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National Guidelines for Transport System Management in Australia

4 Urban transport

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Foreword

This document presents an analytical approach for urban transport proposals under the *National Guidelines for Transport System Management in Australia* (2nd edition) endorsed by the Australian Transport Council (ATC) in November 2006. It is part of a series of five documents that comprise the Guidelines. The other documents cover an introduction, detailed framework for undertaking strategic transport planning and development, detailed information on the appraisal of initiatives and background material.

I gratefully acknowledge the contributions made by committee members towards this very significant piece of work. All of the members have given generously of their time and competencies, over an extended period of time, to make the Guidelines a comprehensive and user-friendly manual that will assist all jurisdictions in the complex business of transport system planning and management. In particular, I acknowledge the significant contribution of the Chair of the Committee, Dr Anthony Ockwell who directed and managed the project throughout its entire process. A list of members is presented elsewhere in this publication.

The Guidelines support transport decision-making and serve as a national standard for planning and developing transport systems. They are a key component of processes to develop and/or appraise transport proposals that are submitted for government funding. Potential users of the Guidelines include governments, private firms or individuals, industry bodies and consultants.

The Guidelines have been endorsed by all Australian jurisdictions. They were developed collaboratively over several years by representatives from all levels of government in Australia through the Standing Committee on Transport (SCOT), in consultation with SCOT modal groups (Austroads, Australian Passenger Transport Group, SCOT Rail Group). The Guidelines have been endorsed by the Australian Transport Council (ATC) and the Council of Australian Governments (COAG).

This is the second edition of the Guidelines. It is an expanded and revised edition that reflects directions from SCOT, ATC and COAG as well as feedback from users. The revision has focused on making the material more cohesive, accessible and user-friendly, while maintaining rigour. These improvements will help to facilitate the widespread adoption of the Guidelines that has been specified by COAG.

The terms assessment, appraisal and evaluation are often used interchangeably in practice to mean the determination of the overall merits and impacts of an initiative. In the Guidelines they are used as follows:

- *Assessment*: A generic term referring to quantitative and qualitative analysis of data to produce information to aid decision-making.
- *Appraisal*: The process of determining the impacts and overall merit of a proposed initiative, including the presentation of relevant information for consideration by the decision-maker.
- *Evaluation*: The specific process of reviewing the outcomes and performance of an initiative after it has been implemented.

The current focus of the Guidelines is land transport — road, rail and inter-modal. There is scope to further broaden the Guidelines to cover other modes and transport issues in the future.

It is envisaged that the experiences of users who apply the Guidelines will continue to provide useful insights into areas requiring further improvement. The Guidelines should therefore be seen as an evolving set of procedures and practices. The agencies involved in the development of the Guidelines welcome feedback that will contribute to the process of revision and improvement.

Michael J Taylor
Chair
Standing Committee on Transport
December 2006

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The Australian Capital Territory, Department of Urban Services and the Australian Local Government Association were consulted throughout the development of the Guidelines.

Introduction

The Transport System Management Framework presented in Volume 2 of the Guidelines provides a generic model for transport planning and development across all settings. Similarly, Volume 3 of the Guidelines presents a generic process and methodology for the appraisal of transport initiatives.

Volume 4 of the Guidelines complements Volumes 2 and 3, focusing specifically on urban transport. This specific focus is necessary because of the additional complexity of urban transport analysis. The material in Volume 4 will assist practitioners apply the generic material from Volumes 2 and 3 to urban transport settings.

Volume 4 is presented in two parts:

1 public transport economic appraisal guidelines[1], and

2 urban transport modelling guidelines.

Urban public transport BCA is specifically addressed here because, to date, there are no public transport appraisal guidelines in Australia, although there is an increasing focus on the role of public transport in urban management, both nationally and internationally.

Urban transport modelling is a unique and complex field of investigation in its own right. Large, computerised urban transport models are used by most jurisdictions in transport policy and planning work, and form a critical input to the BCA of urban transport initiatives.

Developing the material in this volume through the collaborative national Guidelines process allows it to act as a standard to promote consistency across Australia in urban transport modelling and the application of BCA to urban public transport.

This volume does not directly address the BCA appraisal of urban road initiatives. Volume 3, which references relevant Austroads material, guides these appraisals.

1 Much of the input for Part 1 of Volume 4 was provided by Booz Allen & Hamilton (Australia) Ltd. through a consultancy managed by the Australian Passenger Transport Group (APTG).

PART

1

Public transport economic appraisal guidelines

1 Introduction to Part 1

Volume 4, Part 1 presents the methodology for undertaking an economic appraisal of a public transport initiative. It references concepts and data in other volumes of the Guidelines to avoid duplication and, therefore, focuses on issues specific to public transport initiatives. Volume 4 addresses:

- the structure of an economic appraisal and key issues specific to the appraisal of public transport initiatives
- assessing the economic value of changes in travel behaviour that result from initiatives
- assessing changes in the cost of providing public transport services i.e. operating and maintenance costs
- taking account of investment costs, covering both fixed infrastructure and rollingstock, and
- presenting default values for parameters related to public transport that are needed to complete an economic appraisal.

Issues related to social equity are not well suited for inclusion in an economic appraisal expressed in monetary terms. Reference is made to the need to address such matters as non-monetised impacts in the Appraisal Summary Table (AST), described in Volume 3.

The link between parameters used in travel demand estimation is also noted, but demand estimation is not addressed in detail. It is presumed that analysts will have access to data on:

- the investment cost of the initiative
- the number of people who will use public transport in the Base Case and the Project Case
- the source of additional public transport demand e.g. the previous mode of travel and the quantity of travel not previously made
- changes in the demand for car parking between the Base Case and the Project Case, and
- changes in the quantity of public transport resources needed to meet forecast demand, including the number of vehicles, the distance they travel and the time they are in use.

2 Appraisal principles and structure

The economic appraisal of urban public transport initiatives (both projects and policies) follows the same general principles set out in other volumes of the Guidelines. That is the initiative should be compared with a counterfactual situation i.e. the Project Case and the Base Case respectively over an appraisal period; with:

- the potential for the initiative to provide benefits beyond the appraisal period taken account of through inclusion of the residual (i.e. scrap) value of assets as a negative cost in the last year of the appraisal period
- costs and benefits discounted to a present value to reflect the relative value of impacts in future years, and
- indicators such as the benefit–cost ratio (BCR) and net present value (NPV) used to show the economic merit of the initiative.

Public transport initiatives will generally have a number of impacts that need to be taken into account in an economic appraisal. The impacts can be broadly categorised in the following groups.

- Investment costs. Investment costs incurred with the initiative, and investment costs in the absence of the initiative, need to be considered. Substantial investment costs are commonly incurred in the Base Case with public transport initiatives because of the need to re-invest in life-expired current fixed infrastructure and rollingstock[2] that might be complemented, replaced or extended with the initiative.
- Operating costs. Public transport operating costs[3] can be substantial, and will also vary between the Base Case and the Project Case. This will require that operating costs are estimated for the Base Case and the Project Case, or that the difference between the two cases is estimated in some other way.
- Benefits. The term 'benefits' includes all impacts on the community that result from the initiative, relative to the Base Case. Thus, if the impacts result in some people being adversely affected, benefits may be negative (disbenefits) as well as positive. Public transport initiatives can impact public transport users (e.g. through improved services), other road users (e.g. if some former car drivers shift to public transport) and the community at large (e.g. through changes in pollution and other social impacts). Particular care is needed to fully account for these benefits without double-counting.

