Passenger Transport Modelling [T1]
Providing Feedback

This draft document has been published for stakeholder feedback.

Submissions are due Monday 9 February 2015

All submissions should be in writing and preferably emailed to: NGTSM2014@infrastructure.gov.au

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Disclaimer

This document is a draft for public comment. Please note that as a draft document it has not been approved by any jurisdiction, therefore should not be relied upon for any purpose. Until an approved revised edition is published in 2015, users should continue to be guided by the National Guidelines for Transport System Management released in 2006.
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Passenger transport modelling

At a glance

- This volume of the Guidelines provides guidance for developing and applying strategic highway and public transport models when appraising major transport initiatives. The focus in this volume is on the modelling of person-based, or passenger, travel demand across road and public transport networks. This guidance is not intended to be comprehensive; rather, it represents the minimum level of recommended acceptable practice.

- The following key areas are covered in this volume:
  - An overview of the transport modelling process and associated high level issues,
  - Standard transport model structures and techniques for modelling passenger based travel demand,
  - The data inputs required for the transport models, and the associated collection approaches and techniques,
  - The techniques used in transport model development, and
  - The use of transport models for forecasting and evaluation.

- A volume focussing on freight transport modelling will be available by November 2015.
1. Introduction

Any transport model is a tool for understanding and assessing the likely impacts of changes in the drivers of transport, such as transport supply, demographics or land use. In this context, transport modelling can assist with decision-making about the future development and management of urban transport and land use systems.

This document provides guidance for developing and applying strategic highway and public transport models when appraising major transport initiatives.

This document is not intended to be a detailed technical treatise on developing individual components of a transport model, but rather a succinct, practical and pragmatic reference for developing, applying and assessing transport modelling. Detailed information on transport modelling theory and methodological approaches can be found in transport modelling references.

The urban transport modelling guidelines represent the minimum level of recommended acceptable practice and are provided to:

- Establish principles of good transport modelling practice, rather than being prescriptive on transport modelling methodology
- Ensure a consistent understanding in the application of transport modelling
- Provide a better understanding of the transport modelling process.

This document contains five sections:

<table>
<thead>
<tr>
<th>Section</th>
<th>Summary</th>
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<tbody>
<tr>
<td>Overview of transport modelling</td>
<td>This provides an overview of the transport modelling process and high level issues. Material is readable at a project management level.</td>
</tr>
<tr>
<td>Model design</td>
<td>This section covers standard model structures and techniques for modelling travel demand and transport networks. This material is aimed at a technical level.</td>
</tr>
<tr>
<td>Data collection</td>
<td>This covers data collection, types of data, collection approaches and techniques. This material is aimed at a technical level.</td>
</tr>
<tr>
<td>Model development</td>
<td>This covers the techniques used in the development of transport models. This material is aimed at a technical level.</td>
</tr>
<tr>
<td>Forecasting and evaluation</td>
<td>This covers the use of models for forecasting and evaluation. This material is aimed at a technical level.</td>
</tr>
</tbody>
</table>
2. Overview of transport modelling

Transport models are a systematic representation of the large and complex real-world transport and land use system as it exists, and as it might be. They are a powerful tool for developing transport infrastructure options and for examining and assessing these options, as well as for identifying how the transport system is likely to perform in future.

The development and application of transport models is fundamental to the appraisal of many transport initiatives because they:

- Provide an analytical framework to assess existing demands on the transport system and project future demands to systematically test the impact of transport and land use options
- Enable the generation of quantitative measures to provide key indicators in the business case assessment and economic evaluation.

Transport models use mathematical relationships to represent the numerous complex decisions people make about travel so that future demand can be predicted, and to replicate observed travel patterns at various levels of geography.

At the most fundamental level, transport models comprise:

- A demand model (trip generation, trip distribution and mode choice)
- A highway assignment model (road-based public transport, private vehicles, freight and other commercial vehicles)
- A rail, bus, and ferry assignment model (public transport and freight).

Generally, the development of a transport model requires:

- A Statement of Requirements
- A Functional Specification of the transport model
- A Technical Specification of the transport model.
2.1 Statement of Requirements

A Statement of Requirements usually details the objectives of the model; the interfaces with other models; the hierarchy of transport modelling applications; transport model attributes; and transport model outputs. Each of these is described below.

2.1.1 Objectives of the model

The overall objectives for a transport model refer to what it is required to do. This can include:

- Providing the technical means for the ongoing development of procedures to quantitatively test and evaluate transport initiatives, strategies and policies
- Assessing the strategic justification for major transport infrastructure projects
- Defining the geographic coverage – initially for specific metropolitan regions, but allowing flexibility to include regional centres within the context of a state-wide model
- Extending the model to test the impacts of transport strategies on a particular location and the intensity of land use development that might occur there.

2.1.2 Interfaces with other models

This component of the Statement of Requirements defines the interface relationships between the transport model and other models. This interface can provide input to corridor-specific models and the more detailed mesoscopic and microsimulation or operational models.

The key interface attributes are that models share common information and data sources as well as core assumptions, and provide consistency within the hierarchy of transport modelling (see Table 1 below).
2.1.3 Hierarchy of transport modelling applications

Transport modelling development and applications generally fall into the five broad categories described in Table 1.

### Table 1  Hierarchy of transport modelling

<table>
<thead>
<tr>
<th>Land use and transport interaction modelling</th>
<th>• Examines and evaluates the impacts of transport policy and land use changes on urban form and transport.</th>
</tr>
</thead>
</table>
| Strategic modelling | • Examines ‘what if?’ questions in policy development and the definition of strategies.  
• Identifies and assess broad metropolitan-wide impacts if land use, socio-economic, demographic and transport infrastructure changes.  
• Assists in transport infrastructure project generation.  
• Provides metropolitan-wide forecasts of trip generation, trip distribution, mode choice and assignment of trips to the transport network.  
• Creates multi-modal modelling.  
• Models and assesses pricing issues. |
| Scenario modelling | • Assesses the implications of particular strategies at the metropolitan scale. |
| Project modelling | • Assesses strategy components, individual projects, specific land use strategies and transport corridor issues.  
• Assesses the performance of the transport network along specific corridors and for nominated projects. |
| Microsimulation and operational modelling | • Assesses the detailed operational performance of specific transport infrastructure projects and initiatives (e.g. ramp metering), land use developments and local area traffic management.  
• May involve microsimulation of individual vehicle movements and interactions on small-scale networks and the detailed modelling of individual transport routes.  
• May assist identify the effects on delays and queues resulting from changes in the transport system variables i.e. signal phasings, lane configurations, ramp metering. |

In addition to the examples in Table 1, some specific examples of matters model applications aim to assess include:

- Quantifying the effects of land use strategies on transport and vice versa
- The assessment of scenarios involving pricing policies (e.g. fuel, tolls, parking charges), transport infrastructure provision and service improvements
- The interaction between freight, private vehicles and public transport.
Selecting which particular modelling technique to apply is an important part of the Statement of Requirements. The selected tool needs to be sensitive to the relevant issues of a project. Unnecessary complexities should be avoided as they will increase the cost and introduce risks. However, the objectives of the project are paramount, so while the modelling technique chosen needs to be simple, it should not be oversimplified. A good balance needs to be found.

The challenge is to match the context of a project to the strengths and weaknesses of each technique. The first step is to contextualise the project, by identifying its key elements. These key elements should be able to cover the schemes and data, inter-relationships of factors, and objectives of the project. These elements can then become specifications of the model to be applied, such as input variables, scope and mechanisms, and output variables (shown in Figure 1), as follows:

- **Input variables** – should be sensitive to the proposed schemes and make use of available data. Input variables include representation of the demand and the transport network. The transport network is defined by physical attributes (e.g. highway geometry) and traffic control (e.g. traffic signals).

- **Scope and mechanisms** – cover the relevant inter-relationships of factors considered in a project, including its geographic and temporal scope, traveller responses and other capabilities required of the model (e.g. optimisation).

- **Output variables** – should be able to represent the objectives of the project. Output variables include the relevant indicators and accuracy requirements. The likely users of the modelling outputs should be considered when preparing the model outputs.

**Figure 1** Elements of the traffic system model

No clear science exists for selecting the most appropriate transport modelling technique. The selection needs to balance the requirement for rigorous analysis against the cost. It is also important to filter out case studies that do not require modelling to focus resources on projects that require modelling. Guidelines are therefore needed to facilitate the selection process. It is not the purpose of the guidelines to identify a particular technique. The intent is only to structure the decision-making process. In the end, a subjective judgment is required. The guidelines set out four steps as shown in Figure 2.
2.1.4 Transport model attributes

Desired transport model attributes detailed within a Statement of Requirements may include:

- The model is readily accessible to key decision-makers and can enable a prompt and reliable response.
- It is an integrated multi-modal model updated annually to account for new data as well as for identified errors or changes in core assumptions.
- The model provides sensitivity to changes in demographics, individual travel decision-making, social behaviour and land use or some combination of these.
- It enables an accessible and quick response, and is state-owned, developed and maintained.
- The model has the ability to model motorised (including freight) and non-motorised travel.
- It features techniques and transferable parameters that can be used to undertake ‘what if?’ scenario tests.
2.1.5 Transport model outputs

Examples of model outputs contained in a Statement of Requirements might include:

- Road, rail, bus and ferry transport patronage estimates
- Transport network performance (such as vehicle-hours, kilometres of travel and congestion indicators) and accessibility measures (such as services, employment)
- Forecasts of aggregate travel costs and benefits
- Source of diversion
- Input to externalities modelling (such as quantum of emissions)
- Input for economic evaluation and business case assessment.

2.2 Functional Specification

The Functional Specification of a transport model describes the functions it should include, based on the scope of the transport model (see 2.2.1 below) as defined in the Statement of Requirements. It also outlines the model structure (see 2.2.2 below) as well as the functions and methodologies appropriate for the various components (i.e. trip generation, trip distribution, mode choice and trip assignment), the inputs and outputs, and the data source.

2.2.1 Transport model scope

The scope of the transport model is defined by the policy issues the model system aims to address. These may include:

- Land use–transport interaction
- Pricing (toll roads, parking, public transport fares)
- Parking provision (cost, reduction in availability, park-and-ride facilities)
- Road network management (new roads, commercial vehicle priority, traffic management, high occupancy vehicle lanes)
- Freight (mode share, nominated freight routes, impacts of congestion, location of freight centres)
- Public transport networks (extensions, service provision, fares, interchanging, cross-town routes)
- Non-motorised travel (cycling, walking).

Establishing a suitable model scope and structure for transport modelling and analysis is not a simple process. A whole range of modelling approaches exists, ranging from the options of using no formal transport models to the most complex microsimulation models.
The selection of the transport model structure and scope in the Functional Specifications is driven by the requirements of a specific transport study, as well as by the requirements of the appraisal process.

2.2.2 Transport model structure

A broad transport model structure will generally include:

- **A database** populated by data from travel surveys across the region by various mode by time of day, together with traffic volumes across the transport network and patronage levels on the public transport network, including current and projected land use data and demographics (population and employment). The database will also include details regarding the quantum of freight being produced/consumed or imported/exported by commodity and by mode.

- **The inputs to the modelling process**, such as parking supply, land use distribution, fares, car travel costs, traffic management measures, access restrictions, road and public transport infrastructure, and public transport service provision.

- **A travel demand model** to derive the quantum of travel across the region, comprising trip generation, trip distribution and mode choice modules, including factors such as travel purposes and the quantum of commercial vehicle travel.

- **A freight model** to derive the quantum of freight transported across the region sufficient to estimate the quantum of commercial vehicle travel on the road network and the requirements of the freight task on the rail network.

- **A transport supply model** covering the road and public transport networks, covering factors such as parking supply, road and public transport network capacities, travel times and travel costs.

- **An assignment module** to allocate travel demands to the transport supply model in an iterative manner, to ensure the forecast demands are balanced with the transport supply, taking into account congestion effects.

- **The required outputs**, such as network performance indicators including vehicle-hours and kilometres of travel, passenger-hours and kilometres, congestion indicators and tonnages of emissions.

- **Other information** such as emissions (NOx, CO, CO2), traffic volumes, trip lengths, trip costs and benefits and accessibility measures.

2.3 Technical Specification

The Technical Specification of a transport model usually follows the choice of modelling approach and includes the methodologies and processes developed to meet the Functional Specification. It details, among other issues, the input data, model calibration and validation data and the format of the required outputs. Information relating to Technical Specification is covered in subsequent sections of this document.
2.4 Transport modelling process

The transport modelling process comprises a number of stages, as shown in Figure 3. These include:

- **Consolidating the modelling task**, which includes identifying the key transport, socio-economic and land use issues as well as the particular problems to be modelled. This stage is also informed by the definition of goals, objectives and the appraisal criteria to be adopted.

- **Data collection**, which is critical to transport modelling and may include highway and public transport patronage data, import/export or production/consumption volumes by commodity as well as census information and targeted or area-wide travel surveys.

- **Model calibration and validation**, which is required to develop the relationships used in the modelling process and to gauge the performance of the transport model.

- **Options development**, which usually includes variations of transport network options, land use options or combinations of both.

- **Options modelling**, which might enable further refinement and development of options as well as more detailed design and appraisal. This stage usually involves an iterative process covering options development and modelling through to appraisal.

- **Sensitivity analysis**, which varies input data and model parameter values to identify the robustness of the model relationships and the associated forecasts.

- **Economic appraisal**, which uses results of modelling as input to the appraisal process to assess the performance of the options against the specified goals, objectives and criteria.

- **Modelling report**, which involves the full documentation of each of the previous stages, including the transport model details.

See Appendix A for more information on the transport modelling process.
Figure 3  Transport modelling process

1. CONSOLIDATE THE MODELLING TASK
   - Review the purpose, goals and objectives of the study.
   - Identify how modelling can contribute to meeting the study goals and objectives.
   - Identify the scale and scope of the transport modelling required.
   - Confirm the time period to be modelled.
   - Confirm the ‘Base Case’ transport network and land use to be modelled.
   - Confirm the validation criteria.
   - Confirm the timelines for and outputs from the modelling task.

2. DATA
   - Review the available data and identify and source any new data required.

3. MODEL CALIBRATION AND VALIDATION
   - Produce existing conditions transport network model.
   - Produce existing conditions trip matrix.
   - Model existing conditions.
   - Compare modelled results against existing conditions.
   - Refine road network model.

4. OPTIONS DEVELOPMENT
   - Develop trip matrices based on land use options.
   - Develop the transport network options.
   - Document the trip matrices and transport network options.
   - Document the trip matrices and transport network options.
   - Document the results.

