannot be measured or observed at the time the decision needs to be made, and so they need to be estimated by comparing two **forecasts** – one excluding the intervention, the other including the intervention and no other changes.

2.2.2 In the transport context, these two forecasts are called the **without-scheme forecast** and **with-scheme forecast** respectively. Often, separate pairs of forecasts are required for at least two forecast years, to take into account changes in population and other transport infrastructure over time. TAG unit A1.1 Cost Benefit Analysis gives more guidance on selecting forecast years.

2.2.3 Each forecast relies heavily on evidence and assumptions about:

- the number of potential users
- the behaviour of the users
- the provision of infrastructure and public transport services
- the financial cost, time and convenience/inconvenience to users of using transport infrastructure and services
- future trends in economic parameters, such as GDP and fuel prices

2.2.4 In order for forecasts to be credible, the assumptions need to be realistic. Also, as different transport schemes often compete for a common budget, it is important that the forecasting assumptions of models used for appraisal purposes are consistent and unbiased so that the budget can be allocated on a fair basis.

2.2.5 The main basis for appraisal of major transport schemes should be the **core scenario**. This provides a future benchmark against which to compare proposals, based on official projections and data representing a "business as usual" position. TAG unit M4 Forecasting and Uncertainty gives guidance about preparing this scenario.

2.2.6 Forecasts are, by nature, uncertain. Even when using unbiased assumptions (as in the core scenario) there is no guarantee that the outturn result of implementing the scheme will match the forecast. Indeed, the core scenario itself is unlikely to occur, given that desirable policies and scheme proposals will be introduced to ameliorate the transport problems identified. The key concept is that the core scenario and any relevant alternative scenarios provide a basis of comparison to test the potential effectiveness of any policy or scheme proposal.

2.2.7 Modifications to the transport network and future demand should therefore be tested under different assumptions (compiled as **alternative scenarios**) to highlight any risks to the benefits or impacts of the scheme. Alternative scenarios should cover any significant sources of uncertainty, but their use should be proportionate. Assumptions should be listed in an uncertainty log (see TAG unit M4 Forecasting and Uncertainty) so that the assumptions within each scenario are sufficiently transparent.

2.2.8 A shortlist of scenarios may be based on those aspects of uncertainty that pose the greatest risks or opportunities to a proposal, so that the most relevant insights can be gleaned from their use, particularly where resources are limited.

2.2.9 A series of **common analytical scenarios** have been developed by the Department that provide a cross-modal perspective exploring national level uncertainties. Detailed assumptions and inputs for modelling the common analytical scenarios are outlined within the TAG Uncertainty Toolkit. These are available for use as default **alternative scenarios** and may themselves be amended with additional data and assumptions pertinent to the local circumstances.

2.3 Priorities

2.3.1 It can be seen that:

- the quality of analysis depends primarily on the quality of the forecasts used to underpin it and communication about the known risks of using these forecasts
- the quality of forecasts, in turn, relies on the quality of any models being used and a good understanding of their limitations

2.3.2 The priority for the transport modelling practitioner, therefore, should be to produce forecasts of adequate quality using proportionate resources. Transport models will usually be required for this purpose, however, there are some practical constraints to be considered when developing models, for example, the time and costs required to develop the models, data availability and model run times. These constraints should not be the reason of not using transport models for the purpose of appraising transport schemes, instead, practitioners should consider them during the appraisal specification process and tailor their scope of the appraisal and modelling in the Appraisal Specification Report

2.3.3 **It may not be necessary to use the most sophisticated or detailed models**, nor is it likely to be appropriate to invest the greatest proportion of resources to develop the best quality model at the expense of testing its performance for the scheme in question and interpreting its outputs carefully and communicating its limitations.

3. Data collection

3.1.1 Data collection is necessary in order to inform the parameters that represent the model responses (calibration) and to provide a source of information against which the model can be compared to assure its quality (validation).

3.1.2 The main constraints on data collection for modelling are:

- which data are available, and the cost of collecting it
- which data are useful to inform the calibration and validation of the model

3.1.3 A range of data sources are typically required to develop transport models. These can cover:

- **the transport network** – describing the transport supply such as the location of public transport stops, public transport services, fares, road, walk and cycle network connections, layout and capacities and parking costs
- **the demand for transport** – describing the amount of travel between two places (e.g. origin and destination), the reason for travelling and trip making characteristics of locations, households and freight movements
- **the performance of the transport system** – describing the amount of travel on a particular mode at a particular time and location, journey times through a network at different times of day and measures of congestion (e.g. queuing or crowding)
- **behaviours** – the functional relationships assumed, and the parameters used in the mathematical models
- **other** – describing other factors affecting demand, sometimes exogenous to the transport system, such as land use and planning activity and economic data (e.g. GDP)

3.1.4 Increasingly, these data are available from a range of 'off the shelf' sources that can provide a credible starting point for most model development tasks. Practitioners will need to evaluate the accuracy and suitability of each source for the development of a model and be able to justify particular data sources are valid. These can include existing models, land use and planning data, geographic and network data, tracking data of people and goods movements, and ticket data.

3.1.5 The TAG data book provides a useful source of data for input into transport models such as macroeconomic (GDP) and population projections. The TEMPRO data set is also a useful source for providing future projections of trip ends (where people travel from and to), providing a consistent benchmark for forecasting. The CAS data book also provides the assumptions made within each common analytical scenario. Aside from sources such as this, local models will of course require specific local data to ensure sufficiently accurate representation of local transport conditions, such as traffic counts, public transport usage and specific development plans.

3.1.6 It is important when collecting and interpreting data to ensure that sufficient quality assurance is in place. Surveys and data collection should be designed to mitigate for potential risks of bias that may make the data, and ultimately the model on which they are based, misleading. Data should also be quality assured after collection, before used in modelling, to ensure that the limitations and uncertainties with them are sufficiently understood. Such considerations include, for example:

- ensuring that samples are of adequate quality, sufficiently large and recent enough to reflect current travel conditions
- recognising the statistical limitations of the sample (for example the scale of sample error)
- collecting data under typical conditions which the model is aimed at representing (e.g. for models designed to represent 'average' conditions for appraisal purposes, not collecting data during holiday periods or at times of extreme weather).

3.1.7 Data collection is usually the most resource-intensive aspect of transport modelling. It is therefore highly advisable to minimise the amount of data that needs to be collected, by:

- taking into account data requirements in the design of the model
- using data that has already been collected, where this is of adequate quality

3.1.8 Most local authorities and transport agencies have a data collection department that help to manage and store collected data. It is recommended that relevant departments are contacted to source available data and also to share back any collected data, where feasible, so that greater value can be gained from its wider use.

3.1.9 Minimising data collection can increase the risks in calibrating and validating a model.

3.1.10 More detailed guidance on data sources and data collection is given in TAG unit M1.2 Data Sources and Surveys and guidance on the collection of forecasting data is described in TAG unit M4 Forecasting and Uncertainty.

4. Modelling

4.1 Introduction

4.1.1 Over a number of years, a standard structure has been developed for modelling transport demand and supply, based on economic principles. Sections 4.2 to 4.6 describe this standard structure, whilst Appendix A explains the principles. The standard structure is usually adequate and the most proportionate for modelling to provide business case evidence for major road and public transport schemes, given its economic provenance and alignment with welfare-based appraisal provided in the HM Treasury Green Book. However, there are other approaches that can be utilised to enrich modelling capabilities, particularly when these approaches are used to explore strategic policy questions.

4.1.2 A range of alternative transport model approaches can help to supplement decision making relating to transport interventions and section 4.7 briefly describes some of these. Their applicability will vary dependent on the type of transport intervention and stage of development.

4.1.3 Transport models can be applied across a range of use cases from early-stage policy direction through to scheme appraisal and supporting complex design decisions. Whilst TAG focuses on transport modelling to support appraisals, the guidance is also applicable to inform other use cases. The Department welcomes innovation and practitioners may make a case to the Department for using different structures, providing they produce adequate evidence and do not require disproportionate resources.

4.1.4 Even models based on sound economic theory may not represent human behaviour adequately well, and this is a risk to the quality of the forecasts. Therefore, it is important for practitioners to establish the credibility of their models by undertaking quality assurance of the model quality. This is discussed in section 4.9.

4.2 Key concepts

4.2.1 There are several core concepts to be identified up-front that are important in determining the explanatory power of any model designed and developed and its overall performance for use in different applications.

4.2.2 Transport models split the travelling population into different **segments** (known as demand segmentation). The population does not respond uniformly to changes in transport supply and conditions. Socio-demographic factors are important in determining appropriate behavioural responses in the model. For example:

- Travel patterns differ depending on the purpose of that travel. For instance, travelling to one's main workplace provides no choice in destination and is undertaken frequently, whereas recreation and holiday trips are much more discretionary.

- Differentiation between car-available and non-car-available households is clearly important in determining the propensity to make a private vehicle trip.

- Those households with children will frequently make education trips.

- Employment type and income can be important in travel choices, not only in the types of destinations accessed for work, but also ability and willingness to pay for fuel, fares and tolls.

4.2.3 Selection of segments is an important consideration in model design. Segments should be appreciably different in terms of behaviour to warrant the effort and resources to include them. The greater the number of segments in a model, the greater the potential explanatory power, which can be important for more complex policy or scheme testing. However, in more standard model forms, the greater the number of segments, the longer models will take to run, the greater the data requirements, and more computing resources may be required. Model developers should weigh up the importance of the model's explanatory power and the materiality of greater levels of segmentation, relative to its end-use, against the practical matter of available time and resources.