2 The term 'rollingstock' is used in the Guidelines to cover all vehicles used to carry passengers e.g. buses, trams and trains.

3 Public transport operating costs are taken to include all recurrent costs involved in providing public transport services. They include maintenance costs for fixed infrastructure and rollingstock as well as the cost of operating public transport vehicles and managing the provision of services.

As indicated in Section 2.10.4 in Volume 3, the denominator (i.e. the 'cost') in the BCR should include only investment costs, with all other effects in the numerator (described as 'benefits' that occur after the initiative has commenced operation, noting that some individual effects may be negative i.e. be disbenefits). This approach should generally be used for public transport initiatives to ensure consistency.

However, in some cases, this may present difficulties for public transport initiatives. For example, an initiative to increase the quantity of service using existing fixed infrastructure and rollingstock does not involve any investment expenditure, resulting in a denominator of zero and an infinite BCR. Similarly, significant operating and maintenance costs for public transport can mean that treating a rise in these costs as a negative benefit will reduce the BCR relative to the situation in which they are included in the denominator. In cases where these types of factors have a material effect on the results of the appraisal, also report the results of the BCR in a form where changes in operating and maintenance costs are also included in the denominator.

The result of an economic appraisal is the difference between the situation in the Base Case and the Project Case. The Base Case has as much impact on the results of an appraisal as the Project Case, and careful consideration needs to be given to defining and analysing the Base Case. This matter is discussed in more detail in Section 2.1.6 in Volume 3.

As indicated in Section 2.3.1 in Volume 3, secondary economic benefits should generally be omitted.

Similarly, increases in land value that may result from urban public transport initiatives are generally a capitalisation of other benefits. Accordingly, they should not be included in economic appraisal of initiatives because this would double-count benefits.

3 Travel demand impacts and initiative benefits

3.1 Overview

The benefits of a public transport initiative are a consequence of changes in travel conditions (e.g. the time and quality of travel) that, in turn, affect travel demand (e.g. the quantity of travel demand, its location and the mode of transport used). The derivation of benefits will be the product of travel demand, changes in travel conditions and unit resource values for travel in those conditions. Potential beneficiaries of a public transport initiative are described in Table 1.3.1, together with a summary of means for calculating the benefits. The remainder of this section describes how to derive these benefits in more detail.

Section 3.2 considers some key issues that affect the calculation of the benefits of public transport initiatives, including the use of the generalised cost of travel, analysis of travel demand and principles that underlie the estimation of benefits. Subsequent sections address the benefits that accrue to people who use public transport in the Project Case, the benefits gained by people who continue to use the roads system when a public transport initiative is in place, and the benefits that accrue to the community at large. Some parts of this section draw substantially on other work and are reproduced with permission.[4] Appraisal methods for travel behaviour change initiatives also provide useful guidance for assessing some aspects of public transport initiatives.[5]

In this volume, benefits are estimated on the basis of reduced travel costs perceived by travellers, plus other impacts on travellers and the community that are not perceived by travellers. This method differs from the general approach presented in Volume 3, but both methods give the same total benefit. The general formulation of the approach described in this section is commonly used for appraising urban transport initiatives and can more readily draw on the results of computerised travel demand models. Use the approach described in Volume 3 if it is more appropriate. It is essential that only one method is used; it is not appropriate to mix components from the two approaches.

In the absence of better data, default unit resource values for parameters specifically related to the appraisal of public transport initiates are presented in Section 6, following discussions on public transport operating costs in Section 4 and infrastructure capital costs in Section 5.

4 Drawing on Bray (2006) *Economic Evaluation of Transport Projects: Training Course Notes.*

5 For example:

Maunsell Australia Pty Ltd (2006) *TravelSmart III: Evaluation Procedure (draft)*, prepared for the Department of Infrastructure, Victoria.

Maunsell, Pinnacle Research and Booz Allen Hamilton (2004) *Travel Behaviour Change Evaluation Procedures and Guidelines: Literature Review—Evaluation Monitoring and Guidance*, prepared for Land Transport New Zealand.

Table 1.3.1: Summary of potential initiative benefits

BENEFICIARY	DESCRIPTION	BENEFIT	DATA NEEDS AND ISSUES
1 Benefits to those who use public transport with the initiative			
(a) Existing public transport users	Trips made on the same public transport service before, and with, the initiative.	Change in generalised cost of travel.	The generalised cost of travel in the Base Case and the Project Case.
(b) Diverted public transport users	Trips previously made on another public transport service (i.e. route or time) that shift to the improved service with the initiative.	The unit benefit can be estimated directly from changes in generalised cost of travel, or indirectly estimated using the 'rule-of-a-half' (i.e. the benefit for a diverted public transport trip is half the unit benefit gained by existing public transport users).	The generalised cost of travel for the respective services used in the Base Case and the Project Case if available. Otherwise, use the number of trips that are diverted between public transport services between the Base Case and the Project Case and the unit benefit to existing public transport users.
(c) Former car passengers	Car passengers who transfer to public transport. Also applies to former motorcycle passengers who shift to public transport.	The unit benefit is most easily estimated using the rule-of-a-half. Will need a resource correction if the quantity of car use changes because of the transfer of car passengers to public transport.	Number of former car passengers who divert to public transport with the initiative, the unit benefit to existing public transport users, and the extent to which car use changes as a result of the mode shift. If car use changes, estimate benefits as for the next item.
(d) Former car drivers	Car drivers who transfer to public transport. Also applies to former motorcycle drivers who shift to public transport.	Benefits include : › benefit perceived by car drivers—can be most easily estimated using the rule-of-a half, and › resource correction to allow for changes in the unperceived resource cost of travel.	Need data on: › number of car drivers who divert › unit benefit to existing public transport users › saved car-kms and difference between unit resource and perceived car operating costs › extent to which car parking costs are perceived, extent and timing of reduced need for car parks, and the perceived and resource cost of car parking, and › extent to which diversion to public transport enables car ownership to be avoided. Environmental benefits from reduced car use can be recorded under this item or under 3(a) (see below).
(e) Former bicycle users	Cyclists who transfer to public transport.	Same structure as for former car drivers.	In this case, the resource correction could include any unperceived bicycle operating costs as well as the effect of reduced health outcomes due to less physical activity. The number of such users and the extent of misperception of resource costs are generally likely to be small and should only be addressed in detail if a substantial impact is expected.
(f) Former pedestrians	Former pedestrians who transfer to public transport.	Same structure as for former car drivers.	As for former bicycle users.
(g) Other generated public transport users	Trips on public transport, with the initiative, that were not previously made at all.	Same structure as for diverted public transport users.	Number of likely generated trips and the unit benefit to existing users.

BENEFICIARY	DESCRIPTION	BENEFIT	DATA NEEDS AND ISSUES
2 Benefits to those who continue to use private road vehicles with the initiative			
(a) Remaining road users	Road users present in both the Base Case and the Project Case benefit from the transfer of some car drivers to public transport (and transfer of car passengers if this reduces car use) because this leads to less congestion and hence faster and smoother travel. Less traffic with the initiative may also reduce crash costs.	Benefits includes: › reduced travel time › reduced vehicle operating costs (VOCs) › change in number and/or severity of crashes, and › benefit to road traffic that is generated in response to improved traffic conditions, with corresponding reduction in benefits to other existing road users.	Need data on: › changes in travel demand › speed-flow relationship to estimate change in congestion and travel time › average resource value of travel time for vehicle occupants and freight, and › effect of higher speed and reduced volume–capacity ratio on VOCs. May be able to use aggregate data on the average effect of a reduction in a unit quantity of road traffic. Need to allow for the effect of induced road traffic resulting from an initial improvement in congestion as some road users divert to public transport.
3 Other benefits			
(a) Community at large	Change in externalities.	Benefit from: › reduced car use from shift of car drivers to public transport—see also 1(d), and › reduced environmental impact due to faster and smoother travel for remaining road users as a result of reduced congestion with shift of car drivers to public transport—see also 1(d), offset by change in externalities from any change in the supply of public transport.	Issues: › Volume 3 indicates values for environmental impacts of road vehicle and public transport operation. › Austroads guidelines also include upstream/downstream costs (e.g. embedded energy in cars, etc.), which will be important where there is reduced car ownership.