5. OPTIONS MODELLING
   - Run traffic assignments for each transport network and land use option.
   - Examine the distribution of network performance indicators.
   - Produce model outputs and performance indicators for each transport network and land use option.
   - Compare network options with the ‘Base Case’.
   - Compare network options.

6. SENSITIVITY ANALYSIS
   - Determine the basis for sensitivity analysis.
   - Undertake sensitivity analysis.
   - Examine the distribution of network performance indicators.
   - Compare the various options.
   - Document the results from the sensitivity analysis.

7. ECONOMIC APPRAISAL
   - Determine the economic appraisal parameters to be used.
   - Determine the inputs to the appraisal.
   - Undertake the economic evaluation.
   - Document the results from the economic evaluation.
   - Document location of files used for the sensitivity analysis.
   - Document location of files used for the sensitivity analysis.
   - Document location of files used for the sensitivity analysis.

8. MODELLING REPORT
   - Outline the modelling task.
   - Document the aims and objectives of the modelling task and the approach taken.
   - Document the modelling assumptions.
   - Discuss any unresolved issues identified in the calibration step.
   - Discuss the traffic assignment results.
   - Discuss the sensitivity analysis results.
   - Discuss the economic evaluation results.
   - Conclusions.
2.5 Alternatives to modelling

An issue of interest is whether it is necessary to use modelling or other analysis methods for specific applications. An alternative to modelling is to use sketch planning techniques. Sketch planning methods generate only rough indicators and an enumeration of factors and their potential impact on the schemes being examined. Sketch planning is commonly used to reduce the number of alternatives being considered for further analysis. During the course of a sketch planning exercise, a certain alternative may stand out clearly or all other alternatives are eliminated. In this case it is no longer necessary to conduct further analysis.

An example application of sketch planning techniques is illustrated by Van Hecke et al (2008). In this example, sketch planning was applied to deploy certain operations technology, including detection / surveillance, incident management, traffic flow management, traveller information, and a regional weather information system. Recommendation on whether to deploy any of the technologies was based on criteria employing easy to derive or acquire data, including traffic volume, peak-hour conditions, accident records, traffic generators and weather conditions. The analysis is conducted without the benefit of modelling the effect of operations technology, but it is presumed that under certain conditions it is likely that a technology would be cost-effective. Further analysis may then be conducted on the basis of recommendations of the sketch planning methodology.

Another example of sketch planning is the use of prescribed warrants in recommending signalisation of an intersection. One methodology specifies 11 warrants where, if an intersection satisfies a certain number or combination of warrants, the intersection will be recommended for signalisation (Kell & Fullerton 1991). The warrants include traffic volume, type of approaches (for example, major or minor road), pedestrian volume, school crossing, accident exposure and others. Modelling is not necessary to conclude whether an intersection should be signalised or not. In some cases, crude calculations would be sufficient, and past projects or studies with similar characteristics could also be helpful to reach a conclusion without modelling.

Another approach is to use qualitative comparison of alternatives. Factors to consider include environmental, social, strategic planning and economic considerations. A review of advantages and disadvantages of possible alternatives may be sufficient to reach a conclusion. Qualitative comparison could even highlight important factors beyond the scope of modelling (such as aesthetics, social impacts, strategic impacts and complex behavioural responses).

Modelling is generally a time consuming and expensive exercise. Therefore it is good practice to first conduct a preliminary analysis of alternatives using sketch planning and/or qualitative comparison. A decision to proceed to more rigorous analysis using modelling techniques should then be conducted under one of the following conditions:

- The preliminary analysis fails to identify the best course of action.
- The project requires a rigorous analysis for approval from decision-makers.
- There are significant risks involved if the recommendations provided are wrong.

It is recommended to apply various alternatives to modelling and to proceed to modelling only when a need is clearly identified.
3. Model design

3.1 Modelling demand

3.1.1 Travel demands

Reference (Base) Year travel demands for highway, rail and ferry travel can be derived in a number of ways. The usual, and most expensive, way of collecting travel demand data is through travel surveys, either one-off or continuous. Survey methods include self-completion travel diaries, household interview surveys and in-vehicle public transport surveys. Vehicle counts are also useful in providing a database for the calibration as well as validation of the transport models.

Travel surveys can be structured to derive personal travel purpose origin–destination matrices for use in the assignment process by collecting information such as:

- Origin and destination by purpose
- Origin and destination by location
- Car availability and use for travel purpose
- Public transport mode used
- Cost of travel
- Duration of travel
- Time of day of travel
- Age, gender, income and employment status of the traveller.

For freight trips, data collection should focus on information such as:

- Origin and destination by commodity
- Origin and destination by location
- Mode used
- Vehicle or train wagon type
- Cost of travel
- Duration of travel
- Time of day of travel.
3.1.2 Market segmentation

The starting point for analysis of travel demand is to note that travel is almost always a derived demand – that is, it only occurs because of some other underlying demand. Travel occurs and goods are shipped because people want to undertake specific activities at different locations in an area or because goods and commodities are required at different locations.

Demand characteristics (price, income and cross elasticities, sensitivity to time, damage to freight, comfort for passengers, growth rates) and transport costs (packaging, type of service demanded) will vary for different segments of the market. In estimating quantities of freight that could switch between road and rail because of changes in relative prices or service qualities, it is useful to segment the market into the types of freight being transported and their origins and destinations. This is because rail can generally compete effectively only for long-distance freight that is not time sensitive.

Passenger trips may be categorised in many ways, including factors such as trip purpose, trip frequency, trip timing, trip distance and spatial separation of origin and destination (O-D) as well as travel mode used. Further, the socio-economic characteristics of individual travellers and the households to which they belong are also important determinants in predicting the travel behaviour of those individuals. The breakdown shown in Table 2 can be considered broad brush categorisation of passenger travel.

Table 2 Classification of passenger travel in terms of trip purpose, trip frequency, trip timing, spatial separation and transport mode

<table>
<thead>
<tr>
<th>PURPOSE</th>
<th>FREQUENCY</th>
<th>TRIP TIMING</th>
<th>TRAVEL DISTANCE</th>
<th>TRANSPORT MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>Regular</td>
<td>Peak period</td>
<td>Local</td>
<td>Private car:</td>
</tr>
<tr>
<td>Education</td>
<td>Infrequent</td>
<td>Business hours</td>
<td>To city centre</td>
<td>driver</td>
</tr>
<tr>
<td>Shopping</td>
<td>Occasional</td>
<td>Off-peak</td>
<td>Inter-suburb</td>
<td>passenger</td>
</tr>
<tr>
<td>Personal business</td>
<td>‘One-off’</td>
<td>Late night</td>
<td>Regional</td>
<td>Public transport</td>
</tr>
<tr>
<td>Work related</td>
<td></td>
<td>Weekday</td>
<td>Inter-city</td>
<td>rail</td>
</tr>
<tr>
<td>Social</td>
<td></td>
<td>Weekend</td>
<td>Inter-state</td>
<td>bus</td>
</tr>
<tr>
<td>Recreational</td>
<td></td>
<td></td>
<td>International</td>
<td>tram/LRT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Origin-destination*</td>
<td>taxi</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>aircraft</td>
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<td>Non-motorised</td>
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<td></td>
<td></td>
<td>walk</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bicycle</td>
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</table>
*As far as origins and destinations are concerned, the major distinction will be between O-D pairs that are in close proximity (i.e. a trip from origin to destination is completely local and could be made easily on foot, or might never be made by train because the station accessed from the origin is the same used to access the destination), within a locality, and those where the origin and destination are separated so that mechanised modes of transport such as rail that could be used for them are separated. Figure 4 provides a visual representation of ‘within a locality’ and ‘separated’ origin-destination movements. There is also a question of the ease of access to (origin) or from (destination) rail or bus services for a given trip. Good access implies an ability to conveniently walk from home to the station or stop, or from the station or stop to the destination. Difficult access means that some intermediate transport modes (for example, car passenger as a ‘kiss and ride’ user, car driver as a ‘park and ride’ user, bicycle or local feeder bus) would be required to reach a line haul public transport service. The degree of access is a major factor influencing traveller choices of transport modes.

Knowledge of spatial patterns of travel demand is used in transport planning for network and service design. A common method of describing travel demand in a region is through the use of origin-destination matrices. These are tables of trip or commodity movements between the various O-D pairs that exist in a study region (Taylor, Bonsall & Young 2000, pp. 114–116). Consider the schematic map of such a region as shown in Figure 4 below. The study region is identified by a cordon line around it. Travel movements across the cordon line indicate trips made to and from the region. These are external origins and destinations. Observations on the cordon line can be used to assess the numbers and patterns of these through trips. Internal or local trip movements may also exist for trips where either or both the origin and destination of the trip are located inside the study area. Further information on through trips (such as routes chosen for the segments of those trips inside the study area) and local trips can be gathered by defining screenlines inside the study area and then making observations of vehicle movements at the screenlines. Traffic management studies are often concerned with the proportion of through traffic to local traffic in the study area.
Figure 4 shows different O-D configurations. These include through trips and local trips (those that have at least one trip end – origin or destination – inside the study area). Local trips may be further subdivided into categories of within locality, separated with good access and separated with difficult access, as indicated in the figure.
A typical structure for an O-D table is given in Table 3. Travel movements may be expressed in units of vehicles, passengers or commodity flows.

### Table 3  Typical structure of an origin-destination matrix of travel movements

<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>DESTINATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>External</td>
<td>1</td>
</tr>
<tr>
<td>..</td>
<td>..</td>
</tr>
<tr>
<td>N₁</td>
<td></td>
</tr>
<tr>
<td>Internal</td>
<td>1</td>
</tr>
<tr>
<td>..</td>
<td>..</td>
</tr>
<tr>
<td>N₂</td>
<td></td>
</tr>
</tbody>
</table>

- **External**
  - Through trips
  - Local trips, destination in study region (separated trip, good / difficult access)

- **Internal**
  - Local trips, origin in study region (separated trip, good / difficult access)
  - Local trips (within locality)

Temporal distributions of travel demand are also important. Travel demand varies over the hours of the day, the days of the week and the weeks of the year. Cyclic and seasonal patterns can be ascertained to describe these patterns and used to predict the demands for transport services.

#### 3.1.3 Peak periods

Specific time period (am peak, inter-peak, pm peak and off-peak) trip matrices should be developed to better reflect the different travel making propensities and characteristics during these periods. This approach is preferable in urban areas, where commuter peaks place the greatest loads on the available transport infrastructure.

Another approach is to develop daily travel demands and then apply time period factors, by trip purpose, to generate the time period matrices for subsequent use in the assignment process. The time period factors indicate the proportion of the daily travel, by purpose, undertaken during the time period to be modelled and are usually derived from travel surveys. For strategic network assignment modelling, the peak period trip matrices are generally for either a one-hour or two-hour time period, depending on the requirements of the analysis.

#### 3.2 The four step transport modelling process

A commonly used model structure is the ‘four-step’ transport modelling process. (It is noted that there are other models such as activity based models and land use models that can be used to fulfil similar functions.)
The steps in the four step modelling process are shown in Figure 5 and described below. An important feature of the four-step modelling process is the iterative feedback of costs arising from trip assignment to trip distribution and mode split. By iterating between the last three steps (trip distribution, mode split and trip assignment), it is possible to replicate the impacts of congestion on travel costs. This iterative process ensures a balance between the final trip pattern and the costs by which it is derived.

Figure 5 The four-step transport modelling process

3.2.1 Step 1 – Trip generation

Trip generation is the mechanism whereby land use, population and economic forecasts are used to estimate how many person trips are produced within, and attracted to, each zone. Trip generation uses average trip rates for the study area to estimate the quantum of trips undertaken by various trip purposes such as:

- Home-based work trips (such as work trips that begin or end at home)
- Home-based shopping trips
- Home-based education trips (such as trips from home to primary, secondary and tertiary education)
- Home-based recreation trips
- Home-based other trips
- Non home-based trips (trips that neither begin nor end at home)
- Freight trips
- Other non home-based trips (such as service trips and business trips).
The productions and attractions developed in the trip generation step are usually termed ‘trip ends’.

Table 4 provides examples of the type of data that could be used in this step.

### Table 4  Demographic and land use variables used in urban transport modelling

<table>
<thead>
<tr>
<th>Demographic data</th>
<th>Detailed demographic data for the study area including:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• projected resident population by age cohort</td>
</tr>
<tr>
<td></td>
<td>• projected fertility and birth rates</td>
</tr>
<tr>
<td></td>
<td>• mortality rates</td>
</tr>
<tr>
<td></td>
<td>• forecast migration into, or out of, the study area</td>
</tr>
<tr>
<td></td>
<td>• current age cohort of population, and</td>
</tr>
<tr>
<td></td>
<td>• projected population by year for the study area.</td>
</tr>
<tr>
<td>Land use data</td>
<td>Data on land use would include:</td>
</tr>
<tr>
<td></td>
<td>• quantities of land required for various uses to meet projections of population and employment</td>
</tr>
<tr>
<td></td>
<td>• analysis of land use by industry type</td>
</tr>
<tr>
<td></td>
<td>• proportion of commercial land occupied, and</td>
</tr>
<tr>
<td></td>
<td>• register of available open space within study area.</td>
</tr>
<tr>
<td>Economic activity data</td>
<td>The following data may be used to provide an economic activity base for the forecasting future trip-making levels:</td>
</tr>
<tr>
<td></td>
<td>• current employment levels</td>
</tr>
<tr>
<td></td>
<td>• forecast employment by industry and/or occupation classification</td>
</tr>
<tr>
<td></td>
<td>• anticipated employment growth within transport zones</td>
</tr>
<tr>
<td></td>
<td>• assumptions about the employment generating capacity of the region, and</td>
</tr>
<tr>
<td></td>
<td>• estimated input-output function of the study area.</td>
</tr>
</tbody>
</table>

**Zoning system**

A key issue to be resolved when developing transport models is the transport zoning system. The definition of a transport zoning system should accurately reflect the quantum of trips made in a study area.

Transport zones should ideally contain homogeneous land use (for example, solely residential, industrial or commercial use or parking lots) and they should not cross significant barriers to travel (such as rivers, freeways and rail lines). In this context, transport zones should match, as far as practically possible, Australian Bureau of Statistics (ABS) Census Collection District (CCD) boundaries. CCDs may be aggregated or disaggregated, as required, in developing the zoning system for a particular transport model development.