4.2.4 Most models are based on the concept of utility maximisation. That is, each transport user attempts to make the journeys that are most convenient to them at the minimum cost and time to them. To represent utility, or more accurately disutility, models often use the concept of **generalised cost** (or **generalised time**). This is a combination of travel time and cost, as well as other factors that may influence real or perceived disutility, such as waiting at bus stops, real time passenger information and levels of comfort or crowding on transport services. The unit of generalised cost is a monetary value, i.e. pounds in the UK.

4.2.5 Generalised cost is used so that time, monetary cost and comfort of travel can be combined into a common unit of disutility, pounds, which the model uses to determine the travel choices that people make. Costs of fuel and travel are straightforward to define in monetary terms; time is converted into monetary units through use of **values of time**. These are evidence-based values using people's expressed willingness to pay to save time, usually undertaken through survey work using stated preference techniques. Values of time are provided in the TAG data book and described further in TAG unit A1.3 User and Provider Impacts.

4.2.6 Values of time are fundamental for effective modelling of travel behaviour. Each segment within the model will often have a different value of time, varying by purpose, income level and so forth. For example, those travelling to work often have a relatively higher value of time as the consequences of arriving late are perceived higher than for more discretionary travel, such as for leisure activities.

4.2.7 The concept of **convergence** is important in transport modelling, since it directly affects the quality of the results, and the trust that can be placed in them. Most models use an iterative process between supply and demand to reach a converged, stable solution where demand and supply are in relative balance. That is, transport users in the model have closely achieved their optimum travel (utility maximisation), through choice of travel through the network and in the travel choices they have made, such as destination and mode choice.

4.2.8 As shown in Figure 1 in the next section, data flows between the supply and demand models in order to ultimately reach as close a converged state as possible. In practice, exact convergence is rarely, if ever, achieved, but there should be sufficiently small changes in costs and demand in the final iteration in order to ensure that noise in the model is minimised before using the results in the final analysis. See also Appendix A for a more detailed description of convergence.

4.3 The Standard Model Structure

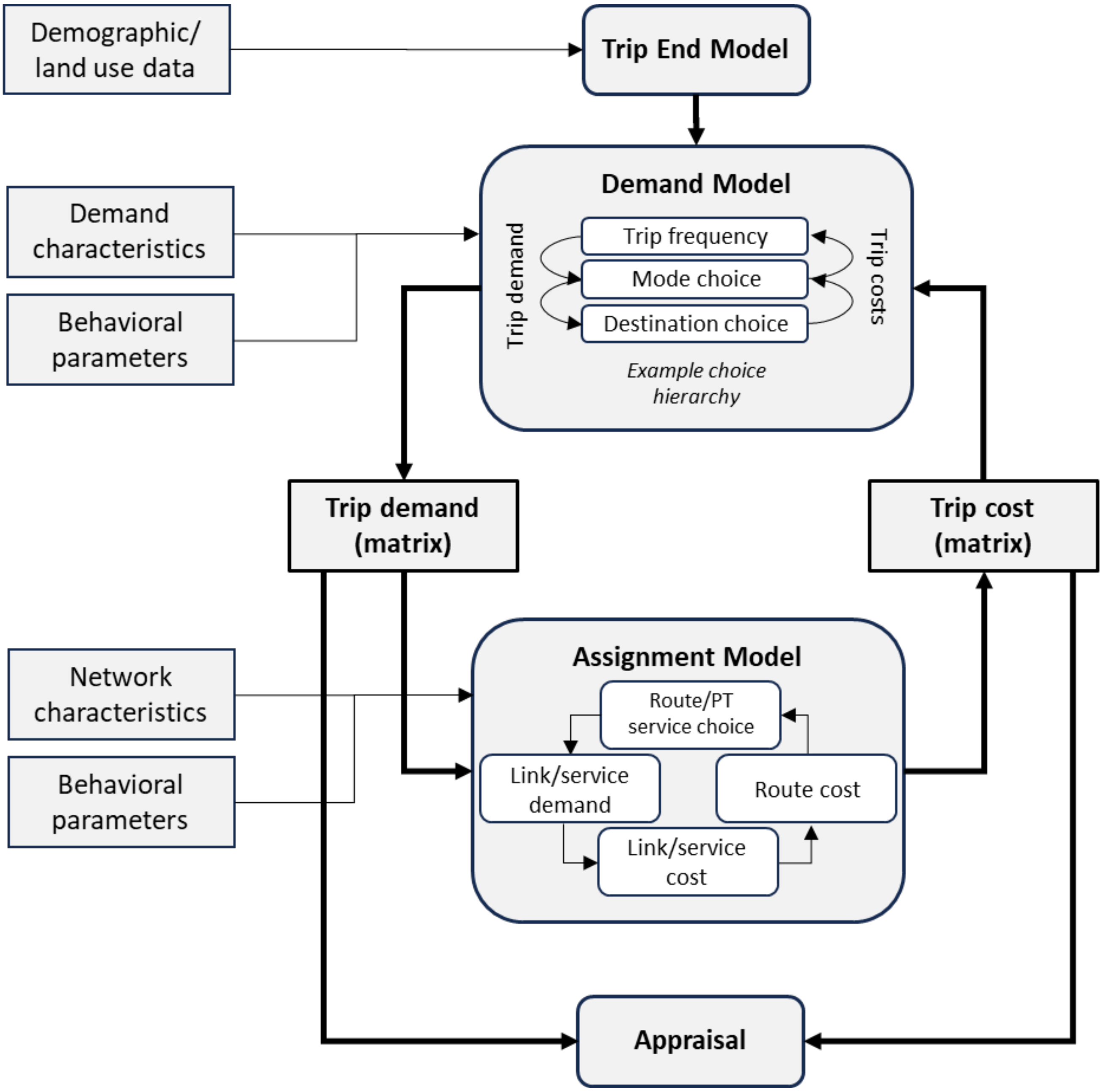
4.3.1 Figure 1 shows the standard model structure which can typically be adapted for most highway and public transport schemes. Many of the principles supporting this structure are also relevant to alternative methods which are discussed later in this unit.

4.3.2 Economic analysis of transport is usually based on units of **trips**. Transport models calculate forecasts of the following quantities given assumptions about the transport network and travel demand:

- the number of trips (demand)
- the generalised cost of each trip (supply)

4.3.3 These quantities need to be organised into origin-destination pairs to represent the demand and the costs of travelling between them. This is handled by storing both demand and supply in multi-dimensional arrays, known as the **trip matrix** and the **cost matrix** respectively. Separate trip matrices are required by mode, since the cost of travelling between origins and destinations by mode will differ; this information is required in the mode choice part of the demand model. Trip matrices will also be required for different times of day, to represent the differences in travel demand during morning and afternoon peaks, the interpeak period between them, and potentially the off-peak overnight period.

Figure 1 The standard transport model structure



4.3.4 As described in section 4.2, the various costs of travel are often combined into a **generalised cost**, representing the total cost across financial cost, time and inconvenience, to travel between locations. This is usually a linear combination of each cost component, which reflects overall perception of difficulty of travel. This is an important aspect to be considered in the design of the whole model ensuring costs of travel and segmentation of demand are appropriate and consistent across assignment and demand models.

4.3.5 Except in the very smallest models, or where using detailed simulation or agent-based approaches, it is not common practice to model trips to or from each individual house, workplace or shop. Accordingly, spatial areas are aggregated into **zones**, and the trip matrix and the cost matrix are usually segmented by zone pairs. It may not always be necessary to use the same zoning system for supply and demand, providing appropriate interfaces can be made between the zoning systems. Further guidance on defining zones is given in the remainder of the Guidance for the Modelling Practitioner.

4.3.6 The **demand model** (see section 4.4) is used to forecast the trip matrix, based on:

- the most up-to-date estimate of the cost matrices
- a measure of travel demand based on the demographic data assumptions (population and employment). The measure most commonly used is known as trip ends, and these are calculated using a trip end model.

4.3.7 The cost matrix is calculated using the **assignment model** (section 4.5) which is based on:

- the most up-to-date estimate of the trip matrix
- a network model (a mathematical representation of the transport network), which is used to calculate the cost of travel between each pair of zones (i.e. origin zones and destination zones).

4.3.8 Assignment models have a dual role – as well as calculating the cost matrix, they also allocate the trips by route and calculate demand for each link (i.e. roads, rail lines, etc.) in the network. This supports analysis of the impacts of transport interventions, which is particularly important for highway and public transport investments. Assignment models can also support active travel decision making, where the route characteristics may have a material impact on routeing (e.g. journey quality or gradient).

4.3.9 When designing the model structure, it is important to consider time periods that should be modelled separately. These are periods that represent homogeneity in levels of service (e.g. congestion, crowding, service frequency). There is often highway congestion caused by peaks in commuting demand in the morning and evening of weekdays, more frequent public transport services tend to be scheduled at these times, and there may be crowding. This is important, since in assignment models there is a relationship between speed and flow (demand) on each link. Generalised costs will be higher in periods of high demand, such as the peak periods. Taking an all-day average, for instance, will not capture the important effects of congestion and crowding on the network.

4.3.10 In general, inputs and outputs of the demand model and assignment model depend on each other. In order to provide a systematic basis to compare forecasts, they should be run consecutively until they have converged to equilibrium within specified tolerances (discussed further in Appendix A). This creates the need for a demand-supply loop structure, which can take considerable computer time to run.