3.2 Key methodological issues

The following sections of this section address:

- the cost of public transport travel as perceived by users, which affects both the travel choices users make and the value of changes in their travel
- principles for assessing travel demand, and
- specific issues pertinent to the estimation of benefits for public transport initiatives.

3.2.1 Perceived cost of public transport travel

Travellers make travel decisions based on their perception of the total 'cost' of their travel, where this cost includes monetary amounts paid (and perceived as being incurred) and a range of other quality and service factors such as the time, comfort, reliability, security and cleanliness of travel.[6] The cost is usually described as the generalised cost of travel, but may also be called the perceived cost of travel or the behavioural cost of travel. The generalised cost of travel is used to forecast the mode and route choice of trips. As it represents the perception of users, it also represents their willingness-to-pay for a journey, and hence is used to value changes in their travel choices. Box 2.4 in Volume 3 provides further discussion of generalised and perceived costs.

In the case of public transport, the generalised perceived cost of travel may be expressed as follows:

$$GC = F + V * [(T_A * W_A) + (T_W * W_W) + (T_R * W_R) + (T_I * W_I) + N_T * \{T_P + (T_{AT} * W_{AT}) + (T_{WT} * W_{WT})\}]$$

where

GC = total generalised cost (=perceived cost)

F = fare ($)

V = standard value of time ($/min of, say, in-bus time or some other benchmark)

T_A = access time i.e. between an origin/final destination and the public transport facility (mins)

W_A = weighting on access time (to reflect its perceived valuation relative to in-bus travel time)

T_W = (expected) waiting time at a bus stop or train station for initial boarding (mins)

W_W = weighting on expected waiting time (to reflect its perceived valuation relative to in-bus travel time)

T_R = unexpected waiting or travel time (associated with service unreliability)

W_R = weighting on unexpected waiting or travel time

T_I = in-vehicle time (mins)

W_I = weighting on in-vehicle time to reflect quality attributes (relative to in-bus travel time)

N_T = number of transfers

T_P = transfer penalty to reflect the inconvenience associated with a transfer (in equivalent in-bus travel time (minutes)) where an interchange occurs

T_{AT} = access/walk time on transfer

W_{AT} = weighting on transfer access/walk time

T_{WT} = waiting time on transfer

W_{WT} = weighting on transfer waiting time.

Values for these parameters are presented in Section 6.

6 The generalised cost of travel is described as the generalised 'price' in other volumes of the Guidelines because it is usual to discuss demand as function of price rather than cost e.g. see Boxes in Volume 3 and 'digression' in Volume 5 of the Guidelines for further explanation. This volume uses 'cost' because it will be more familiar to transport planners.

The generalised cost term is sometimes replaced by 'generalised time' (GT), where:

GT = GC/V, with units of 'generalised minutes'

3.2.2 *Principles for assessing travel demand*

Any initiative that improves public transport should be expected to increase public transport use. However, the extent of the effect on demand can vary:

- Some initiatives may not have an effect on the use of other modes (e.g. car, walking or cycling). In this case, the additional use of public transport will be generated demand induced by the improvement (sometimes referred to as 'induced travel').
- Other initiatives might attract travellers from other modes without affecting overall travel demand. This is generally unlikely to be the case because most significant improvements in public transport can be expected to result in some generation of additional public transport travel and attraction of some users from other modes. In addition, a transfer of some motorists to public transport may reduce traffic congestion, which, in turn, could be expected to affect road travel demand.
- There is therefore potential for a public transport initiative that has a significant effect on accessibility to result in both generated and diverted public transport travel and second-order effects on road use.

The derivation of impacts of a public transport initiative on the quantity, location and mode of travel will generally be undertaken through:

- use of an integrated computerised multi-modal travel demand model, or
- use of a computerised public transport demand model (using 'elasticised matrix' or similar methods to estimate demand changes), or
- a spreadsheet or paper-based approach that considers changes in travel at a simpler level; for example, using elasticities of demand with respect to travel variables.

The appraisal methodology is the same, in principle, for all these approaches. However, the accuracy and level of detail that can be represented in the appraisals will differ. Differences in the form and detail of the data available from them may also require small changes in the manner in which analysts apply the data for appraisals.

Limited detailed data are available to show the effects of public transport improvements in Australian cities on travel demand; in particular, there is limited data to show the extent to which users of a new or improved facility were existing public transport users or were former car passengers or drivers, or if the initiative created newly generated travel. The limited available data are presented in Section 6.

3.2.3 *Principles for calculating benefits*

This section addresses some issues that are particularly pertinent to the estimation and valuation of benefits of public transport initiatives.

Misperception, externalities and the resource correction

The general principle for the valuation of benefits is that they should be based on the revealed willingness of users to pay to gain the benefits. The rationale is that the value of benefits to users should be that indicated by the users, and that it would be sub-optimal to spend more that this amount to gain the benefits. However, there is one exception— where there are tangible impacts from initiatives that users do not perceive, but which need to be taken into account in economic appraisals. This component of benefits is termed the resource correction—it is needed to take account of the difference between the perceived and marginal social generalised cost of travel. The perceived benefits components and the resource correction component are now considered in more detail.

As noted in Section 3.2.1, travel decisions are made on the basis of the perceived (generalised) cost of travel options. The perceived cost (sometimes also called the 'behavioural cost' because of its influence on behaviour) will usually include financial costs such as tolls and fares and the value of travel time. Computerised travel demand models are based on perceived travel costs. The perceived benefit to users of an initiative will be the (net) reduction in the perceived cost of travel with the Project Case compared with the Base Case.

However, car users do not correctly perceive the full economic costs of their travel for three reasons:

- When making travel decisions, motorists fail to take account of all of the actual financial costs they incur because of poor information, the structure of prices and the interval between purchasing the good and using it. For example, a motorist may replace tyres every few years, and forget the wear and consequent cost of tyre use when making individual trip decisions. Similarly, people may not correctly perceive the cost of fuel when making travel decisions because of the time separation between paying for the fuel and using it. This gap is likely to be even greater in the case of use-related depreciation of a car.
- The actual financial costs that motorists pay include taxes, which are a transfer payment that does not represent use of any resources.
- Car use imposes costs on others that are not explicitly charged for. These costs, known as externalities, include pollution and congestion.

These three components of incorrect perception of the social cost of travel are taken into account in an economic appraisal through 'resource corrections', which represent the difference between the social and perceived cost of travel. Information is presented in Section 6 on social and perceived costs that can be used for the economic appraisal of public transport initiatives. When using the results of a computerised travel demand model, ensure that the perceived costs incorporated in the model are used when making the resource correction.