Land uses with specific trip generation characteristics, which cannot be adequately described by the trip generation equations derived for a particular transport model, should be coded as separate zones (such as airports, ports, universities, hospitals, intermodal terminals and shopping centres).
In theory, the accuracy of a transport model should increase with the number of transport zones. However, it may be difficult to obtain reliable input data (employment, population) at a highly disaggregated level. The trade-off, therefore, is between the accuracy of the transport model and the practicality of having existing input data for transport model development at the chosen level of geography, and also being able to forecast the input data.

Another point to be considered when defining the zoning system is the highway and public transport network detail required to support the defined zoning system. A highly disaggregated zoning system will require a concomitantly disaggregated network to ensure all trips from all transport zones can access the transport network (via the centroid connectors) and that there is a reasonable concordance between the modelled and observed traffic volumes.

Transport zone centroids are defined as the ‘centre of gravity/activity’ of a transport zone and centroid connectors are used to load the trips from a transport zone onto the modelled transport network. Centroid connectors should represent, as closely as possible, zonal ingress and egress at reasonable access points to the network. Ideally, centroid connectors should not be connected to intersections: it is preferable to connect them to mid-block points in the modelled transport network.

### 3.2.2 Step 2 – Trip distribution

Trip distribution determines where the trip ends – developed in trip generation (Step 1) –, will go. These trip ends are linked to form an origin–destination pattern of trips through the process of trip distribution. The logic behind trip distribution is that a person is more likely to travel to a nearby transport zone with a high level of activity (such as employment, shopping or recreation) than to a more distant zone with a low level of activity. Similarly, freight is more likely to be transported to the closest port suited to its export.

The most commonly used procedure for trip distribution is the ‘gravity model’. The gravity model takes the trips produced at one particular zone and distributes them to other zones based on the size of the other zones (as measured by their activity or trip attractions) and on the basis of some impedance to travel between zones. Thus, the number of trips between zones is usually related to the degree of land use and activity within each zone and the ease of travel between them.

Impedance can be measured in several ways. The simplest way is to use either actual travel distance (km) or travel times (minutes) between zones as the measurement of ‘impedance’. Alternatively, by ascribing a value of time and a vehicle operating cost rate to travel time and travel distance respectively, together with any tolls paid, a ‘generalised cost of travel’ can be used as the ‘impedance’.

---

1 The ‘gravity model’ in transport modelling is analogous to Newton’s law of gravity, which states that the attractive force between two bodies is directly proportional to their mass and inversely proportional to the square of the distance between them.

2 A combination of time, distance, tolls and other out-of-pocket travel costs such as parking charges.
It is usual to have a separate gravity model developed for each trip purpose, since different trip purposes exhibit different trip distribution characteristics. The outcome of the trip distribution step is a matrix of trips from each transport zone to all other transport zones.

3.2.3 Step 3 – Mode choice

Mode choice allocates the origin-destination trips derived from trip distribution (Step 2) to the available travel modes, by trip purpose. This step estimates the choice between travel modes based on the characteristics of the trip maker (income, car ownership, age) or the decision-maker in the case of freight, the trip itself (trip purpose, the origin and destination) and the characteristics of the travel mode (fares, vehicle operating costs, travel time, parking availability and cost, reliability). The outcome of this step is an estimate of travel by all available travel modes between all transport zones, by the separate trip purposes.

The development of mode choice models usually relies on information such as the observed mode choice (from survey data or other sources), the characteristics of people undertaking the travel (age, employment status, currently studying and at what level, if they hold a licence) and the characteristics of the travel modes (availability, frequency, price, reliability).

Travel modes for people may include:
- Walking
- Bicycle
- Car
- Bus
- Tram
- Train.

Travel modes for freight may include:
- Light commercial vehicle
- Heavy commercial vehicle
- Large commercial vehicle.

Mode choice can be performed before trip distribution (trip-end mode choice model) or after trip distribution (trip-interchange mode choice model). Alternatively, trip distribution and mode choice may be performed simultaneously using a composite cost function (Otuzar & Willumsen 1994).

Trip-end mode choice models split the total demand for travel for each transport zone by the available travel modes. The mode choice in this case is based on the attributes of the trip origin (that is, ease of access to each mode and the ability or inclination to use a particular mode). The trip-interchange mode choice models split the origin-destination travel (including intra-zonal travel) between the available travel modes by responding to the specific service characteristics of the available travel modes. In this approach, the number of trips by travel mode is estimated on the basis of the relative utility (or disutility) of travel by different modes, as perceived by the trip maker.
The most commonly used form for mode choice is the ‘logit’ model, which is based on the assumption that an individual associates a level of utility (or disutility) with each travel mode in undertaking travel between transport zones. Figure 6 below shows a typical formulation of the logit model for mode choice. The horizontal offset accounts for measures of cost difference that are not included in the logit model.

Figure 6 A typical formulation of a logit model for mode choice

\[
P_2 = \frac{1}{1 + e^{N(C_2 - C_1 + \text{Offset})}}
\]

where:
- \( P_2 \) = Probability of choosing Mode 2
- \( C_1, C_2 \) = Generalised cost for Modes 1 and 2
- Offset = Horizontal offset

3.2.4 Step 4 – Trip assignment

Trip assignment assigns the various mode-specific trip matrices, by trip purpose, to the alternative routes or paths available across the transport network. Railed freight is typically assigned to the freight rail network; public transport trips are assigned to the public transport network (where path choice includes all public transport modes); and car trips and road-based freight are assigned to the highway network. This step provides an indication of the likely distribution of travel across the available transport network.

Trip assignment results can be used to:
- Identify and assess deficiencies in a transport network
- Assess the transport network performance
- Evaluate the impacts of transport infrastructure proposals
- Evaluate alternative transport system and land use policies
- Provide inputs to economic appraisal.

Section 3.2 *Network models* provides further details on trip assignment.
3.3 Discrete choice models

Discrete choice models have been employed widely in travel demand analysis since the 1970s, with the most common application being in the choice of travel mode. Modal split is the relative proportion of travellers or shippers using one particular mode compared with the other available modes. Most models of modal choice use a ‘utility’ function representation of the attributes of the different modes and of the travellers or shippers as a main set of independent (explanatory) variables. The utility function is usually a weighted sum of the modal and personal attributes considered (such as travel time and reliability, travel cost, service frequency and socio-economic characteristics). The simplest choice models consider only two alternatives (for example, Mode A and Mode B) and are known as binary choice models. In general terms, a binary model can be expressed as:

\[
\frac{p_A}{p_B} = F(U_A, U_B)
\]

where \(p_A\) and \(p_B\) are the probabilities of choosing modes A and B, \(U_A\) and \(U_B\) are the utility functions for modes A and B, and \(F(U_A, U_B)\) is some suitable function. The models are often expressed for one of the modes only, for example, as:

\[
p_A = f(U_A, U_B)
\]

and they can be extended to include more than two alternatives in the choice set. The discrete choice models are often termed ‘behavioural’ because they can represent causality in that they can be derived from a theory that explicitly maps out the decision-making processes of the individual taking the decision. The theoretical basis is usually that of utility maximisation. It assumes the utility an individual ascribes to an alternative is defined by a utility function in which the attributes of the alternative and characteristics of the individual are determining factors. The choice of a particular alternative is made on the basis of comparing the levels of utility derivable from each of the available alternatives.

Of necessity, the models estimate the probability that \(n_A\) individual, in a given situation, will choose a particular alternative rather than the definite selection of a preferred alternative. Assume that an individual can choose one alternative \(r\) from a set of \(K\) available alternatives and that the utility of alternative \(r\) is for that individual is given by \(U_{ri}\). Alternative \(r\) will then be chosen if:

\[
U_{ri} \geq U_{ki} \text{ for all } r \neq k \in K
\]
Given that there will almost always be some uncertainty concerning the specification of the utility function – because of measurement errors, omission of unobservable attributes and other specification errors – utility functions have a random component. Thus it is only possible to determine the probability that a given alternative will be chosen. We can represent the utility function $U_{ri}$ as:

$$U_{ri} = V_{ri} + \varepsilon_{ri}$$

where $V_{ri}$ is the deterministic part of the utility function and $\varepsilon_{ri}$ is the random part. Then the probability that an individual will select alternative $r$ can be written as:

$$p_{ri} = Pr\{U_{ri} \geq U_{ki}\} = Pr\{V_{ri} + \varepsilon_{ri} \geq V_{ki} + \varepsilon_{ki}\} = Pr\{V_{ri} - V_{ki} \geq \varepsilon_{ki} - \varepsilon_{ri}\} \text{ for all } k \in K \mid k \neq r$$

Specific mathematical forms of the choice model then emerge depending on the assumptions adopted about the form of the joint distribution of the random errors $\varepsilon_{ki} - \varepsilon_{ri}$. If this distribution is assumed to be the normal distribution, then the choice probability model is the probit model. Unfortunately, this model is mathematically intractable. As a result, the practice is to assume that the distribution follows Weibull distribution, which approximates the normal distribution to some degree. The advantage of this assumption is that the resultant choice model is the multinomial logit model, which is mathematically tractable. The function form of the multinomial logit model is:

$$p_{ri} = \frac{\exp(U_{ri})}{\sum_{k \in K} \exp(U_{ki})}$$

[EQ 3.1]

The binomial form of this model – using the earlier notation of alternatives A and B – is:

$$p_A = \frac{\exp(U_A)}{\exp(U_A) + \exp(U_B)} = \frac{1}{1 + \exp(U_B - U_A)}$$
This function is such that if $U_A$ and $U_B$ are equal, then the probability of choosing each of the two alternatives is 0.5, while if $U_A > U_B$, then the probability of choosing A is greater than choosing B. The utility functions are generally weighted linear functions of the attributes. For example:

$$U_{ri} = \alpha_r + \sum_{j=1}^{J} \beta_{rj} X_{rji} + \sum_{l=1}^{L} \gamma_l Y_{li}$$

[EQ 3.2]

Where $\alpha_r$ is an alternative-specific constant, the $\{\beta_{rj}, j = 1, \ldots, J\}$ are constant coefficients for the attributes (e.g. service variables) $\{X_j\}$ of the alternative and the $\{\gamma_l, l = 1, \ldots, L\}$ are constant coefficients for the attributes (e.g. socio-economic characteristics) of the individual decision-maker $i$.

The coefficients of the utility function may be used to provide further information. For example, if a utility function takes the form:

$$U = \alpha + \beta_1 \times price + \beta_2 \times time + \beta_3 \times reliability$$

[EQ 3.3]

then by dividing both sides of equation (7.3) by $B_1$, yields the money value of time ($B_2/B_1$) and the money value of reliability ($B_3/B_1$).

Coefficients in the utility functions are generally estimated from observed data sets using maximum likelihood techniques implemented in software packages such as LIMDEP.
While the multinomial logit model of equation (EQ 3.1) is a powerful tool for understanding travel choices, it has some significant limitations. The most important of these is its reliance on the ‘Axiom of the Independence of Irrelevant Alternatives (IIA)’ (Luce 1959) which states that “if a set of alternative choices exists, then the relative probability of choice among any two alternative is unaffected by the removal (or addition) of any set of other alternatives”. This means that the ratio \( p_A/p_B \) is independent of the other alternatives available in the choice set. This property is the basis of the multinomial logit model. Unfortunately, while the model is attractive and easy to use, it really applies only in rather special circumstances and its use in practice can lead to certain anomalies (for example, the ‘red bus-blue bus’ anomaly\(^3\)). The general solution is to use nested logit models that present a hierarchy of choices in which the decision-maker usually has to choose between no more than two alternatives at any point in the nested structure. Binomial logit models are generally used at each of the decision points. An example of a nested logit model for mode choice is displayed in Figure 7.

**Figure 7** Structure of a nested logit modal choice model

This model incorporates three broad modes of travel: car, public transport and no-motorised transport. The car mode is split into car driver and car passenger. Public transport is split into three separate elemental modes, depending on the mode of access taken to use the transit services (note that this model does not distinguish between rail or bus services). Non-motorised transport is split into bicycle and pedestrian modes. Douglas, Franzmann and Frost (2003) describe the development of similar discrete choice modes for modal choice in Brisbane.

---

\(^3\) Consider the case where travellers can choose between two modes – say car and bus – to make a given trip and further assume that the utility values for both of these modes are equal. Then there are probabilities of 0.5 for the use of both modes. Now assume the public transport operator paints half of the buses red and the other half blue. There are now three modes apparent: car, red bus and blue bus. All modes still have the same utility values, so the ratio between any pair of modes is unity and the overall modal split is (according to the multinomial logit model) one third car, one third blue bus and one third red bus. The proportion of travellers using cars has then decreased from 0.5 to 0.33, but nothing has actually changed except the colours of the buses. This is an illogical result and is due to the fact that the two bus modes are actually variations of the same choice alternative for the travellers – they are not truly independent alternatives.
The use of multinomial logit models in freight transport studies is illustrated in Wigan, Rockliffe, Thoresen and Tsolakis (1998). This study used the models to estimate the value of time spent in transit and reliability of arrival time for both long-haul and metropolitan freight.

More complicated, but more generally applicable, choice models are also available, such as the mixed logit models (see Louviere, Hensher & Swait 2000; Train, Revelt & Ruud 2004). While the standard logit model assumes the utility function coefficients are the same for the entire population (everyone has the same values of time and of other quality attributes), the mixed logit model allows the analyst to make the more realistic assumption that the coefficients vary across the population according to some distribution (such as uniform, normal, log normal). The mixed logit model relaxes the assumption of IIA and allows correlation in the unobserved components of utility between alternatives. The model is, however, much more data intensive and computationally exhaustive.

It must be noted the reliance on the ‘independence of irrelevant alternatives’ axiom does not invalidate the multinomial logit model. It is a perfectly acceptable model as long as care is taken to ensure its basic assumptions are not violated in a given application.

One advantage of the multinomial logit model is that it is possible to derive point elasticity values from it. Considering the choice model defined by equations EQ 3.1 and EQ 3.2, it can be shown that the elasticity of the probability of choosing mode A for an individual with respect to changes in $X_{rji}$ (the $j$th independent variable of alternative $r$) is given by:

$$
\eta_{rAji} = \left[ \delta_{Ar} - p_{ri} \right] \beta_j X_{rji}
$$

where $\delta_{Ar}$ is a delta function defined as:

$$
\delta_{Ar} = 0 \text{ if } A \neq r \text{ (cross elasticity)}
$$

$$
\delta_{Ar} = 1 \text{ if } A = r \text{ (direct elasticity)}
$$

This result indicates that the direct elasticity for alternative A depends only on the attributes of that alternative, while for the cross elasticities only, the attributes of the other alternative $r$ enter the equation.