4.3.11 A further demand-supply loop is required within the assignment model itself. The assignment model calculates both the demand and cost for individual links and junctions in the network. The demand and cost depend on each other as follows:

- the demand for each link depends on the number of trips between each pair of zones (from the trip matrix) and the routes they choose (which are dependent on the cost of choosing each route)

- the cost (in particular, the travel time) of travelling along each link or junction depends on its demand and the mathematical relationship between demand, capacity and cost (i.e. speed-flow relationships, dependent on capacity, speed limit and relevant characteristics of the link). These mathematical relationships are defined in the network model.

4.4 The Demand Model

Overview

4.4.1 Demand models of the standard model structure type are also known as **variable demand models** (see TAG unit M2.1 Variable Demand Modelling). They estimate how people choose to travel by making choices based on the generalised costs of travel to destinations, by different modes and at different times of the day. Hence the term variable demand model represents the real-world behaviour of people potentially making different travel choices in response to changes in travel conditions.

4.4.2 For example, if an authority introduces new bus services, a likely response will be for more people to choose to travel by bus. The corollary of which is that people may switch from using other modes of transport to using the bus. But in introducing these services, effectively decreasing the generalised cost of using the bus between affected zone pairs, people may also decide to travel to different locations, e.g. travelling to better-connected services that otherwise were more difficult to access. People may also decide to travel at different times of the day, depending on the services provided.

4.4.3 The demand model forecasts trip matrices based on:

- trip ends: the number of trips travelling to or from each zone

- generalised travel costs, and assumptions about travellers' behavioural response to cost and perceived factors such as comfort and convenience.

4.4.4 There is a wide range of principles relating to the modelling of travel demand, each of which is discussed in turn below:

- which behavioural responses to include, and which model to use for each response.

- segmentation of the model, particularly by trip purpose and person type

- representation of the trip pattern, taking into account how series of individual trips are made by transport users
- representation of travellers' response to generalised cost
- whether the model generates a new trip matrix solely from trip ends and costs (an absolute model) or updates an existing matrix (incremental)

Behavioural responses

4.4.5 Demand models in the standard structure operate through transport users making a series of discrete choices. These choices are organised into a hierarchy, the order of which is important. Generalised costs at one level of the hierarchy are used by the level above to inform the choice at that level. The hierarchy of choices is determined by the sensitivity of the choices to the generalised cost of travel.

4.4.6 The most sensitive choice is route choice - handled by the assignment model - and is always at the bottom of the hierarchy. Trip frequency (whether to travel or not) is the least sensitive response and at the top of the hierarchy. The order given below is common to many models and is how the Department's National Transport Model is established, based on national evidence. Ideally, local evidence should be considered to understand the sensitivities and hence preferred hierarchy of choices for a local area model, particularly in consideration of the order of mode and destination choice, which can in practice have a similar level of sensitivity.

- Trip frequency (particularly when one of the major modes – car, public transport, walking / cycling are not modelled)
- Main mode choice
- Time period choice
- Destination choice (also known as trip distribution)
- Sub-mode choice (e.g. between rail and bus where public transport is the main mode choice) where represented in a variable demand model rather than an assignment model

4.4.7 Each discrete choice depends on parameters which will affect the modelling response for each choice. These parameters need to be estimated by trip purpose, either by **calibrating** the choice model against observed data or **importing** sensible parameters from another model. In the absence of either, TAG unit M2.1 Variable Demand Modelling presents some illustrative parameters derived from other models.

Segmentation of the model

4.4.8 Travel behaviour varies by **trip purpose** and **person type characteristics** including age, employment status and type, household structure, and household car ownership. Therefore, demand models will need to include demand segments for at least the following three trip purposes, as they have different parameters explaining this behaviour:

- Employers' business
- Commuting (to work)
- Other

4.4.9 As discussed in section 4.2, choosing appropriate segmentation within a model is a trade-off between explanatory power and how material that is to the final use of the model, and the practical implications of cost and availability of data, the greater effort required in calibrating the model, and model run times. Increasing the number of trip purposes from those listed above has such implications.

4.4.10 As well as trip purpose, transport user segmentation is another important aspect of a model's explanatory power for different transport users, which can enhance how the model distinguishes different behavioural responses of different people. Consideration should be given to using greater segmentation for those parts of the calculation that are least data-hungry (particularly person type segmentation in trip end models), with more limited segmentation, such as distinguishing car availability to better represent mode choice behaviour.

Representation of the trip pattern

4.4.11 Demographic data (e.g. population and employment data) is specific to a single zone. This means it does not form a good indicator of the quantity of travel between a pair of zones, but it can inform total demand to and from each zone, or **trip ends**.

4.4.12 Trip ends are the format in which the Department provides its standard forecasts of growth in demand. These are produced through the National Trip End Model (NTEM) and may be freely accessed as a data set through the TEMPRO software. They can be calculated quite simply by multiplying demographic data by **trip rates**, which can be estimated from survey data (in the case of NTEM, from the National Travel Survey). Most transport models will have a trip end model to handle planned local changes in housing and employment. TAG unit M4 Forecasting and Uncertainty described in more detail how one may forecast trip end growth in forecasting and apply future demand changes to the forecast trip matrices.

4.4.13 Although individual trips are used as the unit of travel demand, transport users do not make a single trip in isolation, but instead tend to undertake a series of trips in order to carry out one or more activities. A series of trips undertaken between leaving home and returning home is commonly called a **tour**.

4.4.14 In most models, it is common to split trips according to their position in the tour – whether outbound from home, return to home, or non-home-based trips – and to define the trip ends by **production** (the location where the decision to travel is made) and **attraction** (the reason for travel) because this relates them closely to the most relevant demographic data (e.g. residents).The production / attraction (P/A) definition of trip ends is explained further in Appendix B – it can differ from the origin / destination (O/D) definition, in which the trip ends are characterised by the beginning (origin) and end (destination) of the trip.

Representation of travellers' response to cost

4.4.15 There are three broad approaches to representing travellers' response to cost:

- a fixed demand approach, in which demand is independent of cost, and the future trip matrix is adjusted using changes in trip ends and no variable demand model is required
- an "own cost elasticity" approach where demand in each cell of the trip matrix can vary in response to changes in generalised costs, but the source of any variation is limited to the corresponding cell of the cost matrix only
- a full variable demand approach where demand in each cell of the matrix can vary according to demand changes in other cells of the trip matrix and costs in all cells of the cost matrix.

4.4.16 **Fixed demand** approaches have the quickest run times as they do not require a variable demand model, which eliminate the need of demand-supply model interactions. However, their use is only valid where it can be demonstrated that changes in generalised cost will not generate a noticeable change in demand (for example decongestion or relieving crowding on public transport). As such, fixed demand models are inadequate for most transport schemes and strategies which are aimed at ameliorating many of today's problems.

4.4.17 **Own-cost elasticity models** do not constrain total demand according to the size of the population. This means they are not adequate for representing the transport market as a whole. However, they have been commonly used in rail appraisals that utilise uni-modal models without explicit representation of other modes. They can only be used when interactions with other modes have limited impact (see 4.4.26).

4.4.18 **Variable demand models** are most often used to model personal travel for highway and public transport schemes or strategies, where a change in behaviour is expected in any aspect of travel choice. This includes bus schemes, the performance of which is often dependent on the level of car traffic on the network. Since car forms a large proportion of total travel demand, its growth will largely be constrained by population changes, with some variation according to changes in transport cost. The variable demand model approach, which splits total demand into smaller segments through a series of choice models, is typically the best way of representing this.

4.4.19 For some trip movements it is more difficult to use choice models. Freight movements, in particular, are often part of a complex logistic chain, which means that it is generally not appropriate to assume that each trip can be modelled individually. It is generally assumed that total freight traffic is fixed, and simple factoring methods are often used for freight movements in models oriented at passenger travel, so that changes in freight volumes on the network can be allowed to impact the generalised cost of travel for other transport users. Similar approaches are often used for trip movements from external areas (outside the main geographical study area defined for the model), as for these trips it is often more difficult to represent the full range of destination choices available.

4.4.20 In the earlier stages of modelling a major transport scheme (e.g. for option testing), it may not be proportionate to use full variable demand choice models. Guidance for the Technical Project Manager should be followed.

Absolute and incremental models

4.4.21 Analysts will need to decide whether the demand model should calculate the trip matrix “from scratch”, using the trip ends and costs only, or update an existing matrix. Three approaches are commonly used in different contexts:

- Absolute models estimate future demand without reference to observed base year demand, using forecasting parameters and mathematical expressions without reference to the base year

- Absolute models applied incrementally, in which an absolute model is used to update the base year trip matrix by applying the change between the absolute model results of the base and future years to the base year trip matrix

- ‘True’ incremental models, in which changes in cost (rather than absolute cost) are used to estimate the change in trips from the base year trip matrix

4.4.22 Both **true incremental models** and **absolute models applied incrementally** require a starting matrix, which needs to be split by mode, purpose and time period. These approaches require a **base year trip matrix** which should, as far as possible, be based on a sample of observed data. However, it is unlikely that sufficient data will be available to calculate every cell of the matrix, and in practice a variety of synthetic methods may be used alongside the observed data itself to produce the base matrix (see TAG unit M2.2 Base Year Matrix Development)

4.4.23 Absolute models rely more heavily on the mathematical formulation of the model, whereas incremental models rely more heavily on observed data; absolute models applied incrementally fall between these two extremes. There are risks in relying on the mathematical formulation of an absolute model (imperfect representation of reality) and these can sometimes be greater than the risks of relying on observed data (sampling error and statistical error). However, there are many modelling cases where observed data will not exist (such as new modes or developments) and absolute formulations may need to be used.