It is generally accepted that public transport users are more likely than motorists to take account of costs they incur in using public transport because they pay fares when making trips (or within a reasonably close period if using some type of prepaid ticket) and will be aware of the duration and quality of their travel time. However, they will be similar to motorists in being unaware of the external costs their travel imposes on others, and the presence of taxes in their fares. The presence of taxes is not a concern for public transport appraisal because the perceived cost of travel indicates a willingness-to-pay and hence is an indication of the value of travel to the user. However, the fare does not accurately represent the value of the resources used to provide the public transport service, and hence there is a need to adjust for the difference between the resources needed to provide the public transport services and users' perception of the cost of these resources as reflected in the fares paid. This is the way subsidies are taken into account.

Valuation of travel time

With the exception of travel time spent for work (business) purposes, it is generally necessary to establish the value of travel time by inferring values from prices in related markets (e.g. identifying the willingness-to-pay a toll to save travel time) or using contingent valuation (surveying people to establish how much they would be willing to pay to save travel time). While work has been undertaken by Austroads and others on the value of travel time for motorists, less information is available for public transport users.

A common approach taken by transport authorities is to use the same value of travel time for public transport users as for non-business car occupants. This approach is taken either due to a lack of more precise data on the value of public transport travel time or due to an equity principle—that it seems unfair to differentially value travel time on different modes for seemingly similar users.

In practice, evidence suggests that public transport users, on average, value their travel time at a lower rate than motorists, largely due to income differences. There is also evidence that the value varies between modes of public transport for reasons that are unrelated to the mode, but due to differences in the socio-economic characteristics of users. However, it is recommended that a single (base) value of time generally be used for all public transport users to avoid inconsistencies that would otherwise arise if, for example, an initiative introduced a new mode of public transport—the same people would value their time differently when travelling on different modes, all other things being equal. This does not affect the influence of travel quality attributes described in Section 3.4.1, which should be applied in all analyses. These matters are discussed further in Section 6.

The reported values of travel time and weightings are averages for public transport users as a whole. This does not mean that public transport users are homogenous and all have the same value of travel time. Rather, individuals may have different values of travel time and hence respond differently to changes. However, there will rarely be sufficient information to permit such effects to be taken into account in appraisals, and analyses need to be based on average values of travel time and average behaviour of public transport users as a whole. Similarly, a person shifting between car and public transport will have the same value of travel time, except for modal characteristics, for both modes. Application of the 'rule-of-a-half' method for estimating benefits for those who divert between modes implicitly takes account of this situation.

Estimation of travel demand needs to be based on the perceived cost of travel time if it is to reasonably reflect travel decisions. This includes the effect of weightings on the value of time for different travel components used to determine the generalised cost of travel. Accordingly, the starting point for the valuation of the benefits of an initiative will be the perceived value of travel time, rather than some other value such as a uniform value of travel time for all travellers, irrespective of the mode of transport used (which may better reflect social equity).

Real incomes generally rise over time. For example, in the period 1983–2005, real average earnings per adult in Australia rose by 0.6 per cent per annum (ABS Cat. No. 6302.0 and No. 6401.0). However, the Guidelines use the current values of travel time for all future years. The effect of real rises in the value of travel time can be examined through sensitivity tests.

Change in benefits over time (including ramp-up)

It is usual for benefits to be estimated for several future years, reflecting the availability of forecast data on demographic and transport matters. Benefits for other years in the appraisal period can then be determined by interpolation or extrapolation. Where a forecast is available for a single year only, the limited reliability of data for other years should be noted. Benefits for other years should be based on historic trends, or related factors that may affect the growth in benefits such as population and traffic growth.

Travel demand forecasts are usually based on equilibrium states i.e. the travel demand after taking account of all of the effects of the initiative. However, some initiatives may cause a structural change in travel demand that takes time to have full effect. This effect, called 'ramp-up', is especially evident in public transport and toll road initiatives. If the effect is likely to be significant, it is necessary to determine the benefit that is expected when the initiative has had its full effect, and to phase this benefit in over time. It is essential that the ramp-up effect only reflects the transition to the new equilibrium state. Changes in population, the economy and the transport system that occur during the ramp-up period represent additional impacts that must be added to the ramp-up effect.

There is little quantitative information on the period over which ramp-up may occur, though it may be expected to be related to factors such as the extent of the change in travel accessibility and the financial cost of travel between the Base Case and the Project Case. Few initiatives in Australia are likely to have a ramp-up period as long as the introduction of a new 24 km elevated rail line in Bangkok in 1999. Implemented in the midst of an economic downturn, this initiative halved travel time for many, but fares were more than double those of the alternative bus service. The circumstances in Bangkok could have resulted in a ramp-up period of some five years. The change in circumstances for most initiatives in Australia is likely to be more modest, and changes in demand largely achieved within months of the commencement of small initiatives and two to three years of larger initiatives. Judgement is needed in determining the ramp-up period. While the ramp-up issue is important, as Flyvbjerg notes, 'In cost–benefit analyses, errors in the ramp-ups are likely to have a relatively minor impact on the total present value of benefits as compared to errors in the forecast total demand' (Flyvbjerg 2005).

Option value of public transport

The benefits of public transport are generally well understood, with data, of varying quality, available to enable these benefits to be quantified in monetary terms. However, another source of perceived benefits of public transport, for which there is limited understanding, is the 'option value'; that is, the value people place on having available to them the option to use public transport. This concept is applied commonly in environmental economics, but less often in transport. The option value concept in transport was most recently used with regard to retaining regional rail lines in Europe (Geurs et al. 2006[7]; UK Department for Transport 2003[8]). Insufficient data exist to support the use of option values for urban public transport initiatives in Australia at present. Moreover, option values are likely to be appropriate only in particular circumstances such as the withdrawal of public transport services or establishing public transport in a location where none is available in the Base Case. Given the limited quantitative evidence available, the Guidelines do not include option value as part of the quantified benefits of public transport initiatives. However, the potential option value for public transport can be addressed as a non-monetised impact in the AST (see Volume 3). This is an aspect of appraisal for public transport initiatives where further research appears to be worthwhile.

Equity and transport disadvantage

Volume 4 focuses on the valuation of identifiable economic impacts of initiatives. However, a significant proportion of government public transport sector expenditures is directed to policies and initiatives that primarily have a social focus rather than an economic focus. This includes policies directed at people or groups who are transport disadvantaged, including those with disabilities. It may also include policies with significant distributional impacts on different segments of the community. The benefits of these policies and initiatives cannot be adequately assessed within an economic (BCA) framework[9]. In the first instance, consider these effects under the category of non-monetised impacts in the AST.

It is recognised that further work would be desirable to develop a more appropriate appraisal framework and methodology for social policies and initiatives in transport.

7 This paper provides references for other studies on the subject.

8 http://www.webtag.org.uk/webdocuments/3_Expert/6_Accessibility_Objective/3.6.1.htm

9 The economic framework can shed some light on the benefits of 'social' public transport initiatives. For example, the rule-of-a-half, which is used to value perceived benefits to additional public transport users that result from an initiative (see Section 3.4.1). This rule notes that any additional users cannot gain a unit benefit greater than the benefit that accrues to existing users as they would have been able to gain a benefit by making the trip in the Base Case and hence any additional benefit cannot be attributed to the initiative.

3.3 Benefits to existing public transport users

This section considers the benefits gained for trips made by public transport in both the Base Case and the Project Case. Other categories of benefit described in Table 1.3.1 are considered in subsequent sections.