Properly established discrete choice models are powerful decision-support tools for policy analysis and project evaluation. At a basic level, the models can be used to estimate changes in market shares across modes, or for alternative routes if a project is undertaken that will reduce the price or improve one or more of the service quality attributes for one mode or route. The models may also be used to help a transport operator determine the price to charge that will maximise profits. At a more complex level, the models can be used to estimate the welfare gains to customers from an improvement in a service quality attribute, which is important for inclusion in benefit-cost analysis.
For further information on the development, estimation and application of discrete choice models, the determination of elasticity values from discrete choice models and the application of the models in project evaluation, see: Ortuzar and Willumsen (2011); Taplin, Hensher and Smith (1999); Hensher and Button (2000); and Louviere, Hensher and Swait (2000).

3.4 Demand elasticities

Analysis using demand elasticities is based on the assumption of a direct relationship between the change in a policy-dependent variable and the corresponding change of a particular transport choice. The elasticity of demand, with respect to a given parameter (explanatory variable) may be seen as the percentage change in quantity demanded resulting from a 1 per cent change in the value of the parameter. Both the magnitude of the percentage change and the sense of that change (positive or negative) are important. Direct elasticity refers to the change of demand for one transport service (or mode) in terms of the change in a parameter affecting that service (or mode). Cross elasticity refers to the change of demand for a service or mode resulting from the change in a parameter affecting a different (competing) mode or service. Thus, for example, the change in patronage on a rail service as a result of the increase in the fare charged for that service could be estimated using the direct demand elasticity for rail with respect to fare. The increase to an alternative mode (such as bus) resulting from passengers switching modes could be estimated using the cross elasticity of demand for bus with respect to rail fare.

Similarly, the elasticity of demand with respect to income measures the proportionate change in demand resulting from a proportionate change in the income of the consumer. As consumers have more income, their choices may expand or change.

Elasticity models are used to estimate these effects. If the value of the parameter is \(P\) and the demand (such as number of trips, amount of freight) is \(Q\), then the elasticity \(\eta\) is given by:

\[
\eta = \frac{\Delta Q}{Q} \frac{P}{\Delta P/P} = \frac{P}{Q} \frac{\delta Q}{\delta P}
\]

[EQ 3.4]

---

4 More formally, the elasticity of demand with respect to a particular parameter is defined as the ratio of the proportionate change in demand to the proportionate change in the relevant parameter.
The partial derivative $\frac{\delta Q}{\delta P}$ is used to indicate that all the other explanatory variables (parameters) that can affect demand are assumed to be held constant. This derivative is the slope of the demand curve that relates to $Q$ and $P$. The slope of the curve may vary along its length so the value of $\eta$ as defined by equation EQ 3.4 is only valid for the particular point at which the slope is measured. It should strictly be called the ‘point’ elasticity.

Elasticity values can be derived for many parameters, such as fares, costs and charges, travel times, service reliability, service frequency or service quality (e.g. passenger comfort or possibility of damage to or loss of commodities). Provided the relative change in the value of each of these parameters is small, the overall change in demand can be estimated as a simple sum of the individual change estimates

$$\frac{\Delta Q}{Q} = \eta_A \frac{\Delta P_A}{P_A} + \eta_B \frac{\Delta P_B}{P_B} + \eta_C \frac{\Delta P_C}{P_C} + \cdots$$

[EQ 3.5]

for parameters $P_A, P_B, P_C$, etc. Models of this type have been used for many years by transport operators. They provide a quick estimation of the likely effects of proposed service changes, based on previous experience, as long as the service changes are incremental.

Point elasticity as defined by equation EQ 3.4 is rarely available for practical applications, because knowledge of the mathematical shape of the demand curve would be required to determine it – and this is seldom the case. Rather, most elasticity values used in practice are arc elasticities, estimated by considering measured differences in demand at different values of a given parameter. If the demand $Q_1$ corresponds to value $P_1$ and demand $Q_2$ corresponds to value $P_2$ of the parameter, then the arc elasticity $\eta$ is given by

$$\bar{\eta} = \frac{(Q_2 - Q_1)}{\sqrt{2} (Q_2 + Q_1)} \left/ \frac{(P_2 - P_1)}{\sqrt{2} (P_2 + P_1)} \right. = \frac{\Delta Q}{\Delta P} \frac{\bar{P}}{\bar{Q}}$$

[EQ 3.6]

where $P$ and $Q$ are the respective mean values.
The demand to use a particular mode or service can be affected by changes in travel parameters applying to competing modes as well as changes in the parameters of the given mode. The effect on demand for use of mode $H$ of changes in a parameter $P_G$ on mode $G$ is given by the cross elasticity:

$$
\eta_H^G = \frac{\Delta Q_H}{Q_H} \frac{\Delta P_G}{P_G}
$$

\[\text{EQ 3.7}\]

Elasticity values are generally estimated from time series data. For instance, transport operators may collect information on patronage or commodity movements over time and this can be used to suggest the effects on demand stemming from changes in transport costs or other service parameters (for both their own operations and those of their competitors).

Elasticity values for passenger transport by transport mode may be found in reported studies, such as Oum, Waters and Yong (1992) and Luk and Hepburn (1993). A substantial database of elasticity values has been compiled by the Bureau of Transport and Regional Economics and is available on the BTRE website (www.bitre.gov.au) under databases and products. Taplin, Hensher and Smith (1999) provided a discussion on the conceptual and theoretical requirements on the estimation of elasticity values.

Certain conventions need to be followed when interpreting published values of elasticities. In the case where $\eta$ denotes a demand elasticity with respect to parameters such as cost or trip time, the value of the elasticity is negative – an increase in the price of a service would normally be expected to lead to a decrease in the demand for it, but common practice among economists is to quote only the magnitude (modulus) of the value (as a positive number, with the implicit assumption that the value is actually a negative number). Cross elasticity values are generally positive – an increase in the charges for use of a competing service would be expected to result in an increased use of the other service.
3.5 Network models

Transport network models generally comprise a combination of interconnected links (sections of roads) and nodes (representation of intersections) and are termed ‘link-based’ network models. The transport network model, or ‘supply side’ component of a transport model is intended to reflect, as accurately as possible, the actual available transport network, by incorporating the following link attributes:

- Distance
- Free speed on the link or travel time
- Capacity, as related to the number of lanes or available train paths
- Direction indicator (one-way or two-way link)
- Speed-flow curve identifier or link speed for rail.

The transport network model should be sufficiently refined to support the adopted model zoning system and, as a guide, should cover the following road classifications:

- Freeways and tollways (coded as one-way links with associated ramps coded separately)
- Divided and undivided arterials
- Collector roads
- Local roads (the extent to which these are included is at the discretion of the modeller and the requirements of the particular study)
- Rail lines (freight and public transport)
- Ferry lines and services
- Bus-only corridors.

3.5.1 Highway trip assignment

One of the most commonly used assignment techniques is the capacity restrained assignment that involves the allocation of traffic to routes according to the ability (or capacity) of the route to accommodate traffic. It should be noted that the capacity of a route is not like the capacity of a bottle; rather, it is more like the capacity of a balloon. A bit more capacity can usually be squeezed in, but the balloon (or route) becomes more stressed and resistant to any further increase. In this context, capacity restrained assignments are recommended where networks are congested.
The application of a capacity restraint does not imply that once a certain level of traffic is reached, no more traffic can be assigned, as the theoretical capacity may be exceeded albeit with resultant lower travel speeds. All the traffic derived from the demand forecasting will be distributed to the road network in one way or another, and usually on the basis of speed-flow relationships.

It is common for trip assignment models to employ speed-flow relationships, which describe how the speed or travel time on a particular link will deteriorate as traffic builds up.\(^5\)

A number of specific techniques are available for undertaking a capacity restrained assignment (such as all-or-nothing, equilibrium, stochastic, volume-averaging, incremental). Detailed information on these techniques is provided in the available literature.

The capacity restrained assignment generally begins by estimating the shortest path from each origin to all destinations (expressed in terms of the minimum generalised cost composed of some combination of travel time, travel distance and tolls). Trips for each origin–destination pair are then assigned to the links comprising the minimum path. As traffic volumes build up on a particular link, the speed on that link declines and the travel time increases making the link less attractive to any further traffic, leading to alternative paths to the same destination becoming more attractive.

The outputs from the highway trip assignment are traffic volumes across the highway network, vehicle-kilometres and vehicle-hours of travel, trip length, peak hour and daily traffic volumes, congested speeds and travel times and volume-to-capacity ratios. The output from the trip assignment can be used in economic appraisal and congestion analyses.

**Treatment of tolls**

There is variation in the willingness of travellers to pay and, where there are choices between tolled and untolled routes, it is important for this to be represented. There also tend to be marked differences in the congestion or delay on the tolled and non-tolled roads, and differences in perception of time spent in queues can also influence route choice. A range of approaches has been applied to model demand for toll roads. Depending upon the needs of the study, one of these options would represent current best practice:

- Explicitly represent the choice between use of the tolled road and use of other routes through a logit model
- Segmentation of demand between different value of time categories explicitly to represent the distribution of value of time
- An assignment algorithm incorporating an explicit representation of the value of time distribution.

Further discussion of toll road patronage forecasting will be available by November 2015.

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\(^5\) Defined by the volume-to-capacity ratio.
3.5.2 Public transport assignment

Public transport assignment procedures predict the route choices for public transport trips on the basis of the different attributes of the public transport network. Some of the more critical attributes are:

- **Supply of public transport services** as defined by the capacity of the public transport vehicle and its corresponding frequency. The public transport network consists of the route segments (links) and public transport stops (nodes) that form the public transport routes (lines).
- **The estimated cost of using public transport services** is the average fare paid to take the trip.
- **The generalised impedance of travel by public transport** is a function of the in-vehicle time, the time spent waiting, the time spent getting to a public transport stop, the time spent transferring from one route to another, comfort and convenience, public perception of the quality and reliability of each mode and the fare paid.
- **Some of the main outputs from the public transport assignment** include public transport patronage and line or service loadings, boardings and alightings at stops, interchanging within and across modes, and network-wide indicators such as passenger-hours of travel and passenger-kilometres of travel. Other outputs often required include station entries and exits (subtly different from boarding and alighting).

3.5.3 Traffic simulation methods

The management of a road network often requires the forecasting of the impacts of implementing various traffic management measures. The impact involves the road itself, the whole corridor and its abutting areas. These measures include, for example, signal coordination, high-occupancy vehicle (HOV) lanes, one-way systems, different types of intersection control (priority sign, signal or roundabout), signal priority, driver information systems and incident management. Apart from road vehicles, trams, light rail vehicles, pedestrians and cyclists can also be simulated.

Simulation techniques for traffic assignment can be broadly classified into the following three types:

1. **Microscopic simulation** – the movement of a vehicle in a microscopic simulation is traced through a road network over time at a small time increment of a fraction of a second. A detailed simulation of vehicle-road interaction under the influence of a control measure is therefore possible. This technique is useful for a wide range of applications but requires more computational resources. Random number generators are involved and the calibration of these models requires more effort, and it is difficult to optimise model parameters (such as signal settings).

2. **Macroscopic simulation** – vehicles in a macroscopic simulation are no longer simulated individually. Vehicle movements are often simulated as packets or bunches in a network with a time step of one or several seconds. An analytical model such as the platoon dispersion model is used to govern the movement of a vehicle platoon along a road link. A macroscopic simulation is deterministic by nature and is useful for network design and optimisation.
3. **Hybrid simulation** – this technique combines a detailed microscopic simulation of some key components of a model (such as intersection operations) with analytical models (such as speedflow relationships for traffic assignment). This technique is sometimes known as mesoscopic simulation and provides more detail to what is normally an assignment-only model. It is also possible to interface a microsimulation model with a real-time signal control system such as SCATS – an area of active research and development at RTA NSW (Millar et al. 2003, 2004).

In recent years, Intelligent Transport System (ITS) measures such as adaptive signal control algorithms, incident management strategies, active bus/tram priority and driver information systems have been introduced to freeways and arterial roads. These are complex traffic processes and traffic flow theories are often unable to accurately predict the impacts in terms of delay, queue length, travel times, fuel consumption and pollutant emissions. Computer models equipped with advanced graphical facilities have been developed in recent years to meet the needs of road managers.

Computer software has long been available to simulate traffic management processes amongst road authorities in Australia (see for example Cotterill et al. 1984; Tudge 1988). Past research also includes the development of car-following and lane changing algorithms for microsimulation (Gipps 1981, 1986), the review of eight small area traffic management models (Luk et al. 1983) and the comparison of macroscopic and microscopic simulations (Luk & Stewart 1984; Ting et al. 2004).

More recent research includes the assessment and further development of car-following and lane-changing algorithms (Hidas 2004, 2005; Panwai & Dia 2004). A key finding is that microscopic simulation models require careful calibration to produce meaningful results, especially in relation to lane changing behaviour in congested conditions.
4. Data collection

4.1 Background

It is important that government funds are invested in areas that provide the greatest return. Capital investment in transport infrastructure projects must be underpinned by good information on travel demand patterns (how, why, when and where people travel) and this information can only be obtained from comprehensive and regularly updated surveys of travel activity and demand.

Comprehensive and reliable travel activity and demand information is vital for the development of transport models used to underpin the analysis, assessment and performance of the existing transport system and of proposed transport infrastructure. Up-to-date information is crucial in maintaining the relevance and credibility of transport models and associated analyses. Moreover, such travel information and analyses can be (and should be) used for infrastructure planning and project development appraisal and policy and strategy development.

The availability of reliable existing travel demand data, together with the costs involved in collecting new data, may dictate the specification and structure of the transport modelling system. Being able to establish a valid Reference (Base) Year demand is critical in undertaking the modelling of any major transport infrastructure proposal. Attempts should always be made to make best use of available demand data. The appropriateness of available data (for example, its currency, coverage, robustness and reliability) should be ascertained early in any model development and application undertaking.

4.2 Travel demand surveys

The collection of travel demand data usually requires large-scale travel surveys using either a mail out/mail back self-completion survey or a household personal interview survey.

The mail out/mail back self-completion survey questionnaire is mailed to a household and mailed back to the survey firm or agency after all questions are answered by all members of the surveyed household. Postage costs are usually borne by the survey firm or agency. The Victorian Integrated Survey of Travel and Activity (VISTA) is an example of a mail out/mail back survey.