4.4.24 For appraising major transport schemes, the use of incremental demand models is preferred to absolute models. Incremental models update a trip matrix based on observed data for the base year, whereas absolute models calculate the trip matrix for each forecast year directly based on trip ends and costs. Incremental models make better use of both observed data and their mathematical specification derived from the data, than absolute models.

Multimodal and Uni-modal models

4.4.25 The choice of which modes to include into a transport model is a key design consideration. Models covering urban areas are usually multi-modal as the availability of public transport and parking policies typically drive a range of behaviours. In an inter-urban context, it is common practice to consider both road-based and public transport modes that are focused on providing inter-urban connectivity. Where the use of a road corridor is the focus of the study, it is typical to include a main mode choice response for competing public transport modes.

4.4.26 Where public transport schemes focus on a single sub-mode and the interactions with other modes are of low importance, or will have limited impact, **uni-modal** models may be used. Examples are where there are frequency improvements on a particular rail service or modest journey time enhancements. They are often quicker to design, build and use than multi-modal models and are suitable to support rail only studies. Their use should be carefully scoped out as part of a model specification stage.

4.4.27 Where rail **uni-modal** models are adopted, please refer to TAG unit A5.3 Rail Appraisal and TAG unit M4 Forecasting and Uncertainty, the Passenger Demand Forecasting Handbook (limited to members of Passenger Demand Forecasting Council) and/or get in touch with the Rail Modelling team at the Department for Transport (railmodelling@dft.gov.uk). TAG unit M3.2 Public Transport Assignment Modelling contains guidance on supply representation, network coding and validation so should also be referred to for unimodal models.

4.4.28 Forecasting active travel demand can be particularly challenging in the context of multi-modal transport modelling given that active travel often acts as a feeder mode to other forms of transport as well as a mode of its own. The purpose of active travel can also be recreational in its own right, which makes it difficult to align with standard drivers of travel demand. Further details of modelling active travel are outlined in section 4.8.

4.5 The Assignment Model

4.5.1 The assignment model splits the trips according to the route they are estimated to take through the network, and then calculates the cost of travelling via each route. These cost calculations are needed not only for the assignment model itself, but also (assembled in matrix form) for the demand model. Vehicle flows on links from highway assignment models inform the analysis of many social and environmental impacts.

4.5.2 Route choice has a complex set of options which cannot usually be represented using matrices, since traffic flow volumes on individual links (roads) and public transport service usage and crowding directly impact the speed, experience and hence generalised cost of travel across the network. Therefore, network models that represent this variability across the network are required. Also, when comparing two forecasts (as is necessary in appraisal), the network (and hence the choice of routes available) will vary between the two forecasts. Commercially-available software packages are usually used for the assignment model – these use a mathematical representation of the transport network which, in virtually all cases can be viewed and edited in bespoke or general GIS software.

4.5.3 The demand and cost for each route depend on each other. The assignment model is applied iteratively between calculating route costs and route demand, with the aim of establishing an equilibrium between the two. In highway assignment, in which cost varies according to congestion on the network, the notion of equilibrium is consistent with Wardrop's principle:

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

4.5.4 Under Wardrop's principle, no user will benefit by changing route unilaterally. However, Wardrop equilibria are not always unique, which creates a risk that the difference in traffic flow between two forecasts will be as a result of reaching different equilibria, rather than because of the input assumptions to the forecasts themselves.

4.5.5 The simplest form of Wardrop assignment assumes all travellers in a given user class have the same perception of cost. However, more complex forms of assignment exist in which it may be assumed that different users perceive cost in different ways, such as Stochastic User Equilibrium (SUE). Further details are given in TAG unit M3.1 Highway Assignment Modelling.

4.5.6 Public transport assignment represents the route choice of individual passengers through a multi-modal public transport network. The network is, in some ways, more complicated, as it depends not only on its physical layout but on the routes and frequencies of the services. These models may also operate differently according to their design choice with regards to the representation of services on the network. For instance, one can use frequency-based models, that use average wait times for services, or assignments based on specific timetables. Further details are given in TAG unit M3.2 Public Transport Assignment Modelling.

4.5.7 It may be necessary to create an interaction between the highway and public transport assignments. Travel time for bus vehicles may vary according to congestion on the highway network and the availability of bus lanes. This will affect travel times for bus passengers in the public transport network. In some cases, bus vehicle travel times may also affect the frequency of the bus service as the available fleet is fully utilised.

4.5.8 Public transport costs vary according to passenger crowding on public transport services. The greater the volume of passengers, the higher the perceived cost of travel (e.g. less comfort, having to stand where seats are filled, etc.). If there is ample capacity on all public transport services, crowding may not need to be modelled, but even in this case volume to capacity ratios, i.e. the potential for higher costs due to crowding, should be monitored.

4.5.9 Public transport operators may change their services according to demand on the network. In some cases, it may be appropriate to incorporate operator responses as part of the model, although this will increase run times and some commercial packages may not support this calculation. There may be some instances where this has to be taken into account as an input to each forecast.

4.5.10 It is rare for active mode route choice to be explicitly modelled through assignment models. This is largely due to the disproportionate use of resources to establish complex models in these cases. Examples do exist, such as Transport for London's cycling assignment model, Cynemon., where infrastructure design considerations for cycling are important to be modelled.

4.5.11 In practice, perfect model **convergence** will not usually be achieved in assignment models. TAG units M3.1 and M3.2 in the Guidance for the Modelling Practitioner provide guidelines on the tolerance standards expected.

4.5.12 **Intra-zonal trips** (with origin and destination in the same zone) present a challenge to all assignment models because they are modelled as starting and ending at the same point. In fact, they are not part of the assignment process at all, so costs must be derived using reasonable assumptions, for example as a function of zone size. This has implications for not only how one does this, but that intrazonal trips, not being part of the assignment process, do not contribute to congestion and/or crowding on the network, hence not contributing to the calculation of costs of other, intrazonal trips.

4.5.13 These problems can be reduced by minimising the zone size, although this requires sufficient data at this level of granularity and will increase model complexity and run times. TAG units M3.1 and M3.2 in the Guidance for the Modelling Practitioner provide some further guidance on representing intra-zonal trips.

4.6 Interfaces between Demand and Assignment models

4.6.1 In order to automate the alternate running of demand and assignment models necessary to achieve equilibrium, appropriate interfaces between the two models are required.

4.6.2 The **trip matrix** is output from the demand model and input to the assignment model. It needs to be converted from Production / Attraction (P/A) format (at which the demand model ideally operates) to Origin / Destination (O/D) format for the purpose of assignment.

4.6.3 The **cost matrix** is based on outputs from the assignment model and is used to inform the demand model. Various measures of cost, such as travel time, distance, and charges such as public transport fares or highway tolls, are extracted for each origin-destination pair in the assignment model – a process known as **skimming** (as the costs are skimmed along the routes calculated).

4.6.4 The demand model often requires a **generalised cost matrix** - usually a linear combination of the various components of cost (travel time, fuel costs, and public transport fares for example). This is usually calculated in units of time as opposed to money (as the monetary costs are converted into time units by dividing the monetary value by the **value of time**. The value of time varies by trip purpose and can also vary by income and distance. Values of time also increase year-on-year in line with GDP, see TAG unit A1.3 User and Provider Impacts for further details.

4.7 Alternative Methods

4.7.1 The standard model has advantages of being used widely in appraisal and wider applications, with a resulting accumulation of expertise and evidence and commercial software applicable to their operation. Whilst these models can be built in a number of ways, with different degrees of complexity or simplification, they have strengths and weaknesses in different contexts.

4.7.2 Alternative methods may be deployed, as explained here, that allow more nuanced examination of various aspects of the transport system and its users. Examples include:

- the assessment of land-use change resulting from generalised cost changes
- more detailed modelling of human interactions with activities as agents
- use of more dynamic representations of traffic flow on networks
- exploration of active travel investment
- assessment of new forms of mobility

4.7.3 Each of these methods have their strengths and weaknesses in theory and practical deployment. In considering the transport issue being examined at the outset, consideration should be made as to what modelling approach works best in the context. This would naturally focus on the issue at hand, but consideration should also be given to the desire to innovate, the ultimate purpose and end-use of the results, and the resources available for the analytical project, including the available data.

4.7.4 Whilst TAG focuses on the most common model type in current practice, the four-stage model type, the concepts and standards described surrounding the principles of good modelling practice and evidence are of primary importance when considering the quality of a model for a particular purpose. Key principles such as data quality and assurance, calibration and validation are universal to all model types.

4.7.5 As discussed in section 2.3, it is the duty of the analyst to transparently present why a model is deemed valid for its application, so that the results may be duly trusted and accepted. Analysts may have to find ways of expressing this, dependent on the model design, by linking to the key principles defining model quality in TAG. For example, some model types may heavily rely on data synthesis to allow more granular modelling of certain phenomena, which is difficult in practice to validate. The Department would like to support use of methods other than the most common types. This will be aided by openness and transparency of the modelling assumptions and the validation undertaken for alternative methods.