The benefits to existing users (defined initially as people who make the same journey by public transport in both the Base Case and the Project Case) are estimated on the basis of:

$B_{eu} = T_{bc} * (C_{bc} - C_{pc})$

where

B_{eu} = aggregate benefit to existing public transport users who continue to use public transport with the initiative

T_{bc} = number of existing public transport trips

C_{bc} = perceived cost of travel per trip by public transport in the Base Case

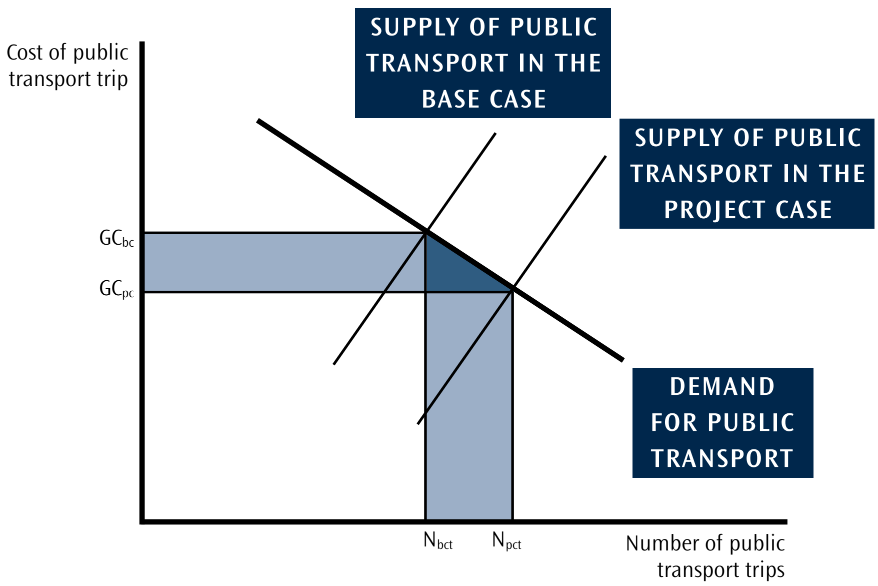
C_{pc} = perceived cost of travel per trip by public transport in the Project Case.

Note that the perceived (generalised) cost of travel should include mode-specific and similar factors that reflect the perceived merits of different public transport modes and other aspects of the journey by public transport (see Section 3.2.1).

The benefits to existing users are shown by the pale blue area in Figure 1.3.1.

Data on the perceived cost per public transport trip can be obtained from a computerised travel demand model or some simpler approach such as a spreadsheet model. It can be obtained either as an aggregate or average value for an entire transport network, or for individual travel movements.

Figure 1.3.1: Derivation of benefit to existing public transport users



3.4 Perceived benefits to diverted and generated public transport users

3.4.1 Perceived benefits

Improved public transport can result in increased patronage on the improved service, with the additional trips being:

- people who previously travelled by public transport at a different time or on a different service, or
- people who previously travelled by another mode (car, cycling or walking), or
- people undertaking travel that was not previously made.

The benefit gained by the first two groups can be calculated directly by comparing the generalised cost of the trips in the Base Case and the Project Case as indicated in Section 3.3. This is not possible for generated travel (because the trips were not previously made) or where the generalised cost of trips that divert from neighbouring public transport services to the improved service in the Base Case is not available.

However, a common general principle, known as the 'rule-of-a-half', is recommended for application to all these trips. This principle states the average (perceived) benefit to diverted or generated trips is equal to one-half of the unit benefit accruing to an existing public transport user. This result is derived by the following logic:

- The first person to undertake an additional public transport trip is expected to do so where there is only the smallest improvement in public transport, in which case they gain only a very small benefit.
- The last person attracted to public transport would do so only because of the full extent of the improvement in public transport, so gain a benefit equal to $C_{bc} – C_{pc}$[10], and
- Assuming that the demand function approximates to a straight line (or the change in demand is not large), the average benefit to all of the additional public transport users is therefore $½ * (C_{bc} – C_{pc})$.

Hence, the total benefits to generated users are:

$$B_{nu} = ½ * (T_{pc} – T_{bc}) * (C_{bc} – C_{pc})$$

where new terms are

B_{nu} = aggregate benefit to new public transport users

T_{pc} = number of public transport trips made in the Project Case.

B_{nu} is shown in Figure 1.3.1 by the dark blue area.

Data on T_{bc}, T_{pc}, C_{bc} and C_{pc} can be obtained from a computerised travel demand model or a simplified spreadsheet model. These data need to be determined separately for periods that have different travel conditions and characteristics, for example, the peak period and other times of the day.

In the case where the travel demand matrix changes between the Base Case and the Project Case in a non-uniform manner (i.e. the quantity of travel between some origins and destinations changes in a different proportion to others), the analysis must be undertaken on the basis of the quantity of trips and the change in the perceived cost of travel for each origin–destination zone pair used in the model. It is incorrect in this situation to use the average cost of travel in the Base Case and the Project Case networks to determine the benefit to diverted and generated users.

10 The benefit to any diverted, or generated, user cannot exceed the benefit gained by an existing public transport user. If the benefits were higher, the diverted, or generated, user would have gained a benefit by transferring to public transport in the Base Case, in which case the change should be assumed to have occurred in the Base Case, and the additional benefit cannot be attributed to the project.

3.4.2 *Unperceived benefits of a mode shift to public transport attributable to the former mode*

If travellers based their travel decisions on the resource cost of their travel, the user benefits described above would fully record the benefits arising from the shift to public transport. In practice, this is not generally the case because, for example, the presence of taxes and subsidies mean that travellers do not perceive the resource costs of their travel. Accordingly, an adjustment is required to take account of the full resource value of the benefit that occurs when people transfer from another mode to public transport. This adjustment, or resource correction, reflects the difference between the benefit based on the perceived cost of travel (see Section 3.4.1) and the benefit based on the resource cost of travel. Where the resource benefits of an initiative are greater than the perceived benefits, the resource correction is an additional benefit. Where the perceived benefits are greater than the resource benefits, the resource correction is a disbenefit. Therefore, the general formula for the resource correction is:

> Benefit due to under-perception of resource costs =
> (resource cost of travel – perceived cost of travel) * quantity of travel.

The following sub-sections describe travel costs that are commonly misperceived and where, therefore, a resource correction is needed. For completeness, all possible needs for a resource correction are addressed, though it is noted that in practice no correction will be required in some instances because the effect is either very small or because users perceive all resource costs.[11]

For former pedestrians who shift to public transport

The resource correction in the case of a former pedestrian who shifts to public transport needs to take account of:

- **Unperceived operating costs**. This is primarily wear on shoes, but it is possible that users perceive this cost; in which case, there is no need for a resource correction. Even if not perceived, the cost is low and will not materially affect the results of the appraisal and hence can be ignored.
- **Crash costs**. There is little evidence regarding the extent pedestrians perceive the risk of being injured or killed in a crash when making a decision to walk rather than use a motorised mode. Given the limited number of pedestrians who will shift to public transport, the uncertainty about their perception of costs when making travel decisions and limited information on the likely change in incidence and cost of crashes, avoided crash costs should generally be ignored. A resource correction can be used if these factors do not apply and where the analyst has the necessary information.
- **Health disbenefits**. A former pedestrian who shifts to public transport will incur a disbenefit due to a reduced amount of exercise from walking. However, given the general awareness in the community about the need for fitness and the appropriateness of walking, it seems reasonably likely that pedestrians will perceive this disbenefit and it will thus have been taken into account in the estimation of benefits in Section 3.4.1. Accordingly, there is no need for a resource correction for it.

For former cyclists who shift to public transport

The resource correction needs to take account of:

- **Unperceived operating costs.** These are primarily the use of tyres and brakes and depreciation of the bicycle. As described for former pedestrians, users may perceive some of the cost, but, even if they do not, the cost will be sufficiently low that it will not materially affect the results of the appraisal and hence can be ignored.