The household personal interview survey involves face-to-face personal interviews and records all responses by all members of the surveyed household. Personal interview surveys have, to date, provided the major form of data collection for developing and updating transport models. Household personal interview surveys generally have high response rates (in the order of 70–80%) and can be undertaken over a much shorter time period than mail out/mail back surveys.

Other forms of travel demand survey may involve a combination of the mail out/mail back and face-to-face interview surveys, as well as computer aided telephone interview (CATI) surveys.
One critical issue to be addressed in designing a travel demand survey is the survey sample size. Generally, the more detailed the travel demand model, the larger the survey sample size required to obtain statistically reliable estimates of the model parameters. Funding limitations will, to some extent, limit the survey sample size and will dictate the level of detail in the travel demand model. One way of dealing with this issue is to conduct relatively small annual travel demand surveys that accumulate to increasing sample sizes over the ensuing years, making it possible to develop a travel demand model that becomes more detailed over time.

4.3 Person travel demand data

The travel demand data collected by the above-mentioned survey approaches represent a snapshot of travel patterns on a particular day and may include the following:

- **Household information:**
  - dwelling type
  - ownership status of dwelling
  - household size
  - number of registered motor vehicles by type
  - number of bicycles

- **Data about people in the household**
  - age
  - sex
  - relationship to head of household
  - employment status
  - resident or visitor
  - licence holding
  - occupation
  - industry of employment
  - personal income
  - if currently studying – primary, secondary, tertiary
  - undertaking other activities

- **Travel data for all travel made on the travel day, on a ‘stop’ basis**
- **Travel origin**
- **Time of travel, including departure time and arrival time**
- **Purpose for the travel**
- **Location of destination**
- **Mode of transport used**
• If the travel was made by vehicle
  – vehicle used
  – number of occupants
  – roads used
  – any toll paid and by who
  – parking location, any parking fee paid and by who
• If travel was made by public transport
  – type of ticket
  – type of zone ticket
  – type of fare paid
  – reason for not travelling on the travel day.

4.4 Other data sources

Other data sources may include:

• Up-to-date traffic counts by hour and by direction aim to cover, as is practically possible, the main highway sections included in the model. Consideration should be given to establishing a regime of screenline traffic counts to provide information for model validation.

• Electronic ticket machine data is an alternative source of public transport patronage data and may eliminate possible bias in survey design and conduct. Some disadvantages of this data are:
  – the absence of information on travel purpose
  – the difficulty in reliably identifying trips involving interchanging
  – the potential difficulty in allocating origin and destination of travel to specific stops and transport zones.

• On-board surveys or surveys at stations can provide data and information on boardings and alightings, loadings, and origins and destinations. These surveys may be used to augment household interview surveys or to provide detailed public transport patronage and demand data for specific areas of interest.
4.5 Survey methodology and data requirements

Models and analytical procedures need data. The data needs to be relevant, current and accurate if useful results are to be gained from modelling and analysis.

Data collection is expensive, time consuming and not always straightforward, so care is needed in the planning, design and conduct of surveys. Without this attention, resources – time, people and money – can easily be wasted for little gain. High quality and relevant data are essential for analysis and serve to support policy formulation and decision-making. Poor quality or inappropriate data are to the detriment of informed decision-making.

One useful way to approach data collection is to view the survey process from the systems perspective. Figure 8 below provides one such process model. This figure represents a transport survey data collection as a process, starting with the specification of objectives of the survey and running through to the archiving of results. Note the existence within Figure 8 of various feedback loops indicating that survey design is not a purely sequential process; for example, analysts must be prepared to modify their survey instruments and sample frames in the light of the outcome of the pilot survey.

Source: Taylor, Bonsall and Young 2002, p.138
This process model identifies a number of steps and stages in the collection and analysis of data. These steps may be grouped into three broad stages:

1. **Preliminary planning**, in which the purpose and specific objectives of the survey are identified, specifications of the requirements for new data are determined (in light of existing data sources) and resources available or required for the survey are identified.

2. **Survey planning and design**, in which the appropriate survey instrument is selected and the sample design (including target population, sampling frame, sampling method and sample size) is undertaken, leading to a survey plan and the conduct of a pilot survey to test all aspects of the plan and to ensure that it works and provides the required data, and that they are compatible with the proposed analysis. This is an iterative stage, in which pilot survey outcomes may lead to revisions in the survey plan. Good and successful surveys necessarily pay significant attention to getting this stage right.

3. **Survey conduct**, in which the full survey is undertaken, data extracted and analysed, study reports prepared and databases archived for future reference.

This process is fully explained in Taylor, Bonsall and Young (2000, pp.137–145).

### 4.6 Survey techniques

Surveys are used to obtain data, which are then used to estimate model parameters for predicting the behaviour of transport users in order to make demand forecasts and to estimate the economic and financial values of projects. Most transport data surveys are sample surveys, in that only a small fraction of the overall population (for example, travellers, vehicles, network links or customers) is surveyed to provide data that are then extrapolated to provide a description of the total population. Data are collected at a few locations taken to represent transport activity, travel movement and traffic flow across the study area or a sample of individual travellers, customers or operators is surveyed because it is infeasible, impractical or uneconomic to survey the entire population. This means that survey data often need expansion from the sample to represent the full population. As discussed in the following sections, care in survey organisation and attention to detail are needed to ensure that survey data can properly represent their parent population.

There are two broad approaches to data collection:

1. **Observational (passive) surveys** – where surveyors (human or mechanical) record the occurrence (and often time of occurrence) of specified transport events or phenomena, such as the passage of vehicles past a point on the road, the arrival of trucks at a warehouse, or the number of passengers exiting from a railway platform in a specified time interval.

2. **Interview (active) surveys** – where the surveyors make contact with the individual travellers, customers or decision makers to seek information directly from them, such as the freight movement surveys undertaken by the Australian Bureau of Statistics (ABS) in the mid-1990s (Maitland & Higgins 1999).

The information gathered in active surveys can be much richer than information available from passive surveys because:
• Observations are limited in scope to the direct area under study. For instance, the arrival of a vehicle at a cordon line indicates the point at which the vehicle entered or left the study area, but provides little information on the actual origin or the ultimate destination of the trip, nor the frequency with which the vehicle makes that trip or the purpose for which it is made. An active interview or questionnaire survey could obtain this additional information.

• Observational surveys are limited to study of actual behaviour at the study site. They provide information on ‘revealed demand’ – the actual behaviour that is occurring under the environmental conditions pertaining to the study area at the time of the survey. Revealed demand is the observed use of an area or facility. Environmental states, such as traffic congestion or lack of parking and seasonal conditions (including time of day), may restrict the ability of some individuals to access the specific site or facility or to choose to use an alternative (for example, another destination). This phenomenon is known as ‘latent demand’ and its extent cannot be gauged using observational surveys. An active survey method could seek to determine the existence and extent of latent demand, especially if the survey is designed and applied to include ‘non-users’ of facility or service as well as the users.6

The passive surveys aim to make no interference with the normal operation of the survey site and to not disturb the behaviour of the individuals under observation. The active surveys cannot avoid some interference and may even create disturbances that could affect the behaviour of the respondents. Great care is needed in the survey design for both observational and active surveys to ensure any interference is minimised and that significant bias is not introduced into the survey results because of how the data were collected.

Active (‘interview’) surveys may be conducted in three alternative ways: direct personal interviews, questionnaire surveys and remote interviews (generally conducted by telephone, but also possible over the internet).

4.6.1 Direct personal interviews

Personal interviews may be conducted in a variety of locations. Interviews in people’s homes have been widely used for collecting detailed data on the travel behaviour of households and individual. Most metropolitan areas and other large cities have databases of personal travel conducted using ‘household interviews’. Household interview surveys were conducted in Adelaide in 1999 and Perth in 2002-03, among other cities, while Sydney has a rolling cycle of home interview surveys running continuously.

6 For example, on-board surveys conducted on bus, train or tram are often used to collect data on public transport users, but could not indicate much about those travellers who are potential users of public transport, but are currently using some other mode. This one reason for the use of home interviews in general travel surveys. Likewise, shippers of freight may be better surveyed at their company locations.
Freight and commercial vehicle surveys are also conducted using interviews at company offices (see for example Raimond, Peachman & Akers 1999) where they may involve staff and customers. Interviews may also be conducted outside the home or business, such as at shopping centres or recreation facilities, at railway stations and airport terminals, on board (public transport) vehicles, or by the roadside (many truck surveys have been conducted using the latter).

Direct interviews can be used to collect detailed data about businesses, households and individuals and their travel behaviour and freight systems usage, and about other traits such as attitudes and perceptions. In some cases, direct interviews may be conducted in a laboratory setting as well as ‘in the field’. Stated preference studies are often undertaken in a laboratory where specialised resources can be used (for example, to create a simulated environment for the respondent to be immersed in the situational context behind the survey). Hensher, Brotchie and Gunn (1989) described a methodology for surveying rail passengers using active survey techniques. Hensher and Golob (1998) described an interview survey of shoppers and freight forwarders conducted in Sydney in 1996.

One problem with the direct interview is that it can take a considerable period of time to complete, which may cause significant inconvenience to the (volunteer) interviewee. A second problem is that the interviewer must make direct contact with the survey respondent. This may involve considerable time spent travelling by the interviewer to visit the respondents and the need for multiple ‘call backs’ if the respondent is not ‘at home’.

4.6.2 Questionnaire surveys

One solution to overcome the time constraints associated with direct interviews is to use questionnaire surveys, often to be returned through the post (‘mail back’) at some future time. Examples of these surveys are roadside or i-vehicle surveys. These can be attempted by direct interview, but individual travellers may be delayed and inconvenienced in the process, or may reach their destination before the conclusion of the interview. It may be more reasonable and effective to distribute a written questionnaire to the travellers, asking them to complete and return the survey once the journey is finished.

The questionnaire can contain questions similar to those posed in an interview, but there are many limitations. For example, the questions must be clear and unambiguous as it stands, as there is no opportunity for an interviewer to offer an explanation. Fewer questions can be asked, as excessively long questionnaires reduce the number of completed responses. There is also the possibility for the respondent to offer false or misleading answers that an interviewer would recognise as such, but that are much harder to detect on a written form. However, the major problem with questionnaire surveys of this type is the likelihood of a low response rate. While response rates of the order of 10–20% may be acceptable in some areas (such as general market research on consumer goods), there is a considerable body of transport research that suggests that much higher rates of response – 80% or better – may be necessary to properly gauge true levels of travel activity in a population. Richardson, Ampt and Meyburg (1995) provide a full discussion of this issue, as well as detailed advice on the conduct of interview and questionnaire surveys.
4.6.3 Telephone and internet surveys

The third alternative is the use of telephone (or internet-based) surveys. These are similar to the direct interview except the interview is conducted remotely over a telecommunications network, with telephone interviews usually using random dial-up access. The advantages of this survey technique are cost and convenience. The interviewer stays in the one place (a call centre) and can make contact with a large number of respondents in a short time. Data entry can also be automated, as responses are directly entered into a computer database during the interview.

The disadvantages of the technique include the relatively short length of the interview that is normally possible over the telephone and perhaps a growing ‘consumer resistance’ to the telephone interview, given the method is widely used in general social and market research surveys and in direct marketing. Richardson, Ampt and Meyburg (1995), among many other transport survey researchers, maintain that good quality data on travel behaviour (at least of quality commensurate with that obtainable from face-to-face interviews and questionnaires) cannot be collected using telephone interviews.

Internet-based surveys are more like observational surveys in that respondents to the surveys generally find the survey website of their own volition, rather than through active encouragement by surveyors. This technique is being used, for instance, in studies on driver route choice, where detailed information is required that is quite difficult to obtain through more conventional survey approaches (see Abdel-Aty 2003). However, bias in sampling is quite likely to be an issue in these surveys and the field is as yet relatively unexplored.

4.6.4 Costs

Direct interview surveys are generally the most expensive, followed by questionnaire surveys (especially with regard to the number of valid completed questionnaires returned) and then telephone surveys. Observational surveys can be relatively inexpensive, at least in terms of elemental costs such as hourly wage rates or where automatic data loggers can be employed (as for automatic vehicle counts). However, large-scale observational surveys (such as vehicle number plate surveys that require a large number of observed vehicles) can prove very expensive and are sometimes not particularly efficient in terms of the collection of usable, quality data.

4.6.5 Revealed versus stated preferences

A further distinction in interview surveys should be drawn between the collection of revealed preference data (what people are seen to do or record that they have done) and stated preference data (what people say they would do in different circumstances, such as when faced with changes in transport fares, services or costs).
Generally, the household travel surveys concentrate on revealed preference data. They record historical data on travel behaviour, which then form a snapshot of travel activity in an area at one particular point in time. These data provide little information on how people might change their behaviour in response to new transport policies or to changing travel environments or to the availability of new modes or services. Stated preference data may be used for these purposes and stated preference experimental methods provide powerful tools in this regard. At the same time, there are considerable problems in ensuring that stated preference information is valid and reliable. Louviere, Hensher and Swait (2000) provide a full coverage of this survey methodology and its use. It should be noted that stated preference methods are a rich source of information for the development of discrete choice models of travel behaviour.


4.7 Sample size estimation

As indicated in Section 4.17, most transport data surveys are sample surveys. Sampling is usually necessary because it is too expensive to survey all members of the population (for example, to obtain travel diaries from all inhabitants of a metropolitan area) or it is physically impossible to do so (such as testing the roadworthiness of all vehicles) or because the survey testing process would be destructive (such as determining the strength of railway sleepers).

Almost all transport surveys involve observing some members of a target population to infer something about the characteristics of that population. In this sense they are statistical sampling surveys. As the effectiveness of the survey is dependent upon choosing an appropriate sample, sample design is a fundamental part of the overall survey process.

Sample design includes the following elements:

- Definition of target population
- Definition of sampling unit
- Selection of sampling frame
- Choice of sample method
- Consideration of likely sampling errors and biases
- Determination of sample size.

Two main methods exist for selecting samples from a target population: judgement sampling and random sampling. In random sampling, all members of the target population have a chance of being selected in the sample, whereas judgement sampling uses personal knowledge, expertise and opinion to identify sample members.

Judgement samples have a certain convenience. They may have a particular role, such as ‘case studies’ of particular phenomena or behaviours. The difficulty is that because judgement samples have no statistical meaning, they cannot represent the target population. Statistical techniques cannot be applied to these samples to produce useful results as they are almost certainly biased.
There is a particular role for judgment sampling in exploratory or pilot surveys where the intention is to examine the possible extremes of outcomes with minimal resources. However, to go beyond such an exploration, the investigator cannot attempt to select 'typical' members or exclude 'atypical' members of a population, or to seek sampling by convenience or desire (choosing sample members on the basis of ease or pleasure of observation). Rather, a random sampling scheme should be adopted, to ensure the sample taken is statistically representative.