Land Use Transport Interaction (LUTI) models

4.7.6 In situations where transport improvements creation distortions to the economy, for example where changes in journey costs are significant and lead to a major improvement to land use accessibility, **Supplementary Economic Modelling** (SEM) maybe required. The standard transport model structure does not account for this type of impact of land use patterns, such as the location of housing or employment. By contrast, LUTI models use economic principles to relate changes in future transport provision to the spatial locations of employment and housing.

4.7.7 LUTI models can include consideration of a wide range of markets:

- financial markets
- property markets
- labour markets
- product markets (including services)
- transport markets

4.7.8 Only the last of these is covered in the standard transport model structure.

4.7.9 LUTI models may provide useful insight into wider economic impacts compared to just transport availability. TAG unit A2.1 Wider Economic Impacts Appraisal provides details of how these impacts should be included in a transport appraisal. To derive first-order transport user benefits in appraisal, the land use responses **must** be switched off. Other types of models exist for appraising these impacts and further information of LUTI models and other forms are given in TAG unit M5.3 Supplementary Economic Modelling.

Agent-based methods

4.7.10 In transport modelling, agent-based methods simulate travel-related decisions at the level of the individual and aim to replicate the behaviour of individuals (agents) as they interact with other agents, and the environment, and how this manifest in the wider transportation system. Common examples of agent-based methods in transport modelling are:

- pedestrian modelling
- microsimulation traffic modelling
- dynamic assignment modelling
- activity-based demand modelling

Activity-based demand models

4.7.11 The terms agent-based and activity-based are often used interchangeably, yet they cover different concepts. Agent-based modelling is used in a wide variety of fields, one of which is transport modelling. The implementation of agent-based methods in activity-based demand models requires detailed modelling of individuals or agents and their activities. Activity-based demand models use behavioural theories about how individuals make decisions about activity participation in the presence of constraints. This includes decisions about when and where to participate in activities and how to get to these activities.

4.7.12 Activity-based demand models have some similarities to the standard models, where travel demand is derived from peoples' needs and desires to participate in activities. They share many similar concepts, such as utility maximisation and the use of choice modelling, but for activity-based demand models, these concepts are extended to cover the activities to be carried out by every individual and how they are linked. Activity-based demand models focus on individuals' or agents' activities, and not just trips or tours as in the standard models. Activities are the actual goal of individuals (with trips/tours derived from the connection between activities) and this may evolve and change over time, resulting in changes in associated travel demand.

4.7.13 Activity-based demand models represent a wider range of choices that affect travel demand – they represent time and space constraints more realistically, show linkages among activities and travel for each individual, as well as across multiple individuals in a household. This enables activity-based demand models to better represent the effect of travel conditions and other influences on activity and travel choices.

4.7.14 This makes them particularly relevant for considering activities that can be performed virtually, as well as physically, while at home, out-of-home or even during travel. An example of this would include policies influencing working from home choices that can be represented explicitly using an activity-based demand model structure. In the standard model structure, this would be imposed as input assumptions, such as through changing in trip rates. This characteristic can make activity-based demand models useful for testing relevant policies in this area.

4.7.15 The range of possible implementations of activity-based demand models is more diverse than the standard model, as the agent-based approach permits a wide range of implementation options. Further information on agent-based methods and activity-based demand models can be found in Guidance for the Modelling Practitioner, which explains where these approaches could be considered and how they may be used to form part of an evidence base to answer policy questions.

4.7.16 The broader range of behaviours and influences represented in activity-based models are not fully represented in the current economic appraisal methods set out in TAG unit A1.3 User and Provider Impacts. Therefore, the use of activity-based demand models in economic appraisals require additional consideration and further research. This is an issue analogous to that of land use models where the guidance in TAG unit M5.3 Supplementary Economic Modelling provides advice to address the limitations of the appraisal methods when such models are used.

Dynamic assignment

4.7.17 Many transport schemes will be appraised using steady state assignment models which assume a constant rate of demand for each link during a period of time. Dynamic assignment models differ from this by allowing varying rates of demand on each link at different times during the assignment period.

4.7.18 Dynamic assignment models may be disproportionate for some transport schemes but may be valuable if it is important to understand how the state of the network (e.g. queue formation) varies during a time period. Further guidance on this is given in TAG unit M3.1 Highway Assignment Modelling.

4.7.19 As an alternative to dynamic assignment, some steady state assignment packages can be used to represent very short periods of time and allow traffic queues to be passed from one time period to the next.

4.7.20 These “semi-dynamic” assignment approaches can often be applied using **mesoscopic** methods. This forms a middle ground between steady state assignment modelling (sometimes referred to as macro-modelling) and microsimulation described below. With mesoscopic models, some of the dynamic behaviour of traffic is simulated at a probabilistic level but a limited representation of driving behaviour is included.

Microsimulation

4.7.21 The standard model structure will generally assume that demand is aggregated into the total number of trips in each matrix cell in a discrete time period, which may not be an integer. Microsimulation models differ by simulating the interactions of individuals (typically either people or vehicles) in time and space using agent-based methods.

4.7.22 Most commonly, these models are used to assess the performance of road networks, interactions between vehicles (e.g. cars and buses) and often their interaction with pedestrians. Due to their modelling of individual vehicles and more detailed representation of network elements, behaviour and time, microsimulation models can better reflect dynamic phenomena such as queuing behaviour (e.g. stationary and transient queuing), blocking back through junctions than aggregate models. They can reflect the impact of parking behaviour or incidents upon the network reflecting the variability in both traffic conditions and driver behaviour. They can also represent more complex signal control features such as demand dependency and bus priority using detectors through a representation of intelligent transport systems in the model.

4.7.23 These detailed behaviours mean that microsimulation models can provide detailed operational analysis of proposals typically beyond the capability of strategic highway assignment models. This can add significant benefit to the understanding of network problems, the design of a scheme and its optimisation through the design process. This includes features such as the interaction with nearby junctions, the number of lanes and flare lengths required, lane markings and signage, signal staging, phasing and timings and the progression of vehicles through the junction.

4.7.24 Microsimulation models help by assessing a range of outcomes as a result of random variation to replicate the variability of the real world. Random seeds are used to initiate a set of random numbers that drive specific characteristics in each model run. It means that each run using different random seeds will differ as a result. This can be an advantage to appraisal as a range of equally plausible results may be obtained, to aid understanding of potential variability on the network. This also means that a number of runs are required to achieve a level of stability and confidence on the performance of the model before it can be used in appraisal.

4.7.25 The dynamic nature of microsimulation models makes them challenging to integrate with a demand model to ensure consistent demand and supply is achieved, or to ensure adequate stability for economic appraisal. For these reasons, when used for appraisal purposes, they typically operate with higher tier models (i.e. steady-state models such as the standard model type) that forecast the main demand effects relevant for a scheme.

4.7.26 Outputs of microsimulation models also provide a rich visualisation of the results. This includes 3D videos of the network, incorporate detailed mapping and buildings, provide 360-degree views and first person in vehicle drive throughs. This can provide added value to stakeholders, enabling visualisation of schemes, their interaction with the surrounding environment and aid consultation with stakeholders.

4.8 Modelling Active Travel and New Mobility

Active Travel

4.8.1 Transport models of the types described in this unit are often disproportionate to develop for schemes specifically pertaining to active modes. This is in no way reflective of the relative importance of active travel, more that such schemes may be more appropriately analysed using techniques more suited to a smaller scale.

4.8.2 Investments in active travel can be very localised, such as a new pedestrian crossing, or more extensive, such as larger area pedestrian schemes or significant reallocation of road space to active travel. Modelling techniques should focus on estimating the potential for new active mode infrastructure to impact on demand. The modelling and appraisal of these different types of schemes can draw on a combination of modelling approaches and tools such as:

- Travel time accessibility – analysis to review the connectivity of places via active travel networks. By generating isochrones these tools show how different physical constraints (e.g. rivers or motorways) can impact the ability to access key services.

- Demand and elasticity – methods that look at the scale of demand within a specific catchment and the potential for that to be delivered via active travel using empirical information.

- Mode choice modelling – demand modelling, for example, using the standard logit-based methods as described in TAG unit M2.1 Variable Demand Modelling to consider trip costs by different modes and the likely share by mode.

- Route choice modelling – network-based assignment methods, similar to those of the standard models, seeking to identify preferred routes between locations based on proximity and physical attributes that may influence their attractiveness.

- Capacity simulation and journey quality – application of microsimulation methods to reflect the physical environment to model specific constraints and interactions that can drive active mode behaviour. This can include crowded environments such as stations and interchanges as well as how cyclists interact with vehicular traffic.

- Road user interaction – extension of microsimulation methods to include both active travel and its interaction with road traffic – particularly where there is pedestrian and vehicle interaction such as in shared spaces.

4.8.3 Due consideration should be given to the representation of active travel when developing multi-modal models. These modes can be represented as part of the mode choice model. Particularly when considering active modes as part of a package of local interventions, it will be important to ensure a robust estimation of future active travel demand.

4.8.4 Specific guidance supporting the forecasting and appraisal of schemes relating to active travel can be found in TAG unit A5.1 Active Mode Appraisal. The reader may also wish to refer to TAG unit M5.2 Modelling Smarter Choices when considering demand management measures and other active travel initiatives in the area of the model.

Treatment of new forms of mobility

4.8.5 New forms of mobility, such as mobility as a service (MaaS), connected and autonomous vehicles (CAVs), and demand responsive transport (DRT), are increasingly forming part of business cases. These new forms of mobility vary based on how they are perceived by the users and the type of users they provide transport solutions for. These influence the transport choices affected, nature of decision-making process, and behavioural responses, and how these vary between different types of users.