11 It is noted that no allowance was made in Section 3.3 for a resource correction for existing public transport users. Such a correction would be needed if, for example, a uniform resource value of travel time was adopted for users of all transport modes given that the perceived value of travel time varies between modes (see Section 3.2.3 for further discussion of this matter). This would become a complex adjustment, and it is recommended that such an approach not be used. Rather, concerns regarding equity that may arise from the use of different behavioural values of travel time for different modes should be addressed elsewhere in the Appraisal Summary Table described in Volume 3.

- **Crash costs**. Use the same approach as described for former pedestrians.
- **Health disbenefits**. Use the same approach as described for former pedestrians.

For former car passengers who shift to public transport

A shift of a car passenger to public transport will not typically result in reduced car use, and can generally be ignored. In this case, there is no further resource saving to take into account over and above the consumers' surplus gained by the former car passenger, which is recorded within the estimated benefit (B_{nu}) in Section 3.4.1.

However, if the analysis suggests that a significant change is expected to occur (e.g. an initiative that is designed to encourage children to use public transport for travel to and from school in the place of travel in private cars), the change in car use could be significant, and benefits should be calculated as indicated in the next sub-section.

For former car drivers who shift to public transport

In the case of car drivers who shift to public transport, there are further significant benefits to be taken into account because of the misperception of resource costs by motorists. These additional resource savings include:

- **Unperceived operating costs**. As indicated in Table 2.1 in Volume 5, which shows the financial, resource and perceived costs of car use, resource savings in vehicle operating costs that are not perceived include items such as the gap between the financial and resource cost of fuel and the resource cost of most other items that are a function of vehicle use such as tyres, maintenance and a share of vehicle depreciation. Some of these effects will partially offset each other. For example, motorists over-perceive the resource cost of fuel because the financial price includes taxes, but under-perceive costs such as tyres that are incurred only occasionally. The resource correction will be a benefit equal to:

  Car-kilometres of reduced vehicle use * (resource cost of car travel per kilometre – perceived cost of car travel per kilometre).
- **Reduced road supply costs**. Less car use will reduce the resource cost of road maintenance, which is a further benefit because this resource cost is not explicitly perceived by motorists. However, unless the reduced car use is exceptionally large, the resource correction can be ignored as it will be very small, because cars cause negligible damage to roads and there will be little potential to reduce other costs such as traffic policing. If the effect is substantial, the benefit will be the full resource value of any avoided road maintenance. Analysts will need to obtain the estimated avoided financial cost of road maintenance from engineers, and deduct taxes such as GST.
- **Crash costs**. A shift of some car drivers to public transport can result in a decline in the number of crashes due to fewer car-kilometres of travel. This may be offset by the change in the number and severity of crashes due to changes in road traffic conditions such as higher speeds. The benefit can be valued using conventional approaches for the economic appraisal of road initiatives. Again, crash costs are not generally considered to be perceived by motorists when making travel decisions, and the benefit will be equal to the total resource value of reduced crash costs.
- **Environmental benefits**. Less car use reduces environmental costs, according to the reduction in vehicle-kilometres of travel and changes in traffic congestion. Data on the unit resource value of environmental benefits from reduced car use are presented in Section 2.9 in Volume 3. The resource value of various environmental impacts is expressed in relation to the quantity of vehicle use i.e. car-kilometres of travel. The quantity of saved car-kilometres needs to be estimated to determine the monetary value of the benefit. As the resource value of environmental costs is not generally perceived by motorists, the benefit will be equal to the total reduction in car-kilometres of travel multiplied by the appropriate (marginal) unit resource value of environmental benefits.

- **Reduced car parking**. For an economic appraisal, the principal concern is the number of car parking spaces that will be avoided as a result of the initiative, the value of the avoided car parks and the timing of the impact. This is a complex matter. One of the following situations that are applicable to the initiative should be used to derive the benefit of reduced car parking. The possible situations are:

  (a) *The price of parking is perceived by car drivers when making travel decisions, and is included in the generalised cost of car travel used to determine the extent to which drivers divert to public transport.*

  In this case, the benefit to these travellers, as described in Section 3.4.1, will include the perceived benefit from saved car parking. A resource correction is needed if there is a divergence between the perceived and resource cost of the car parking (in the same way as for car drivers who shift to public transport while incorrectly perceiving the resource cost of their car travel). The resource cost of car parking can be determined in two ways. First, the resource price is the market price of car parking, less taxes such as GST and parking surcharges imposed by governments, plus any subsidy for the car parking. Where car parking is provided on a commercial basis, substantial subsidies over the long-term are unlikely, and the last of these effects can be ignored. The second approach is to determine the resource cost of car parking from first principles, taking account of the value of land and construction (see Section 6 for a default value for the unit cost of constructing car parking spaces). Allow a value specific to the circumstances of the initiative. The resource correction will be equal to the resource cost minus the market price, multiplied by the number of car parking spaces saved. The correction will be a negative benefit if taxes exceed any subsidy.

  (b) *The price of parking is not included in the generalised cost of car travel used to determine the extent to which car drivers divert to public transport.*

  This may occur because, for example, there is no explicit charge for the parking or because the parking is paid for by an employer or through salary packaging. In this case, include the full resource value of car parks saved as a benefit. This value will vary with the circumstances, and four possible situations are identified.

  (i) The saving occurs in an area where planning restrictions permit no new car parking spaces. In this case, no physical capacity is avoided. However, the vacated space can be used by another person. Given the potentially high demand for the vacated space, the value of the space is likely to be an amount close to its market price (i.e. the willingness of another motorist to pay to use the parking space). In this case, the benefit is the number of car parking spaces saved multiplied by the market price of car parking, including taxes. However, there are some off-setting disbenefits[12], and it is recommended that the net benefit **should be half of the market price** of the car parking space. The market price should be determined for the car parks involved.

  (ii) The demand for car parking exceeds supply and there is continuing development of car parks. In this case, the availability of the car park resulting from the shift of the car driver to public transport enables the cost of an additional car park, which would otherwise be needed, to be avoided almost simultaneously with the driver's shift. Default resource costs for car parking space are provided in Section 6.

  (iii) The supply of car parking space exceeds demand. In this situation, the car park vacated by the former car driver remains unused and there is no resource saving until additional car parking capacity is required and slightly less capacity needs to be constructed than would otherwise be the case. The benefit in this case is the same as for (b ii), but will occur at the future time when some car park construction would be avoided.

12 In order to use the vacated space, the new motorist is likely to have undertaken travel that was not previously made (e.g. they previously used a more distant parking location or used public transport). As the resource cost of their additional car travel is higher than the perceived cost, and there is an opportunity value if they vacated some other car parking space, there will be some off-setting disbenefits.

(iv) The former car driver used ground level space on private property or on-street parking. In this case, it is likely that there is no resource benefit from the reduced demand because the site remains and cannot be used for another purpose other than car parking by other drivers. Where the saving enables an off-street car park that might otherwise have been built to be avoided, the benefit will be as for (b iii), though the resource cost should be commensurate with the nature of the car parking involved.

- **Reduced car ownership**. Car drivers who transfer to public transport may be able to avoid the need to own a car due to the change in mode. If this is the case, and given the general conclusion that motorists do not perceive vehicle depreciation or the opportunity cost of capital when making individual travel decisions, a resource correction is needed to take account of the additional, unperceived resource saving. The unit resource benefit of avoided car ownership is presented in Section 6.