Random samples may be taken by one of four basic methods (Cochran 1977): simple random sampling, systematic sampling, stratified random sampling and cluster sampling. Taylor, Bonsall and Young (2000 pp. 155–58) describe each of these sampling methods and their applications, as do Richardson, Ampt and Meyburg (1995).

Simple random sampling allows each possible sample to have an equal probability of being chosen, and each unit in the target population has an equal probability of being included in any one sample. Sampling may be either 'with replacement' (any member may be selected more than once in any sample draw) or 'without replacement' (after selection in one sample, that unit is removed from the sampling frame for the remainder of the draw for that sample). Selection of the sample is by way of ‘raffle’. A number is assigned to each unit in the sampling frame and repeated random draws are made until a sample of desired size is obtained. For most applications, the use of a table of random digits is the most convenient means of drawing a random sample. Most statistical textbooks contain such tables. The methods of statistical inferences applied to sample data analysis are predicated on the basis that a sample is chosen by simple random sampling. Data collected using other sampling methods need to be analysed using known techniques that include corrections to approximate simple random samples.

There is always a possibility that a sample may not adequately reflect the nature of the parent population. Random fluctuations ('errors'), which are inherent in the sampling process, are not serious because they can be quantified and allow for using statistical methods. However, if due to poor experimental design or survey execution there is a systematic pattern to the errors, this will introduce bias into the data and, unless it can be detected, it will distort the analysis. A principal objective of statistical theory is to infer valid conclusions about a population from unbiased sample data, bearing in mind the inherent variability introduced by sampling. Bias and sampling errors are two, quite different, sources of error in experimental observations. As described in Richardson, Ampt and Meyburg (1995, pp. 96–101), bias (or systematic error) needs to be removed from sample data before statistical analysis can be attempted, for statistical theory treats all errors as sampling errors.

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7 Noting that minimisation of experimental errors is of course important in improving the precision of parameter estimates based on survey data.
A distribution of all the possible means of samples drawn from a target population is known as a sampling distribution. It can be partially described by its mean and standard deviation. The standard deviation of the sampling distribution is known as the standard error. It takes account of the anticipated amount of random variation inherent in the sampling process and can therefore be used to determine the precision of a given estimate of a population parameter from the sample.

Surveys for specific investigations usually attempt to provide data for the estimation of particular population parameters or to test statistical hypotheses about a population. In either case, the size of the sample selected will be an important element and the reliability of the estimate will increase as sample size increases. However, the cost of gathering the data will also increase with increased sample size – an important consideration in sample design. A trade-off may have to occur and the additional returns from an increase in sample size will need to be evaluated against the additional costs incurred. If the target population may be taken as infinite, then the standard error ($s_x$) of variable $X$ is given by

$$S_X = \frac{s}{\sqrt{n}}$$

[EQ 4.1]

where $s$ is the estimated standard deviation of the population and $n$ is the sample size, assuming that the sampling distribution is normal. Even when the sampling distribution is not normal, this method may still apply because of the Central Limits Theorem which states that the mean of $n$ random variables form the same distribution will, in the limit as $n$ approaches infinity, have a normal distribution even if the parent distribution is not normal. The standard deviation of the mean is inversely proportional to $\sqrt{n}$. The implication of equation 4.1 is that as sample size increases, standard error decreases in proportion to the square root of $n$. Here is an important result. The extra precision of a larger sample should be traded off against the cost of collecting that amount of data. To double the precision of an estimate will require the collection of four times as much data.

Similar results are found for other statistical parameters. For instance, the standard error ($s_p$) of a proportion $p$ (e.g. a measure such as ‘the proportion of households owning one vehicle’) is given by:

$$S_P = \sqrt{\frac{p(1-p)}{n}}$$

[EQ 4.2]

The practical application of these results requires some prior knowledge of the population, such as a prior estimate of the sample standard deviation ($s$) in the case of the mean value of variable $X$ or an initial estimate of the proportion $p$. The results of previous surveys, or the pilot survey, may be used to provide this knowledge.
5. Model development

5.1 Estimation techniques

Frequently, analysts may wish to develop relationships between the factors contained in their data. These relationships are statistical models and provide a useful, but simplified, view of the process being studied. This simplicity is limited by the need to provide a reasonable representation of the process. Statistical models use sample data to develop a mathematical relationship between factors, often of the form:

\[ Y_i = b_0 + b_1X_{i1} + b_2X_{i2} + \cdots + b_mX_{im} + \varepsilon_i \]  

[EQ 5.1]

where the \( Y \) and \( X_j \) terms represent the variables considered in the model, the subscript \( i \) represents the \( i^{th} \) observation, the \( b_0, b_1, \ldots b_m \) terms represent the model parameters, and the \( \varepsilon_i \) is an error term. The variables can also be divided into dependent and independent variables. Dependent variables (\( Y_0 \) are the variables to be explained by the model). The right-hand side of equation (8.1), less the error term, is the expected value \( E(Y_i) \) given a set of observed values \( X_{ij}, j = 1 \ldots m \). The independent (explanatory) variables \( (X_j) \) are the variable providing the explanation.

Regression is a general statistical tool through which the analyst can develop a relationship between dependent and independent variables. It can be used to develop descriptive relationships or investigate causal relationships. The first step in developing a relationship is the definition of what constitutes a good fit. The answer is usually a fit that leaves a small total error. One error type is shown in Figure 9. It is defined as the vertical distance from the observed data point \( Y_i \) to the corresponding fitted data point \( E(Y_i) \). Mathematically, this is the difference \( (Y_i - E(Y_i)) \). This error is positive when the data points are above the line and negative when it is below the line. Several methods for minimising this error can be suggested. These include minimising the error term itself, minimising the absolute value of the error term \( |(Y_i - E(Y_i))| \), and minimising the square of the error term \( (Y_i - E(Y_i))^2 \). The last approach is the most commonly used technique, and leads to what is known as ‘least squares’ parameter estimation.
The least squares method is based on the following mathematical analysis. To fit a linear relationship

\[ E(Y_i) = a + bX_i \]  \hspace{1cm} \text{[EQ 5.2]}

to a data set \( \{X_i, Y_i, = 1, \ldots, n\} \), form the ‘Residual Sum of Squares’ (RSS) given by

\[ \text{RSS} = \sum_{i=1}^{n} (Y_i - a - bX_i)^2 \]  \hspace{1cm} \text{[EQ 5.3]}

and then select the values of the parameters \( a \) and \( b \) that minimise the value of RSS. It can be shown that these best values of \( a \) and \( b \) are

\[ b = \frac{\sum_{i=1}^{n} X_i Y_i - n \bar{Y} \bar{X}}{\sum_{i=1}^{n} X_i^2 - N \bar{X}^2} \quad \text{and} \quad a = \bar{Y} - b \bar{X} \]
The degree of fit of the estimated relationship can be tested statistically. One common measure of the goodness of fit is the correlation coefficient (\(r\)) or, more commonly, the coefficient of determination (\(r^2\)). The coefficient of determination for the simple regression relation (equation EQ 5.2) is given by

\[
r^2 = \frac{\left( \sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y}) \right)^2}{\sum_{i=1}^{n} (X_i - \bar{X})^2 \sum_{i=1}^{n} (Y_i - \bar{Y})^2}
\]

and this coefficient is the proportion of the overall variance in the independent data \(\{y_i\}\) explained by the regression relationship \((0 \leq r^2 \leq 1)\).

This method extends immediately to multivariate relationships of the form of equation EQ 5.1, through the application of multiple linear regression. While multiple regression is a straightforward, powerful and widely-used model estimation technique, care is needed in the development of any multiple regression model intended for practical applications, and generally the advice of a statistician will be helpful. For example, the choice of the set of independent variables \(\{X_{ij}, j = 1, \ldots, m\}\) needs to be considered carefully. There are three broad issues concerning the independent variables that may affect the structure and development, and hence usefulness, of a multiple regression model:

- Multicollinearity
- Heteroskedasticity
- Autocorrelation.

**Multicollinearity** occurs when (as is often the case) some of the ‘independent’ variables are highly correlated with each other – the statistical theory on which multiple regression is based assumes them to be independent of each other. Care is needed in selecting a subset of the independent variables for inclusion in the multiple regression relationship. The usual approach is to enter or delete independent variables one-by-one in some pre-established manner. Some of the approaches used are forward inclusion, backward elimination and stepwise solution. With *forward inclusion*, independent variables are entered one-by-one only if they meet certain statistical criteria. The order of inclusion is determined by the respect contribution of each variable to the explained variance. In *backward elimination*, variables eliminated one-by-one form a regression equation that initially contains all variables. With a *stepwise solution*, forward inclusion is combined with the deletion of variables that no longer meet the pre-established criteria at each successive step.
**Heteroskedasticity** is also a common phenomenon. It relates to the variation of the absolute errors in measurement of an independent variable with the actual magnitude of that variable. Statistical theory for regression analysis assumes that the variance of the error term is the same for all values of the independent variable. This is called **homoskedasticity**. There are many instances where this may not be the case. For instance, in considering the masses of consignment loads to be transported, an error in measurement of 1 kg would be insignificant for an item of machinery of mass (say) 400 kg, but would be very significant for a parcel of mass 5 kg. For standard regression analysis, the consequences of heteroskedasticity in an independent variable are to underestimate the standard error of the estimated (dependent) variable \( Y \) and to falsely raise the apparent significance of independent variables \( X_j \). It does not affect the estimated values of the model coefficients, but does reduce the efficiency of the model as an estimating tool. One solution is to use weighted least squares analysis, in which each observation of an independent variable is adjusted for the expected size of its error term. Another possibility is to transform an independent variable (for example, by using its logarithm, \( \log(X) \)). This approach is useful for variables where there is a great range of sizes in the observations (such as the distribution of household incomes in a region).

**Autocorrelation** occurs when successive observations of a given variable are highly correlated. This phenomenon frequently arises in data observations taken over time. Here again, the problem for multiple regression analysis is the underlying assumption that observed values of the independent variables are independent of each other. In fact, autocorrelation is most important in its own right and there is a special field of statistical analysis devoted to ‘time series’ analysis. Autocorrelation reflects cyclical behaviour in a variable over time, such as seasonal variations in agricultural production, travel demand or road crashes in a region. Knowledge of these cycles is important in understanding the patterns of demand for transport services, among other things.

There are a number of statistical tests and procedures to identify and cope with these potential problems in regression modelling.

As suggested by equation EQ 5.1, multiple regression analysis is based on the assumption that there is a linear relationship between the dependent and the independent variables. When the relationships are non-linear, it may still be possible to use standard multiple regression – by transforming the relevant variables. For example, if there is a multiplicative relationship

\[
Y = kX_1X_2
\]  

[EQ 5.4]

this can be transformed into a linear relationship by taking logarithms of both sides of the equation EQ 5.4, therefore

\[
\log(Y) = \log(K) + \log(X_1) + \log(X_2)
\]

which is then a linear model.
Likewise, if there is a quadratic relationship between a dependent and independent variable such as

\[ Y = a + b_1X_1 + b_2X_2^2 \]

then the variable \( Z = X_2^2 \) may be used instead, as \( Y = a + b_1X_1 + b_2Z \) is a linear relation that can be treated using the standard regression approach.

It may be noted that when logarithms are taken of both the dependent and independent variables (such as as for equation EQ 8.4) then the regression coefficient for the independent variable is an elasticity estimate (Section 3.1).

Chapter 17 of Taylor, Bonsall and Young (2000, pp. 392–410) provides a more detailed discussion of regression modelling techniques. See also Fahrmeir and Tutz (1994).

Multiple linear regression is a technique often used for estimating model parameters. However, it requires that assumptions are made about the distribution of errors – strictly that the independent variables all follow normal (Gaussian) distributions. An alternative technique for estimating the parameters of a model that does not have this limitation is maximum likelihood estimation. It is a standard statistical technique employed for estimating the parameters of statistical distributions. The method requires the analyst to develop a likelihood function which represents the combined probability a given data set comes from a particular distribution with specified parameter values. A simple illustration should convey the idea. Consider a random variable \( X \) with probability density function \( f(X | \theta) \) where \( \theta \) is a parameter defining the distribution. A data set of observations \( (X_i, i = 1, \ldots, n) \) has been collected. Then the likelihood function for this data set with parameter \( \theta \) is the product of the probabilities of observing the set of data observations, which is

\[
L(\theta) = f(x_1 | \theta)f(x_2 | \theta) \ldots f(x_n | \theta) = \prod_{i=1}^{n} f(x_i | \theta)
\]

[EQ 5.5]

The parameter \( \theta \) may then be estimated by finding the value of the parameter that maximizes the value of \( L(\theta) \). This is usually done by taking the logarithms of both sides of equation EQ 5.5, which yields the equation

\[
l(\theta) = \log(L(\theta)) = \sum_{i=1}^{n} \log(f(x_i | \theta))
\]

[EQ 5.6]
which is a linear sum of terms that can be optimised using standard methods. The maximum likelihood technique can be used, for instance, to determine the parameters of statistical distributions (e.g. normal distribution of Poisson distribution) fitted to data sets or, as shown in Taylor, Bonsall and Young (2000, pp. 414–415) as an alternative method to determine the coefficients in a multiple linear regression relationship. The technique forms the basis of the parameter estimation procedures used to determine the coefficients in logit models of discrete choice processes. (e.g. see Louviere, Hensher & Swait 2000).

A further method for model parameter estimation is ‘entropy maximisation’ or the use of the mathematical theory of information (Shannon 1948; Van Zuylen & Willumsen 1980). This method is used, for instance, in the estimation of origin-destination matrices from observed link counts – see Taylor, Bonsall and Young (2000, pp. 116–20).