4.8.6 Their impacts are not sufficiently captured by some modelling assumptions and simplifications in the standard models, which complicates interpretation of how best they may be represented. The key question here is what impacts are important to capture:

- Supply side impacts – these include network capacity (e.g. CAVs may have different gap acceptance at junctions affecting the number of vehicles that can use the network), quantification of the level of service delivered by the supply system, and accessibility.
- Demand segmentation – the requirement on demand segmentation within transport models may vary depending on the mobility options, the type of users who can access these, and the extent to which behavioural responses vary between them.
- Demand choices affected – the nature of behavioural responses to these mobility options and how people’s decision-making process is influenced by them.

4.8.7 There is limited evidence around the likely impacts of these new forms of mobility and about how they should be modelled, including how best to incorporate them into the standard model structure or whether alternative modelling methods are required. Further research in this area is required to form guidance on modelling new modes of transport.

4.9 Assuring Model Quality

4.9.1 Transport models are important tools that help provide insights ahead of investment decisions or plans. It is therefore important that modelling practitioners construct suitable models appropriately that are tailored to the situation at hand and to transparently present and communicate the potential risks around the accuracy or use of the model for its intended purpose, so these may be considered and potentially mitigated. The main risks from constructing a model are as follows, these points being discussed subsequently in turn:

- the model may mislead decision makers, either because:
  - there are errors in the inputs (for the transport network or the demand data)
  - the model is not being used in accordance with its underlying theory
  - the model's representation of human behaviour is unrealistic
- a disproportionate level of effort and resources are invested into building the model.
- the expectations of the model for its intended purpose by its end-users have not been adequately managed.

Quality assurance of model inputs

4.9.2 Inputs to transport models should be transparent and straightforward to audit. Model inputs should be checked carefully and reported by a practitioner independent of the original coding. All reporting should be made available to the sponsoring organisation and wider stakeholders.

Using models in accordance with their design

4.9.3 Any model is a simplification of reality. Although it is often sensible to use existing models to save unnecessary costs, a model designed for one purpose may not be suitable for a different situation. For example, a model designed for the appraisal of a scheme in one spatial area may not be sufficiently detailed or may not be supported by sufficient data to appraise a second scheme in an adjacent area, even if the model covers the area of the second scheme spatially.

Achieving an appropriate representation of human behaviour

4.9.4 The quality of the model response should be tested by running the model for a designated base year (usually the current year or a recent historic year) and carrying out the following tests:

- validation: comparing model outputs with independently obtained observed data, such as that discussed in section 3

- realism testing: rerunning the model with prescribed changes to inputs, such as fuel prices, public transport fares and car journey time, to check that the model responses (elasticities) are realistic (see TAG unit M2.1 Variable Demand Modelling).

- sensitivity testing: rerunning the model with structural or random changes to model parameters, to check the model results are robust to changes in these parameters (or otherwise indicate areas of risk in application if the model inputs are changed).

4.9.5 Even when a model performs well against these tests, there is no guarantee that it will not produce misleading forecasts, but the risk of this happening is considerably reduced. Conversely, a model which does not perform particularly well against these tests may still be useful for some purposes (e.g. early stage option sifting), providing the risks are understood, managed, and reported. However, even at these early stages, models should only be used if their response is plausible.

4.9.6 Detailed guidance on the tests required and standards expected for model validation, realism testing and sensitivity testing can be found in TAG unit M2.1 Variable Demand Modelling, whilst guidance on tolerance levels for assignment validation is given in TAG unit M3.1 and M3.2 in the Guidance for Modelling Practitioners.

Ensuring the appropriate use of model development resources

4.9.7 The risks of using disproportionate time and resources in model development can be minimised by specifying the model scope correctly from the outset. Models should be sufficiently sophisticated to represent travel movements for the scheme effectively, whilst avoiding unnecessary complexity. Consideration should be given to the appropriate level of detail in demand responses, zoning system and networks, informed by the types of schemes to be tested, their complexity and their anticipated effects on travel behaviour and network operations.

4.9.8 Even with the best attempts to specify the scope and design of the model prior to commencement, there may be circumstances where practitioners may need to simplify the approach during the project and document any simplifications made and their impacts on expected model performance.

5. Forecasting

5.1 Introduction

5.1.1 For most transport schemes, the forecasting process requires the model (described in section 4) to be run multiple times using different assumptions about future supply and demand. Section 5.2 relates forecasting to the outputs required for appraisal and sets out the number of model runs required for a given set of assumptions.

5.1.2 When preparing evidence using forecasts, it is important to mitigate any risks that the forecasts may mislead. Care should be taken to avoid bias, whilst uncertainty in the forecasting assumptions should be explained and quantified. Section 5.3 discusses the mitigation measures in more detail.

5.1.3 Appendix A explains the economic principles of modelling, and how these are modified for forecasting.

5.2 Forecast Design

5.2.1 The Guidance for Appraisal Practitioners sets out the analysis work that usually needs to be undertaken to appraise a scheme. For most schemes, forecasts of economic benefits will be calculated for:

- the scheme opening year
- at least one other forecast year, called the final forecast year

5.2.2 Additional forecast years between the scheme opening year and the final forecast year should be modelled where appropriate (for example, just before and after major step changes in demand or supply that will significantly affect the calculated scheme impacts and the profile of benefits).

5.2.3 For economic appraisal, it is preferred if the final forecast year is as far into the future as forecasting datasets will allow (including NTEM, items on the uncertainty log, and data used to calculate economic impacts and environmental impacts that may be monetised). This ensures that the benefits realised by a proposal can be captured in the analysis as completely as possible. However, when forecasting very far into the future, the uncertainty around the forecasting assumptions, and the potential for the occurrence of unforeseen events, increases. It is prudent to explore this uncertainty through sensitivity testing and scenario analysis.

5.2.4 The forecasting model needs to be run twice for each modelled year; one scenario where the scheme proposal is present and one where it is not. This allows comparison between those two futures, so that future transport conditions and the benefits and costs of the proposal can be assessed. As will be seen in section 5.3, the scheme will need to be appraised under multiple sets of assumptions set out in scenarios, to test the robustness of the benefits to uncertainty.

5.3 Quality assurance of forecasts

5.3.1 Quality assurance is an essential part of the development of a transport model. Model developers must be mindful of potential sources of error and bias within the model system and seek steps to address them.

5.3.2 Sources of uncertainty within the model system are inevitable; it is not possible to collect exhaustive data for every detailed aspect within the model as it will not exist. It is good practice as part of the quality assurance to be transparent in communicating these uncertainties in a proportionate manner. As a minimum, this should be via reporting, tackling the parts of the model which will have the most material impact to its end use. This is so that the implications are understood and can be adequately explained.

5.3.3 Sensitivity tests (running models by varying assumptions, particularly for more uncertain parameters or data within the model) are a good way of testing how a model may respond differently were model parameters to vary. For example, a behavioural response may in practice be stronger or weaker than one is able to observe; flexing and testing these assumptions can be a good way of better understanding the model and hence provide better insights in its end use. Detailed advice is available in TAG unit M4 – Forecasting and uncertainty.

5.3.4 From an appraisal point of view, quality assurance of models is vital to ensure that the economic costs and benefits, and value for money of a potential option is robustly represented. This includes transparency of the material uncertainties that should be considered alongside these outputs and metrics. This provides assurance around the appropriate allocation of public resources to transport investment.

5.3.5 The **uncertainty log**, as set out in TAG unit M4 – Forecasting and uncertainty, allows analysts to gather together all potentially material uncertainties within the model input assumptions and parameters. This also allows clear reporting of the sensitivity and scenario tests that have been conducted as part of the appraisal/assessment, highlighting the specific aspects of uncertainty that have been acknowledged or further examined.

6. Reporting

6.1 Introduction

6.1.1 During the reporting stage, the focus is on the practitioner to evidence that the model is developed from sound data, uses best practice approaches, provides reasoned justification for adjustments (calibration) and provides a rational explanation of the suitability of the model for forecasting.

6.1.2 Through experience of reviewing transport models and their reporting, the Department has identified a list of important areas for review that should be considered by modelling practitioners. The core reporting requirements to be followed are set out in TAG Guidance for Technical Project Manager and the Guidance for Modelling Practitioners (TAG units M2.1, M3.1, M3.2).

6.1.3 The following sections provide a guide for practitioners on the types of information that are expected to be included for review of scheme appraisals. Producing such material covers many of the checks and analyses that will help to mitigate model development risks. These are not exhaustive and should be supplemented with additional reviews, to help build the evidence base further. Similar principles may apply to modelling in other contexts, e.g. the results need to be stable enough and demonstrated as realistic in any context where they are used, not just appraisal.

6.2 Model Specification Report

6.2.1 Model specification reports (these can also be part of an appraisal specification report) provide an overview of the intended development approach for a transport model. They provide a good basis for engaging with stakeholders and the Department to agree on the proposed modelling approach. Table 1 provides minimum range of aspects that should be considered by practitioners and form the basis of a model specification report.