  However, reducing car ownership is not always possible. For example, a former car driver might leave the car for other household members to use. In this situation, the other household members perceive that they are better off by having access to the car. Alternatively, there is no benefit if the former car driver leaves their car unused at home. As a default case, estimate the average unit benefit of reduced car ownership on the basis that it is half the unit benefit for a former car driver who is able to avoid car ownership simultaneously with a shift to public transport. A more specific estimate can be made if information is available on the new use of cars previously used by car drivers who shift to public transport. In calculating the benefit from reduced car ownership, it is assumed that each driver makes two trips per day. Therefore, the saving in the number of cars owned is half the number of public transport journeys made by former car drivers.[13]

3.4.3 *Unperceived benefits of a mode shift to public transport attributable to the new mode*

Account needs to be taken of differences between the perceived and resource cost of travel by public transport, as follows.

Public transport crashes

Crashes still occur with public transport, as indicated by claims made against public transport agencies by passengers and damage caused to public transport and other vehicles. A resource correction is needed to account for the total resource cost of these crashes if they are not part of the cost of travel perceived by public transport users, as is generally the case. Data on crash costs can be obtained from user manuals for road initiative appraisals[14] and information from public transport agencies, using actual data on crash rates and costs that they incur. It is possible that at least some of the cost of public transport crashes is incorporated in the estimate of public transport operating costs (see Section 4). Care is needed to ensure that this item is not double-counted.

Environmental externalities generated by public transport

Public transport vehicles cause externalities such as noise and air pollution that impose costs on the community. As these costs are generally not perceived by public transport users, they are not part of the generalised cost of travel described in Section 3.2.1 and therefore need to be taken into account in the appraisal as a resource correction. The benefit is equal to the quantity of additional public transport service provided multiplied by a unit value for each of the externalities generated by public transport vehicles. Data on the unit value of environmental externalities generated by buses are presented in Volume 3.

13 Note that public transport use is sometimes reported as boardings, where a person makes two or more boardings to complete a single journey; for example, if they use a feeder bus as well as a line-haul mode.

14 For example, Roads and Traffic Authority (1999).

Public transport fare resource correction

All additional public transport users have to pay a fare, which is part of their perceived costs in making their mode choice decision. However, as the resource cost of providing public transport (both capital and operating) is included elsewhere in an economic appraisal (see Section 4), fares are a transfer payment. Accordingly, it is necessary to add fares back in, as a component of the benefits, to derive the net resource benefit.

3.5 Benefits to motorists who remain on the road system[15]

3.5.1 Initial estimation

When some former car drivers shift to public transport in the Project Case, other motorists who continue to use the road network face less traffic congestion, and thus gain a benefit.[16] The size of the benefit is larger if the initiative also reduces the number of buses using the roads and smaller if the number of buses increases.

Determining the extent of this benefit requires:

- an estimate of the quantity of road traffic (number of cars and the average distance travelled) removed from the road system, remembering that not all people who shift from car to public transport were former car drivers
- an estimate of the change in travel speed, and
- a value of travel time for car occupants to estimate the saving that will accrue to road users.

An estimate of the change in travel speed can be determined using one of four methods:

1. where the initiative involves a transfer from a single road or a corridor, a simple manual approach can be used[17], or
2. in cases where the effects are likely to be substantial and dispersed, it may be necessary to use a computerised travel demand model to identify the changes in travel time for remaining road users, or

15 The benefits described in this section are a component of what are often termed ‘decongestion benefits’. Other decongestion benefits include reduced air pollution and reduced social intrusion.

16 Note that this assumes that public transport has been improved by some means other than reducing road capacity. A project that assists public transport by withdrawing road capacity such as a bus lane may result in increased congestion for existing road users. The methodology to calculate the disbenefits to motorists who continue to use the road system in this case is the same—the only difference is that the analysis shows a disbenefit rather than a benefit.

17 For example, Bray and Tisato (1997) and Akcelik (1991). Travel time is indicated in BTCE (1996) as:

$$t_a = t_o\left[1 + a\left\{(x-1) + \sqrt{(x-1)^2 + bx}\right\}\right] \quad (1)$$

where t_a is average travel time per km, t_o is free speed travel time per km, $x = q/Q$ is the volume/capacity ratio (or degree of saturation), an indicator of congestion level, q is traffic volume (vehicle-km/hr), Q is road capacity (vehicle-km/hr), and a and b are constants.

With $T = qt_a(q)$, marginal travel time is given by:

$$t_m = \frac{dT}{dq} = q\frac{dt_a}{dq} + t_a, \text{ where } \frac{dt_a}{dq} = \frac{t_o a}{Q}\left[1 + \frac{(x-1) + b/2}{\sqrt{(x-1) + bx}}\right] \quad (2)$$

Luk and Hepburn (1995) provide a useful approximation for constants a and b based on the speed (v) when $x = 0$ and 1 (denoted v_o and v_1 respectively) i.e.:

$$a = 0.25v_o \text{ and } b = 16(1/v_1 - 1/v_o)^2, \text{ where } v = 1/t_a. \quad (3)$$

BTCE (1996: Table III.2) reports values for v_o, v_1, a and b for Australian cities for various road types. Considerations here are limited to arterial roads for which $v_o = 58$ kph, $v_1 = 38$ kph, $a = 14.5$ and $b = 0.001318$.

3. use a computerised travel demand model for a general situation to test the effect of withdrawing marginal amounts of road traffic under various circumstances to establish relationships between a given reduction in car-kilometres of travel and savings in travel time for remaining road users that can then be applied more generally, or
4. use information such as that prepared by the Department of Infrastructure, Victoria (2005) that combines the second and third methods described above to indicate a value for congestion relief benefits in terms of cents per vehicle-kilometre of reduced car travel under various traffic conditions.

Account should also be taken of any change in bus traffic on arterial roads in determining average travel speed with and without the initiative. For example, a busway or new or upgraded rail line will remove some buses from the arterial road system and add to the improvement in travel time for traffic remaining on the road system.

3.5.2 Adjustment for induced road traffic

The benefits that result from any reduction in road traffic will be eroded if additional traffic uses the road space made available by the diversion of trips to public transport. However, the benefit to road users is not eroded completely by these second-order effects, because the people who make the additional car trips gain a benefit from their travel. In the case where the additional traffic occurs because some people shift their time of travel, say, from the shoulder of the peak to the peak, or from another road, there are benefits to the people who shift and second-order travel time benefits for traffic in the period or location from which the traffic diverts.

A fully specified multi-modal urban transport model may be applied to estimate the net benefits of any public transport system initiatives, including any induced traffic effects. In this case, the second-order effect is taken into account through the modelling analysis. However, in many cases, such a model may not be available, or full application of a model may not be worthwhile for smaller initiatives. In these situations, a road traffic assignment (only) model may be applied with fixed paths[18] to provide an initial estimate of the decongestion benefits. For appraisal purposes, the net decongestion benefit should be taken as half this estimate, with the factor of one-half representing an allowance for the second-order traffic generation, redistribution and modal split effects (Land Transport New Zealand 2005). This assumption should be used as a default guide, and any variation from this guide should be justified. Bray and Sayeg (2002) provide a more detailed discussion and appraisal of the effects of induced traffic on the economic benefits of a major public transport scheme.

18 The traffic assignment paths (or routings) should be determined in the Base Case. The Project Case should then be run through the model, with the modified traffic volumes constrained to the same paths fixed in the Base Case.

4 Public transport operating resource needs and costs

An initiative may result in changes in the supply of public transport due to:

- introduction of new services or modes; and/or
- changes in public transport patronage resulting in a need for additional services.