### 5.2 Network checking

Given the complexity and coverage of the real-world transport network system being modelled, it is reasonable to expect that any given transport network model may contain coding errors. In this context, it is advisable to spend as much time as possible checking the transport network model prior to the model calibration stage. Some techniques that can be used to check the coding of transport network models are:

- Visual checking of the network in the study area against aerial and ‘streetview’, photography (GoogleMaps or equivalent)
- Checking connection points of centroid connectors by visual inspection or assigning the demand to the network and confirming that all demand has been assigned (expecting intrazonal trips)
- Building paths to or from selected zones (on the basis of minimum distance, time or generalised cost) – this is one of the best ways of checking the network coding; the path building process will ensure the paths built by the model are logical and any errors in the coding are identified and corrected, eliminating any illogical paths during the assignment stage
- Confirming the capacity coded for links is at least as high as any observed traffic volumes recorded for that link
- Comparing actual travel times along key links with those from the network model
- Comparing link distances from the model with actual distances
- Checking the frequency and stopping patterns of public transport routes
- Checking the operational conditions of rail links.
5.3 Calibration and validation

Calibration involves estimating the parameters of the equations of the various components of the transport modelling system (trip generation, distribution, mode choice) so the modelled travel patterns, traffic volumes and patronage estimates replicate observed survey data. Calibration of transport models is predicated partly on the availability of large-scale origin–destination (O–D) survey data, which – due to the high costs involved – is becoming scarce. Household travel surveys (see Section 4.1.7) and census journey-to-work data can provide more detailed information for model calibration.

One function of the validation process is to quantify how accurately a transport model reproduces a set of Reference (Base) Year conditions (such as traffic volumes or patronage estimates). It is used to test whether the transport model is ‘fit-for-purpose’. The validation process may test the sensitivity of the model to changes in parameters and demand. There needs to be assurance that the model will be accurate for base and future years.

The validation process should use data separate to that used in the model calibration. Calibration data is critical to ensuring the accuracy of the parameters and equations used in the transport modelling system, while validation data is critical to testing the overall validity of the modelled forecasts against a set of criteria. The main criteria to be used in assessing the ability of a transport model to reproduce a set of Reference (Base) Year conditions are presented in Appendix B.

In general, transport model validation should cover the following:

- Description of the data used in calibrating and validating the model
- Reporting on the ‘fit’ achieved to the calibration data
- Reporting on the validation outcomes for a Reference (Base) Year.

5.4 Vehicle operating costs and the value of time

Austroads produces estimates of various road use unit costs (such as value of time, crash costs and vehicle operating costs) for Australia. These are suitable for using in appraisal and as input parameter values of time and vehicle operating costs in the transport modelling process. Part 1 of this volume provides a detailed coverage of parameter values for public transport appraisal.

5.5 Generalised cost weightings

When calculating the generalised cost of public transport travel, it is usual practice to weight the different components of public transport travel to reflect the passengers' utility (or perception of utility) for each component. Part 1 of this volume provides a detailed discussion of these weights.
5.6 Matrix estimation

Matrix estimation should be used to update existing travel demands using the most recent highway and public transport count data and should not be used to forecast travel demands. Matrix estimation is not a substitute for well-specified and well-developed travel demands derived from the full demand modelling process.

The reliability of matrix estimation is largely dependent on the quality and currency of the input data and the degree of confidence ascribed to the data. It is critical that, in any updating of travel demands by matrix estimation, the integrity of the travel patterns and trip length distribution is maintained. It is possible the matrix estimation process may yield a very good match against the observed traffic counts, but the resulting origin–destination patterns may bear little resemblance to actual trip patterns.

5.7 Transport network validation

In general terms, transport network validation will usually include:

- Comparing modelled travel times with observed travel times
- Comparing modelled screenline volumes with observed screenline volumes
- Comparing modelled service patronage volumes with observed service patronage volumes
- Checking that paths through the network are realistic
- Comparing distances between specified O–D pairs derived from the model with actual distances
- Comparing modelled public transport travel times with timetables
- Checking public transport routes in terms of stopping patterns, timetables and frequency.

5.8 Assignment validation

Appendix B provides criteria for the validation of network models. Some general principles for validation are:

- Validation should be against independent data (such as traffic counts and screenline volumes, and public transport patronage data such as boardings and alightings).
- Validation should be presented in terms of both percentage differences and absolute values, as well as reporting on the criteria in Appendix B.
- Validation (with respect to volumes and travel times) should be undertaken on a link basis and should include links that comprise adjacent competing routes.
The validation approach described above and the criteria referred to in Appendix B provide information on how well a transport model reproduces reality at a point in time; in other words, how well a model replicates a static condition. Given that transport models are used to forecast how a change in inputs may lead to a change in modelled conditions, an additional validation approach is required to identify how realistic a transport model’s outputs are, as inputs are changed. Such a validation approach is termed ‘dynamic validation’ and may involve:

- Modifying speed-flow curves for different highway classes to identify whether the changes in assigned traffic are logical
- Modifying public transport fares (for example, increasing fares by 10% and noting the change in forecast patronage and corresponding change in road traffic volumes)
- Modifying the value of time used in the generalised cost and path building formulations, and noting the changes in mode share
- Modifying public transport frequencies and noting the change in forecast public transport patronage and traffic volumes
- Modifying the zonal trip generation (employment and population levels) and noting the change in vehicle-kilometres of travel on the highway network.

5.9 Model convergence

It is necessary to assess the stability of the trip assignment process referred to in Section 3 before the results of the assignment process are used to influence decisions or for input to economic appraisal, or both.

The iterative8 nature of the assignment process leads to the issue of defining an appropriate level of assignment convergence. In practical terms, an assignment process may be deemed to have reached convergence when the iteration-to-iteration flow and cost differences on the modelled network are within predetermined criteria.

The recommended indicator for assessing the convergence of urban transport models is the delta (δ) indicator. This indicator is the difference between the costs along the chosen routes and those along the minimum cost routes, summed across the whole network and expressed as a percentage of the minimum costs. An urban transport model is deemed to have reached convergence when δ is less than one per cent (see Table 8).

---

8 Feedback of generalised travel costs derived from the trip assignment process to the trip generation and mode split sub-models within an urban transport model, until a pre-defined level of convergence is achieved.
Table 5  Example of model convergence output

Summary of convergence for 2031 Base Case two-hr am peak.

<table>
<thead>
<tr>
<th>ITERATION</th>
<th>DELTA</th>
<th>AAD</th>
<th>RAAD</th>
<th>% FLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>1.03119%</td>
<td>4.53441</td>
<td>0.0029626</td>
<td>0.18298%</td>
</tr>
<tr>
<td>42</td>
<td>0.68327%</td>
<td>9.86224</td>
<td>0.0080850</td>
<td>2.70688%</td>
</tr>
<tr>
<td>43</td>
<td>0.93032%</td>
<td>6.95290</td>
<td>0.0047448</td>
<td>0.63728%</td>
</tr>
</tbody>
</table>

Source: Melbourne Integrated Transport Model

Generally, the number of iterations required to reach convergence increases:

- The more trips are in the demand tables
- The more zones that are in the model
- The more links in the network.

Consideration of the time required for the model to converge should be made during specification of the model.

5.10 Transport model documentation

Transport model documentation is a step towards improving the understanding and usefulness of travel demand models. If the model documentation is too brief, or it is not updated with changes to the model, then it will not be useful to transport modellers.

Model documentation may contain a variety of information. The following is a list of suggested topics:

- Description of the modelled area and transport network coverage
- Land use and demographic data for all years modelled, by transport zone or the level of geography adopted for the modelling and analysis
- Description and summaries of all variables in the networks
- Source and coverage of traffic counts used in the model development process
- Description of the trip generation model and any core assumptions
- Identification of special generator and external trips input to trip generation
- Summary of trip generation results
- Description of the trip distribution model and any core assumptions
- Description of the impedance measures used in trip distribution, including intra-zonal and terminal times
- Summary of trip distribution results
- Description of the mode choice model by trip purpose
- Description of the variables used in the mode choice model
- Summary of the mode choice results
- Identification of the source and value of inter-regional trips
- Description, if applicable, of the time period models and any core assumptions
- Description of the trip assignment models and any core assumptions
- Description of the impedance measures used in the trip assignment models
- Identification of the volume–delay and path-building algorithms applied in trip assignment
- Summary of the trip assignment results (vehicle-kilometres of travel, vehicle-hours of travel, passenger kilometres travelled, delay and average speed)
- Identification of model validation tests and results for each model stage.

5.11 Auditing

In common with many other activities, transport modelling quality is defined by process. This means that a forecast traffic volume or patronage level cannot be determined as being 'good' simply by looking at the forecasts. Instead, confidence in the processes used to derive the forecasts should be sought via the structure of the transport model and its calibration and validation. It should be stressed that forecasts are only as good as the input assumptions.

Generally, using transport modelling in the appraisal of initiatives and impact assessment involves three broad processes:

- Data collection
- Model specification and calibration
- Model application to the scheme appraisal and evaluation.

Each of these processes should either follow accepted guidelines or accord with good practice. The following is a suggested list of information that should provide a suitable basis for the:

- Evaluation of transport models in the context of the stated objectives of users
- A statement of the modelling objectives and the elements of the model specification that serve to meet them
  - a specification of the base data:
    - description of travel surveys
    - sample sizes
    - bias assessments and validation, where available
  - description of transport networks
    - structure
    - sources of network data (such as inventory surveys, timetables)
  - description of demographic and employment data (such as sources, summary statistics)
• A document reporting on model specification and model estimation:
  – model structures, variables and coefficients
  – outputs of statistical estimation procedures
  – model fit to data
• Evidence of validation:
  – fit to independent data
  – comparison with other models
  – sensitivity tests and elasticities
• Description of the forecast year inputs (such as networks, demographic data, economic assumptions):
  – sources of data
  – statistics describing the main features of the data
• Documented validation of the forecasts, paying attention to the types of model runs and types of output most vulnerable to error (e.g. tests of small changes, economic benefit estimates):
  – comparison with other forecasts, where available
  – comparison with historic trends, if relevant
  – reasoned explanations of the forecasts (such as the sources of the diverted traffic, the reasons for diversion – size of time saving)
• A record of model applications.

Appendix D provides a Model Audit Checklist.
6. Forecasting and evaluation

6.1 Projection of demand growth

Many transport problems are a combination of deterministic and stochastic processes that may vary over time. Time series analysis is the statistical technique used to study such problems. From a stochastic point of view, traffic flow on a particular link of a network could be regarded as consisting of four components: trend ($Tr$), seasonal ($Se$), cyclic ($Cy$), and random ($Ra$) components. The trend component may result from long-term growth in traffic. Seasonal variation may result from different flows at different times of the year. Cyclic components can result from long-term economic changes. The random component may result from short-term variations in traffic flow. When there is an additive relationship between the components, they can be combined as in equation EQ 6.1 and Figure 10 below.

$$X(t) = Tr(t) + Se(t) + Cy(t) + Ra$$  

[EQ 6.1]

The loads on a transport network reflect the time-dependent variations in social, economic, industrial, agricultural and recreational activities in the area it serves, as well as long-term trends in the levels of those activities. For instance, traffic data – such as hourly or daily traffic volumes – that are indicative of these loads, must be recorded as time dependent data. Freight flows in a region may vary over time (for example, over weeks and months of the year) as an outcome of the seasonal factors in production and demand. The distinguishing feature of time-dependent data is that they come from processes that are undergoing continual change. If we are to understand the data, we must extract the components of change that are involved and separate the random effects from the trends and cycles that influence the data. Stationary processes (those whose parameters are stable over time) offer the possibility of repeating observations in order to uncover the degree of variability existing in the data. Time series data do not permit repetition of observations as data collected at one point in time will, of necessity, differ from those collected at other times.
Methods for the analysis of time series data, including the use of moving averages and autocorrelation coefficients, are outlined in Taylor, Bonsall and Young (2000, pp 416–22) and described more fully in textbooks such as Chatfield (1984).

Time series data are important information sources for transport analysis. They include data on system performance and impacts over time, such as freight flows, passenger movements or road fatalities, as well as economic performance and activity data (such as quarterly GNP statistics and fuel sales) and socio-economic data (such as population and employment data sets). Gargett and Perry (1998), Amoako (2002) and Sutfcliffe (2002) provide recent examples of the use of time series data in analysis of freight movements in Australia.

6.2 Forecast horizon

In the past, the practice has been to develop a forecast for one year, usually the year of opening of the initiative. Given that demographic projections are usually available for a number of forecast years, it is recommended that at least two forecast years are used – one for the opening year and the other 10 years after opening.

Using the second forecast year enables issues such as fare level changes, value of time and vehicle operating cost increases, and land use changes to be explicitly input into the model and may result in a more robust forecast and appraisal outcome.
6.3 Network options

The ‘base case’ network should be based on the validated Reference (Base) Year network and should include all the supply-side proposals (such as committed highway and public transport infrastructure) and operational proposals that are expected to be implemented by the forecast year.

The ‘option case’ network should be based on the ‘base case’ network with the difference between the two networks being the project being appraised and any other changes, such as a service scenario, that are different to that in the ‘base case’ network.

6.4 Induced benefits

There is evidence that the implementation of significant transport network infrastructure will result in induced travel. While this is a quite complex area to model, it is possible to begin to approximate the induced benefits of a proposal by undertaking a series of ‘cross assignments’.

The cross assignment approach is intended to identify all benefits by applying the ‘rule-of-half’ and is implemented by assigning the Option Case demand to the ‘base case’ network and assigning the ‘base case’ demand to the Option Case network. Appendix C presents more detail on the cross assignment process. It should be noted that implementing the cross assignment approach to the benefit calculations will result in two additional assignment runs for any one option.

6.5 Sensitivity tests

Sensitivity tests around a ‘base case’ case should be undertaken in order to identify the robustness of the forecasts to changes in assumptions. Some examples of sensitivity tests that could be undertaken are:

- Different unit rates for travel time, vehicle operating costs, public transport wait times and transfer penalties
- Changes in public transport fare levels, parking charges, road pricing
- Changes in the demographic assumptions (i.e. population and employment levels)
- Ranges of growth in travel demand
- Changes in model parameter values
- Different economic growth assumptions
- An assessment of complementary schemes.
Appendix A  Transport modelling process

The following is provided as a guide to assist in defining and implementing the transport modelling process.

Consolidate the transport modelling task

This step involves discussing the transport modelling requirements to determine the scale and scope of the transport modelling.

- Review the purpose, goals and objectives of the task or study
- Review the timeline for the task or study
- Identify how transport modelling can contribute to informing the study goals and objectives within the specified timeline
- Identify and confirm the scale and scope of transport modelling required:
  - strategic level
  - regional level
  - corridor level
  - microsimulation
- Confirm the time period to be modelled:
  - peak (am, inter-peak and pm)
  - 24-hour
- Confirm the transport network and land use options to be modelled. These options need to be defined early in the process to determine the resources required to undertake the modelling
- Confirm the calibration and validation criteria for the modelling task:
  - root mean square error (RMSE)
  - GEH
  - travel time reporting
- Confirm the timelines for the modelling task
- Confirm the outputs from the modelling task. Examples of transport modelling outputs are:
  - highway link volumes
  - public transport patronage
  - transport network performance indicators e.g. vehicle-hours, vehicle-distance, passenger-kilometres, levels of congestion, average speeds and travel times.
Data collection

Identify and source the data required for the transport modelling task:

- Revealed preference data
- Origin–destination
- Traffic counts (mid-block, intersection)
- Route (link) travel times
- Demographic (population, employment)
- Land use (quantum of industrial, residential, commercial land)
- Stated preference data
- Public transport boarding and alighting data.