Table 1 Minimum contents in a model specification report

Section	Contents
Background to the project	• What is the identified problem and likely solutions? • Has a suitable study area been defined? Is evidence provided to support this? (for example, through the use of existing models) • Has availability of existing models been considered? Documentation should include an assessment of models based on their structure and components, such as the age, quality and spatial coverage of the underlying data, and the model’s adherence to quality criteria for calibration and validation.
Overall model structure	• List of proposed model components and capabilities • Where uni-modal rail models are proposed, practitioners should consider: – Is it a UK rail study involving changes to the timetable (and/or train capacity)? Do the changes apply only to existing railway stations and railway lines? – Are the interactions with other travel modes relatively minor or predictable, or are these interactions of low importance, therefore, out-of-scope to the study? – Are changes in station access/egress or station choice out of scope or unimportant?
Data	• Data requirements, including consideration of demand data, traffic/passenger flow data and journey time data • What is the availability of existing data and what is proposed to be used? • What are the proposed approaches to fill any data gaps (e.g. new surveys)? • How will data be used in model development, calibration and validation? • Does the proposed data collection and collation strategy provide sufficient coverage to support the proposed model build, both spatially and across modes?

Base Year Model	• Proposed approach to developing transport models, which includes description of proposed model networks and zone plans, highway and public transport assignment models, details of treatment of congestion on the road system and crowding on the public transport system, and treatment of active modes • Base Year and time periods to be modelled. Provide evidence to support the selection of modelled time periods. Where data is not available, detail the proposed approach to identify time periods to be modelled. • Description of the overall spatial coverage of the model and the evidence to support this. • Details of matrix development methodology – how will data be used, what are the proposed screenlines, how will source data be used (e.g. mobile network data, gravity model), what is the approach to matrix calibration and validation. • Description of the approach to validation and data requirement. • Does the proposed validation provide sufficient coverage to demonstrate fitness for purpose for appraisal of the scheme. • Description of the assignment methods to be used (e.g. dynamic or steady state).
Demand modelling	• Description of the approach to demand modelling – explain the basis of the behaviours to be modelled. • Description of the proposed approach for developing the demand model and rationale for its setup. • Does the methodology proposed align with the principles of TAG, for example, in terms of model form, and whether choices and mode coverage are appropriate.
Forecasting	• Proposed forecast years and the rationale for those. • Description of the forecast scenarios to be modelled. • Description of the methods to be used in forecasting future traffic demand. • Description of the methods to be used for forecasting future supply. • Details of the Sensitivity Testing that will be carried out (to include high and low growth, as well as other significant sources of uncertainty) as well as others to be considered.
Statement of suitability	• Are the proposed methods likely to capture scheme impacts? • What impacts may not be covered that are worth acknowledging?

6.3 Data collection

6.3.1 TAG unit M1.2 Data Sources and Surveys provides extensive guidance on the range of data sources available to practitioners, the key features of each and the potential biases that may exist.

6.3.2 A **data and surveys report** should set out three distinct aspects of the data collection process. It should set out the **sources of data** (both existing and new data), reporting on the processes used to collect the data and any specific challenges faced. It should describe the **checking** process adopted and demonstrate why there is confidence in using specific data for the model build. It should finally be **descriptive**, providing any insight derived from the data that informs key parts of the model development process.

6.3.3 The report should be produced to include the following specific information:

- Details of the **sources** (for example, who collected the data, any challenges encountered), locations (illustrated on a map), methods of collection, dates, days of week, durations, sample factors, and estimation of accuracy.

- Where origin and destination data are used (for example, through road-side interview, mobile network data or other), specific details of data processing, validation and expansion methods should be provided.

- Details of any specialist surveys (such as stated preference).

- **Checking** processes should be summarised to outline how any data cleaning and review was undertaken to ensure the data is of suitable quality/ Any adjustments made to the data must be described.

- **Descriptive** information derived from the data should be provided including:

  - Traffic and passenger flows, including daily, hourly, and seasonal profiles, as well as details by vehicle class or service group where appropriate.
  - Journey times by mode, including variability if appropriate.
  - Details of the pattern and scale of congestion or crowding.
  - Desire line diagrams for important parts of the network.
  - Diagrams of existing traffic and passenger flows, both in the immediate corridor and other relevant corridors.

6.4 Assignment Models

6.4.1 TAG units M3.1 and M3.2 in the Guidance for the Modelling Practitioner provide a detailed breakdown of the requirements for the development of assignment models. They also include specific reporting requirements. A summary of the key items to evidence include:

- Description of the overall spatial coverage of the model and evidence to support it.

- Description of the road traffic and public transport passenger assignment model development, including model network and zone plans, details of treatment of congestion on the road system and crowding on the public transport system, generalised cost functions adopted.

- Description of the data used in model building and validation with a clear distinction made for any independent validation data.

- Evidence of the validity of the networks employed, including range checks, link length checks, and route choice evidence.

- For highway models, details of the modelling of junctions, including data for the treatment of level crossings and junctions, in particular traffic signals and whether these have been updated or optimised.

- Details of the segmentation used, including the rationale for that chosen.

- Details of final matrix development approach adopted and in particular where this has differed from that proposed in the model specification report (which can be part of an Appraisal Specification Report).

- Details of site specific 'special cases' where additional data / particular focus is given – e.g. airports, ports, business parks, park and ride, retail parks or industrial areas.

- Validation of the trip matrices.

- Details of any 'matrix estimation' techniques used and evidence of the effect of the estimation process on the scale and pattern of the base travel matrices.

- Validation of the trip assignment, including comparisons of flows (on links and across screenlines/cordons) and, for highway models, turning movements at key junctions. A diagram of modelled and observed traffic flows, both in the immediate corridor and other relevant corridors.

- Journey time validation, including, for highway models, checks on queue pattern and magnitudes of delays/queues. This should also include the validation of bus congestion feedback in integrated highway and public transport models.

- Detail of the assignment convergence.

6.5 Demand Models

6.5.1 TAG unit M2.1 Variable Demand Modelling provides extensive guidance on the development of demand models. It also describes the basis for establishing whether there is a need for demand modelling, and where necessary the steps and decision making required to develop an appropriate Variable Demand Model. Where practitioners demonstrate that a demand model is not required, this should be documented. Where demand models are developed, these should be documented in a Demand Modelling Report. This should include:

- Description of the demand model and rationale for its set up.

- Description of the data used in the model building and validation – particularly where relevant to the demand model inputs.

- Rationale and evidence for the choices available within the demand model, their inclusion or exclusion, and the chosen ordering of the hierarchy.
- Details of the segmentation used, including the rationale for that chosen. This should include justification for any segments or movements that are not subjected to variable demand modelling.
- Evidence of model calibration and validation and details of any sensitivity tests.
- Details of any imported model components (e.g. parameters) and the rationale for their use.
- Details of the realism testing, including outturn elasticities of demand with respect to fuel cost and public transport fares.
- Details of the demand/supply convergence

6.6 Forecasting

6.6.1 TAG unit M4 Forecasting and Uncertainty provides guidance on the development of forecasts for scheme appraisal. In reporting, the following items are expected within scheme forecasting reports:

- Description of the methods used in forecasting future traffic demand (for example, use of NTEM/TEMPro, National Road Traffic Projections or other sources).
- An uncertainty log providing a clear description of all forecasting assumptions in core and alternative scenarios. This will include the planning status of local developments and all local (and relevant national / regional) transport schemes.
- List of forecast years modelled and the rationale for their inclusion.
- Description of the future year transport supply assumptions (i.e. networks examined for the without-scheme scenario, core scenario and variant scenarios).
- Description of the travel cost assumptions (e.g. fuel costs, PT fares, parking). Include reference to the base year assumptions to illustrate how these are assumed to change over time.
- Provide demand summaries for the base year, background growth, development trips and the forecast year matrix total, by time period and user class.
- Presentation of the forecast travel demand and conditions for the core scenario and variant scenarios including a diagram of forecast flows for the without-scheme scenario and the scheme options for affected corridors.

- If the model forecast includes very slow speeds or high junction delays, evidence of their plausibility.

- An explanation of any forecasts of flows above capacity, especially for the without-scheme scenario, and an explanation of how these are accounted for in the modelling/appraisal.

- Presentation of the sensitivity tests carried out.

7. References

Department of the Environment, Transport and the Regions (1996). Design Manual for Roads and Bridges, Volume 12.

Institution of Highways and Transportation (1996). Guidelines on Developing Urban Transport Strategies.

MVA, David Simmonds Consultancy, ITS University of Leeds (1997). National Transport Model Feasibility Study – Project 1: Policy Model. Report to the Department of the Environment, Transport and the Regions.

Ortuzar J de D and Willumsen L G (1994). Modelling Transport (Second Edition). Chichester, England. Wiley.

Standing Advisory Committee on Trunk Road Assessment (SACTRA) (1994). Trunk Roads and the Generation of Traffic. HMSO. London.

8. Document Provenance

This Transport Analysis Guidance (TAG) unit is based on the previous TAG unit M1.1 (January 2014) and was expanded in spring 2024.

Appendix A: Economic theory of modelling and forecasting

A.1.1 The model should represent the following principles of supply and demand:

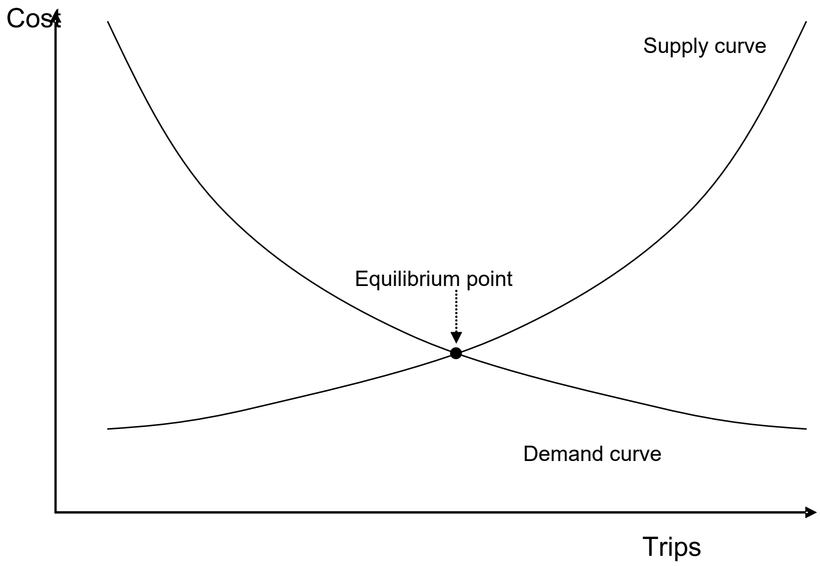
- an increase in demand causes cost either to remain unchanged or increase (e.g. through increasing congestion on the highway network, or increasing overcrowding on public transport services). This is represented in a function known as the **supply curve**;
- an increase in cost (as a result of limited supply) causes demand either to remain unchanged or decrease. This is represented in a function known as the **demand curve**.

A.1.2 Model results should only be used once they have reached **equilibrium**, where the model solution is consistent with the relationships between demand and supply in **both** the supply curve and the demand curve. Although the transport system will not necessarily be in equilibrium in reality, the equilibrium solution provides a consistent basis on which to compare forecasts. In practice, finding exact equilibrium usually requires disproportionate resources, so it is usually found within tolerance standards as set out in TAG units M2, M3.1 and M3.2. Failure to **achieve acceptable convergence** to equilibrium can lead to highly misleading appraisal results.

A.1.3 There is a special case - the **fixed demand approach** – in which it is assumed that none of the changes to the network are expected to increase (or reduce) the number of trips made. This assumption significantly reduces run times, but is generally not valid. Analysts should provide justification if they are using the **fixed demand approach** for major transport schemes, demonstrating that the underlying assumption holds.

A.1.4 To understand these concepts, consider a very simple example with one group of users. In classical economics it is conventional to treat both supply and demand as functions of cost, but to ‘invert’ the normal graph by plotting cost on the vertical axis, as in Figure 2.

Figure 2 Demand/Supply Equilibrium



A.1.5 Since both demand and supply curves relate volume of travel to generalised cost, the actual volume of travel must be where the two curves cross. This is the **equilibrium point**. Note that in the one-dimensional example shown here, the equilibrium point is unique, but this may not always be the case for multi-dimensional models and depends on the form of the demand and supply functions.

A.1.6 Finding the equilibrium point is not always trivial. In the fixed demand approach, the demand curve is effectively vertical (i.e. the number of trips is fixed for all costs), but in the more general case it is usually necessary to search for equilibrium using an iterative procedure that updates supply and demand alternately. Ideally, this process should continue until the modelled solution is close to the correct equilibrium solution (proximity); however, most of the conventional measures of convergence compare one iteration of the procedure with the next (stability).

A.1.7 Most transport models will, in fact, need **two** equilibrium models: one main loop between demand and supply, and a smaller loop between route choice and route cost in the assignment model. This is explained in section 4.2.

A.1.8 Figure 3 extends Figure 2 with typical demand and supply curves for future year forecasts:

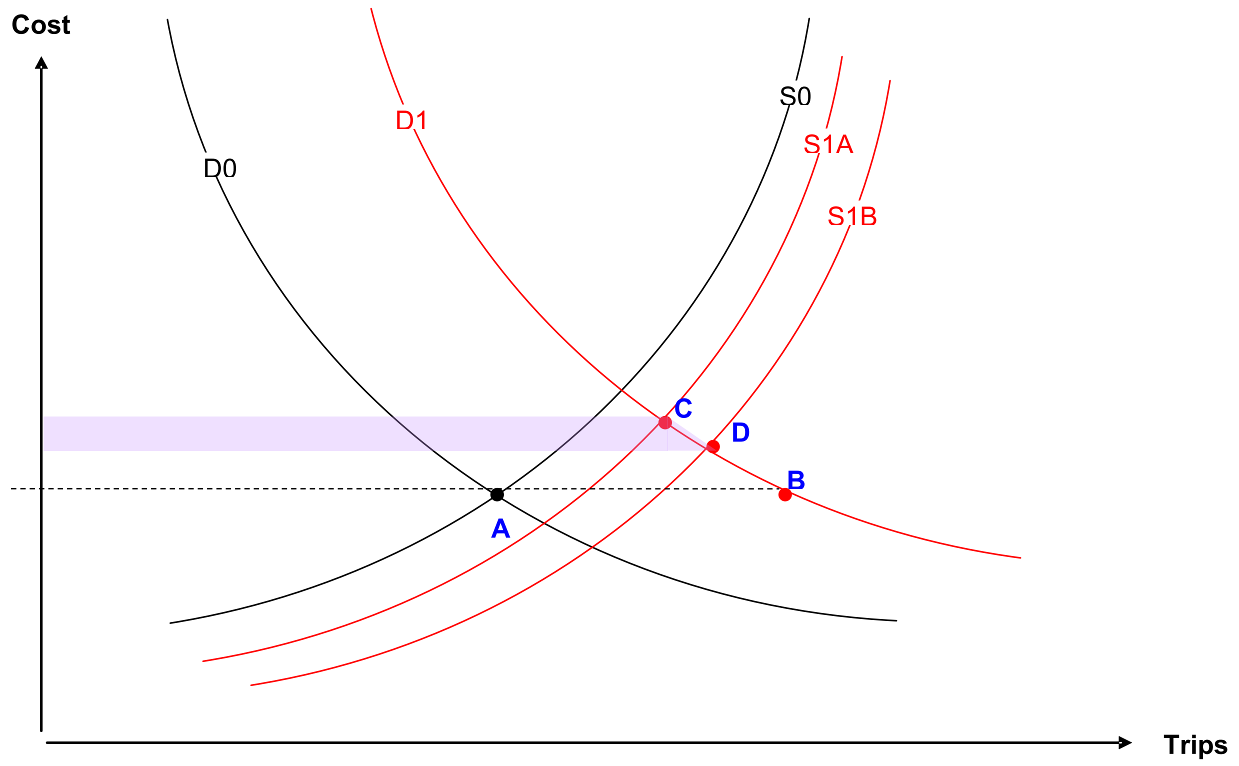
- Curves D0 and S0 represent the demand and supply curves respectively for the model base year, previously shown in Figure 2
- Curve D1 represents the demand for a future forecast year. Typically, demand is higher than the base year due to changes in population, employment and income
- Curves S1A and S1B represent the supply curves for the without-scheme and with-scheme forecasts respectively. Typically the supply curve for the

without-scheme case will be lower than the base year, as some network improvements may be planned to accommodate increased demand independent of the scheme in question. If the scheme increases capacity and/or speed of travel, the cost will be reduced further, leading to the with-scheme case having a supply curve still lower than the without-scheme case

A.1.9 The model runs are represented in the diagram as follows:

- point A is the equilibrium point in the base year
- point B is the reference forecast, representing future year demand, under the assumption that costs do not change from the base year. This forecast is not in equilibrium (as it does not intersect with any supply curves)
- point C is the without-scheme forecast, representing future year demand and supply in the absence of the scheme
- point D is the with-scheme forecast, representing future year demand and supply with the scheme in place

Figure 3 Changes in demand and supply curves for forecasts



A.1.10 The shaded area shows the change in consumer surplus for the scheme, estimated using the rule-of-half measure and calculated between points C and D. Failure to achieve equilibrium for both without-scheme and with-scheme forecasts will result in this area on the graph being calculated incorrectly, giving a distorted and misleading view of the scheme benefits under equilibrium conditions.

A.1.11 Figure 2 and Figure 3, although a good representation of what usually happens across the model as a whole, are highly simplified. The demand and costs for any given individual zone-to-zone pair may not exhibit these properties when examined in isolation.

Appendix B: The Production / Attraction definition

B.1.1 The Production / Attraction (or P/A) definition is used to represent the various trips that form a tour (whether outbound from home, return to home, or non-home-based) in such a way that relates them most closely to the available demographic data. As the strongest and most relevant demographic data generally relates to resident population, it is useful to distinguish trip ends that relate to "home" from those that relate to "non-home" activities.

B.1.2 The shortest, and most common, pattern for a tour has two trips – an **outbound trip** from home to an activity, and a **return trip** from the activity to home. Both of these are **home-based trips** with one end at home, and these are distinguished from **non-home-based trips** which have neither end at home. Tours with three or more trips have an outbound trip to the first activity, followed by a series of non-home-based trips to the other activities, and ending with a return trip from the final activity to home.

B.1.3 Home-based trip ends are split by **production** (home) and **attraction** (the reason for travel). Across a suitably large geographical area, it is usually best to scale the attractions to match the productions, as the productions are based on the most relevant and reliable data (resident population) and the fit of production trip ends to planning assumptions is usually better.

B.1.4 In theory there are various ways of defining the productions and attractions for non-home-based trips, but TAG and the Department's trip end forecasting dataset NTEM (National Trip End Model) uses the simplest possible definition, as follows:

- the production is defined to be the origin of the trip
- the attraction is defined to be the destination of the trip

B.1.5 An example relating the P/A definition to the origin-destination (O/D) definition is shown in Figure 4.

Figure 4 Example of P/As and O/Ds for a sequence of trips