Model calibration and validation

Undertake the Reference (Base) Case transport model calibration and validation according to the criteria presented in Appendix B.

Develop options

Forecasts are used to determine the performance of alternative scenarios of future land use and transportation systems. Options development would normally include different land use and transport systems and mixtures of highway and transit services and facilities. Since land use affects travel and travel affects land use, both must be considered.

Options modelling

Undertake the modelling of the various options and produce the assignment outputs and network performance indicators such as:

- Total vehicle-kilometres, vehicle-hours of travel and passenger kilometres travelled
- Total network travel time
- Vehicle operating and travel time costs
- Emissions – CO2, CO, NOx, CH4, HC, PM10, PM2.5.
  - The modelled options should be compared to the calibrated and validated Base Case model on the basis of:
    - traffic volumes
    - public transport patronages
    - network performance indicators.
Sensitivity analysis

Sensitivity analysis is usually undertaken to assess the response of the forecasts to a range of assumptions around an agreed transport network and demand scenario, usually the ‘Do-Minimum’ Case. The sensitivity testing may include:

- An allowance for generated / induced travel
- Ranges of growth in travel demand
- Changes in model parameter values
- Public transport fare changes
- Different planning or economic growth assumptions
- An assessment of complementary schemes.

Modelling Report

A Modelling Report demonstrates that the transport model appropriately reproduces an existing situation and summarises the accuracy of the base from which the forecasts are produced.

The Modelling Report should also include the aims and objectives of the modelling task, document the assignment validation and output, document the details of any model calibration and report on the economic appraisal.

The Modelling Report should include:

- A description of the modelling task, aims and objectives
- A description of the data used in calibrating and validating the model
- The model calibration outcome
- Documentation of the modelling assumptions
- Documentation of the model validation
- Documentation of the economic appraisal.
Appendix B Reference (Base) model validation criteria

The following criteria should be used to validate the Reference (Base) model to ensure that modelled results are consistent with observed data (i.e. traffic counts and travel times). If the criteria are met (or if not met, and there is sufficient confidence that the transport model is still fit-for-purpose), the Reference (Base) model is considered adequate for predicting the present and is fit-for-purpose for forecasting.

Ideally, the observed data should be the most recently available traffic counts and travel times.

Link flows

- **Link volume plots**
  - For each time period, produce a map of the transport network showing modelled and observed link flows and the differences between them. The totals should be summarised for available screenlines. These plots are used to check modelled and observed flows by geographic area and level of flow.
  - As a guide, a reasonable error tolerance for hourly flows on individual links is approximately ±20 per cent. A major link is considered to be one that carries at least 15 000 vehicles per day in one direction. In the case of screenlines, an acceptable error tolerance is ±10 per cent.

- **Scatter plot of modelled and observed flows**
  - Produce an XY scatter plot of modelled versus observed flows for:
    - all individual links
    - freeways links
    - screenlines
  - Superimpose the y=x line on each plot. Report on the R2 for each plot.

- **GEH statistic**
  - The GEH statistic, a form of Chi-squared statistic, is designed to be tolerant of larger errors in low flows. It is computed for hourly link flows and also for hourly screenline flows and has the following formulation:
    \[
    GEH = \sqrt{\frac{(v_2 - v_1)^2}{0.5(v_1 + v_2)}}
    \]

    where:
    - \(V_1\) = modelled flow (in vehicles/hour)
    - \(V_2\) = observed flow (in vehicles/hour).
• **Percentage root mean square error (RMSE)**
  - The RMSE applies to the entire network and has the following formulation:

  \[
  RMSE = \sqrt{\frac{(v_1 - v_2)^2}{C - 1} \times \frac{\sum v_2}{C}} \times 100
  \]

  where:
  
  \(V_1\) = modelled flow (in vehicles/hour)
  
  \(V_2\) = observed flow (in vehicles/hour)
  
  \(C\) = number of count locations in set.

**Travel times**

Provide a comparison of modelled and observed travel times as an XY scatter plot for each time period modelled. The scatter plot should also include the 95 per cent confidence limits for the modelled data. More specifically, modelled versus observed distance against time can be plotted for individual travel time routes.

**Assignment convergence**

Provide evidence of assignment convergence by detailing the:

- Type of assignment (equilibrium, volume averaging, incremental)
- Convergence achieved at the final iteration and the number of iterations required in achieving convergence
- Percentage change in total generalised user cost in the final iteration
- Proportion of links with flows changing <5%
- Normalised gap \(\delta\): this is the flow-weighted difference between current total costs and the costs incurred if all traffic could use the minimum cost routes – should be less than 1% between successive assignment iterations.
Appendix C  Induced benefits calculation

\[ T_1 = \text{the number of trips in the 'Do-Minimum' Case} \]
\[ T_2 = \text{the number of trips in the Option Case} \]
\[ C_1 = \text{the cost of travel in the 'Do-Minimum' Case} \]
\[ C_2 = \text{the cost of travel in the Option Case}. \]

The yellow-shaded term in the following table uses the 'do-minimum' network, with the costs weighted by the trips in the Option Case trip matrix. This is undertaken by assigning the Option Case trip matrix to the 'do-minimum' network while keeping the paths and link speeds unchanged (that is, there are no speed or path-building iterations and the paths are those from assigning the 'do-minimum' trip matrix to the 'do-minimum' network).

The green-shaded term in the following table uses the Option Case network, with the costs weighted by the trips in the 'Do-Minimum' Case trip matrix. This is undertaken by assigning the 'Do-Minimum' Case trip matrix to the Option Case network while keeping the paths and link speeds unchanged (that is, there are no speed or path-building iterations and the paths are those from assigning the Option Case trip matrix to the Option Case network).
Appendix D  Model audit checklist

General information

Check if a model specification and detail is available for:

- The type of model used
- Geographic area covered by the model and the level of zonal disaggregation
- The transport networks (active, public transport, highway, freight) included and their details
- The time periods modelled
- The vehicle types modelled
- How the external trips are modelled.

Data sources

Check if a data source description and the source’s reliability are available for:

- Transport network data (link lengths, link types, free flow speeds, capacities, number of lanes)
- Travel data and collection methods (traffic counts, origin–destination surveys)
- Other.

Matrices

Check for details on:

- The description of each step in the development of the Reference (Base) Year and forecast trip matrices, including methods, assumptions, parameters and factors applied – include details of any matrix estimation procedures that have been used
- Evidence of matrix fit to observed data (screenlines, comparison with independent origin–destination flows)
- Evidence of sensitivity testing of input parameters or elasticities
- Detail on the matrix methods or techniques used – if variable matrix methods or growth constraint techniques have been used, provide details on the method and parameters adopted and the justification for the approach
- The basis for the development of a commercial vehicle matrix.
Assignment

Check for details on the:

- Description of how the transport network was developed
- Assignment method used (incremental, equilibrium, volume-averaging, other)
- Generalised cost formulations used for route choice to include the methodology for incorporating tolls on route choice
- Speed-flow functions adopted (equations, coefficients, calibration, validation)
- Any intersection modelling being undertaken and the basis it is being undertaken on.

Forecasting

Check for details on:

- Comparison of forecast year growth rates with historical trends (land use, household size, car ownership, traffic volumes, commercial vehicle volumes)
- Average growth across screenlines to ensure local growth is reasonable
- Comparisons with other forecasts (if any).
Appendix E  Abbreviations

ABS  Australian Bureau of Statistics
ATC  Australian Transport Council
BAH  Booz Allen Hamilton
CCD  Census Collection District
GEH  GEH formula
O–D  Origin–destination
RMSE  Root mean square error
VATS  The Victorian Activity and Travel Survey
# Appendix F  Glossary

The following is a list of some commonly used terms in transport modelling and their definitions.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td>An indication of the proximity of a person, site or zone to a particular activity or group of activities. It is also defined as the ease or difficulty of making trips to or from each zone.</td>
</tr>
<tr>
<td>Aggregate data</td>
<td>Data that relates to a mass of group of people, vehicles or area. The collective properties of the variable are of interest.</td>
</tr>
<tr>
<td>AON assignment</td>
<td>The AON (all-or-nothing) assignment technique by which minimum travel time paths are computed for each zone pair and all flows between these pairs are loaded onto these paths.</td>
</tr>
<tr>
<td>Capacity restraint</td>
<td>A traffic assignment technique that takes into account the build up of congestion with increased traffic volumes. It adjusts the link travel times according to the prevailing flows.</td>
</tr>
<tr>
<td>Centroid connector</td>
<td>Imaginary links that represent the street network within a zone. They ‘connect’ trips from a zone to the modelled network.</td>
</tr>
<tr>
<td>Destination</td>
<td>The point or area of termination of a trip.</td>
</tr>
<tr>
<td>Disaggregate data</td>
<td>Data at the level of individual persons, households, etc.</td>
</tr>
<tr>
<td>Employment</td>
<td>The number of employees, or jobs, in relation to the zone of work. This may be stratified by employment type e.g. retail, manufacturing, etc.</td>
</tr>
<tr>
<td>External trip</td>
<td>A trip that has either an origin or destination, but not both, in the study area.</td>
</tr>
<tr>
<td>Equilibrium assignment</td>
<td>An assignment process by which all used routes between zone pairs have equal and minimum costs, while all unused routes have greater or equal costs.</td>
</tr>
<tr>
<td>Generalised cost</td>
<td>This cost is usually a linear additive function of some, or all, of the following costs: travel time between zones, access and wait times, ride time, distance between zones, fares, fuel costs and parking charges.</td>
</tr>
<tr>
<td>Gravity model</td>
<td>A model that distributes the number of trips between all trip-producing zones and trip-attracting zones.</td>
</tr>
<tr>
<td>Home</td>
<td>A group of rooms or a single room, occupied or intended for occupancy as separate living quarters by a family, group of persons or by a person living alone.</td>
</tr>
<tr>
<td>Home-based trip</td>
<td>A trip that has its origin or destination at the home end. It may be a person trip, vehicle trip, walk trip, or public transport trip.</td>
</tr>
<tr>
<td>Household</td>
<td>A person or persons living in the one home.</td>
</tr>
<tr>
<td>Incremental assignment</td>
<td>The process by which flows between all zone pairs are loaded onto the network in pre-specified steps.</td>
</tr>
<tr>
<td>Internal trip</td>
<td>A trip that has both its origin and destination in the study area.</td>
</tr>
<tr>
<td>Link</td>
<td>A section of a highway or public transport network defined by a node at each end.</td>
</tr>
<tr>
<td>Logit model</td>
<td>Also known as the ‘multinomial logit model’, it calculates the proportion of trips that will select a specific mode or activity.</td>
</tr>
<tr>
<td>Minimum path</td>
<td>The route between a zone pair that has the least cost (time, distance, generalised) in comparison to all other possible routes.</td>
</tr>
<tr>
<td>Minimum path tree</td>
<td>All the minimum paths between zone pairs that emanate from an origin zone.</td>
</tr>
<tr>
<td>Modal split</td>
<td>The division of trips between different modes of travel (private transport, public transport).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>----------------------</td>
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</tr>
<tr>
<td>Node</td>
<td>A numbered point on a network representing a centroid or a junction of two or more links.</td>
</tr>
<tr>
<td>Non home-based trip</td>
<td>A trip that has neither origin nor destination at the home end. It may be a person trip, vehicle trip, walk trip, bicycle trip or public transport trip.</td>
</tr>
<tr>
<td>Origin</td>
<td>The point or zone at which a trip begins.</td>
</tr>
<tr>
<td>Person trip</td>
<td>Any trip made by a person.</td>
</tr>
<tr>
<td>Screenline</td>
<td>An imaginary line, usually along physical barriers such as rivers, railway lines or roads. Screenlines split the study area into a number of parts. Traffic classification counts, and possibly interviews, may be conducted along these lines to compare or calibrate data and models.</td>
</tr>
<tr>
<td>Travel time</td>
<td>The time taken to travel between two points.</td>
</tr>
<tr>
<td>Trip</td>
<td>A one-way movement from an origin to a destination for a particular purpose. It may be a person trip, a vehicle trip, walking trip or public transport trip.</td>
</tr>
<tr>
<td>Trip assignment</td>
<td>The process by which flows between zones derived from the trip distribution process are allocated to the minimum path routes through a network.</td>
</tr>
<tr>
<td>Trip attraction</td>
<td>Usually used to describe trip ends connected with non-residential land uses in a zone. Also defined as the non home end of a home based trip or the destination of a non home based trip.</td>
</tr>
<tr>
<td>Trip distribution</td>
<td>The process by which the total numbers of trips originating in each zone are distributed among all the possible destination zones.</td>
</tr>
<tr>
<td>Trip end</td>
<td>Either a trip origin or trip destination.</td>
</tr>
<tr>
<td>Trip generation</td>
<td>The process by which the total numbers of trips beginning, or ending, in a zone are determined, based on demographic, socio-economic and land use characteristics.</td>
</tr>
<tr>
<td>Trip matrix</td>
<td>A two dimensional matrix that represents the demand for travel among all zones in a study area for individual or grouped purposes, modes or types.</td>
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<tr>
<td>Trip production</td>
<td>Usually used to describe trip ends connected with residential land uses in a zone. Also defined as the home end of a home-based trip, or the origin of a non home-based trip.</td>
</tr>
<tr>
<td>Trip purpose</td>
<td>This can be defined as work trips, school trips, recreational or social trips and shopping trips.</td>
</tr>
<tr>
<td>Zone</td>
<td>A portion of the study area with homogenous land use, socio-economic and demographic characteristics.</td>
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<tr>
<td>Zone centroid</td>
<td>An assumed point in a zone that represents the origin or destination of all trips to or from that zone. Generally, it is the weighted centre of trip ends, rather than the geometrical centre of a zone.</td>
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</tbody>
</table>
References


Goulias, K. 2003, *Transportation Systems Planning: Methods and applications*, CRC Press, USA


Roads and Maritime Services (2013), Traffic Modelling Guidelines, Roads and Maritime Services, NSW.