This requires:

- a decision on the resource units to be used in assessing changes in public transport services (e.g. bus-kilometres, bus-hours and fleet size)
- a method to estimate the change in resources, and
- relevant unit costs for the changes in resources.

This section considers how changes in public transport operating resources should be estimated and how the cost of these changes should be established.

4.1 Estimating public transport resource needs

Table 1.4.1 sets out methods to calculate the annual operating resources associated with services on a specified bus route. When changes are made to a bus network, this method can be applied to all the routes affected between the Base Case and the Project Case: the total operating resources for all these routes are summed for the two cases, and the difference (Project Case – Base Case) is then calculated. This difference in operating resources may then be multiplied by relevant unit costs (see Section 4.2) to derive the difference (Project Case – Base Case) in annual operating costs.

The method is described for bus services for simplicity; however, similar methods can be applied for other urban public transport modes.

In the case of bus services, three measures of operating resources are usually required (as in Table 1.4.1): bus-kilometres, bus-hours and peak vehicles. These are as defined in Table 1.4.2.

Table 1.4.1: Method for estimation of bus route operating resources

TASK	NOTES RE METHODOLOGY
A. Estimate route (end-to-end) distance and running time	› Route distances are typically derived from a map (or vehicle odometer). › Running times may be estimated from existing timetables or other sources. They need to allow for traffic congestion, bus stop time, etc.; they may differ by time period (peak, inter-peak, evening, etc.) and possibly direction. › As a broad estimate, for urban on-street bus operations, typical end-to-end operating speeds are in the order of 25–30 km/hr.
B. Estimate required service headways (frequency)	› In peak periods, the appropriate headways are likely to be determined by the level of demand on the route (peak direction, at the maximum load point): $\text{Services/hour} = \dfrac{\text{Demand/hour}}{\text{Capacity/vehicle.}}$ › Typical capacity/vehicle estimates for the peak (1-hour) period are given in Section 6, Table 1.6.11. › In non-peak periods, maximum headways are likely to be set on 'policy' grounds. › On routes with relatively high demand, non-peak headways may be determined as for the peak period, using the formula above, but generally with capacity/vehicle limited to all-seated loads (i.e. no standees).
C. Derive peak vehicle requirement (PVR)	› PVR = RTT/headway (rounded up to next integer as necessary), and applied to peak period statistics. › RTT (round trip time) = Direction A running time + Direction B running time + Minimum layover time per round trip. Minimum layover time for a typical bus service would be 5–10 minutes per round trip.
D. Derive route operating statistics for typical periods	› Periods used would be typically a weekday peak 1-hour and a weekday inter-peak 1-hour. › Bus-kilometres for period = Round trips/hour * Round trip distance * Duration of period (hours). › Bus-hours for period = Round trips/hour * Round trip time * Duration of period (hours). › Peak vehicles = PVR, as above (usually relevant only to peak period).
E. Incorporate allowances for 'dead running'	› The above operating statistics relate to on-route running only. These need to be adjusted to allow for 'dead running' to/from the depot or other routes. › At the strategic appraisal level, the following adjustment factors to be applied to the bus-kilometres and bus-hours statistics will provide broad estimates: Peak periods 1.20 Off-peak periods 1.05. › At the detailed appraisal level, vehicle scheduling procedures could be used to derive more accurate adjustment factors.
F. Derive annual operating statistics	› For each of the typical peak and off-peak periods for which the above analyses are undertaken, annual estimates of bus-kilometres and bus-hours may be derived by multiplying: › Typical period statistics (Task D) › Dead running factors (Task E) › Operations annualisation factors. › The operations annualisation factors represent the ratio of operations statistics (bus- kilometres, etc.) for a full year to that in the typical period. For example, for peak periods, an appropriate factor from a 1-hour peak period may be 1000 (i.e. 4 peak hours per day, 250 working days per year). › Some additional guidance relevant to estimation of annualisation factors is provided in Section 6.9.

Table 1.4.2: Operating statistics definitions

ITEM	DEFINITION
Bus-kilometres	Total distance operated by buses in the period concerned. Includes all non-service running (to/from depot, between routes, miscellaneous, etc.). May be derived from odometer readings or other sources.
Bus-hours	Total time that buses are out of the depot with a driver in charge. Includes all dead running, short breaks (up to 10 mins) between trips (waiting at termini, etc.), but excludes extended periods with or without a driver (e.g. parked, driver meal period). May be derived from analysis of vehicle/driver schedules (but in practice often not readily available).
Peak vehicles	Maximum number of buses required in use at any one time on a normal weekday in order to provide the specified services. May be derived from analysis of vehicle/driver schedules.

4.2 Estimating public transport operating costs

It is vital that information on public transport operating costs is in a form that allows changes in operating costs between options to be determined. Expressing operating costs solely as a cost per kilometre of vehicle travel is inadequate. Take, for example, a Project Case where the vehicle-kilometres of service are the same as in the Base Case, but the travel time is reduced because of some improvement in transport infrastructure. It is generally expected that operating costs are lower in the Project Case because, among other things, fewer vehicle-hours are required to provide the service, which leads to savings in crew costs and the number of vehicles needed could be reduced.

Benchmark studies on methodologies to analyse bus and train operating costs in Australia were conducted more than 25 years ago (R. Travers Morgan 1978; R. Travers Morgan 1980).

In practice, public transport operating costs need to be expressed as a function of at least three variables (see Table 1.4.2):

1. the number of vehicles required to meet peak requirements, typically with some overhead costs and costs such as depots and vehicle washing being a function of the number of vehicles in the fleet
2. the distance travelled, with costs such as tyres and a share of fuel and maintenance being related to the distance travelled, and
3. the time the vehicle is in operation, with costs such as driver and other crew time and some overhead costs and fuel consumption related to the distance travelled.

In the case of train services, the distance and time parameters should each be divided into a component related to train (i.e. consist) units and a component related to vehicle (i.e. car) units.

This composition of costs, if correctly derived, should generally reveal all changes in operating costs between options. For example, fuel consumption is a function of both the time vehicles are in service and the distance they travel. A change that results in higher travel speed will show a reduction in operating costs due to improved fuel consumption. More complex operating cost functions can be derived to reflect these effects more precisely if data are available.

Where possible, operating cost functions should be derived based on analysis of cost data relating to the specific city and operator to which the proposed initiative applies. Experience indicates that the cost of operating public transport can vary substantially because of differing levels of efficiency of agencies. For example, Wallis and Bray (2001) report that the competitive tendering and contracting of bus services in Adelaide resulted in a decline in average bus operating costs of 38 per cent. For situations where case-specific cost information is not available, some typical Australian public transport unit cost figures are provided in Section 6.7.

The annual costs of operating a bus service can be expressed as:

$C = N_{pv} * C_{pv} + B_{km} * C_{bkm} + B_{hr} * C_{bhr} + RL * C_{rl}$

where

- C = total annual cost
- N_{pv} = number of peak vehicles
- C_{pv} = unit annual cost per peak vehicle
- B_{km} = number of bus-kilometres operated per annum
- C_{bkm} = unit cost per bus-kilometre operated
- B_{hr} = number of bus-hours operated per annum
- C_{bhr} = unit cost per bus-hour operated
- RL = road length of bus route
- C_{rl} = unit cost per km of road used by bus services.

For the appraisal of most substantial public transport initiatives, the costs that are of relevance are long-run costs: when comparing a Project Case and a Base Case, the relevant cost differences are those that could be expected over the long-run. Experience indicates that, in the long-run, most categories of public transport operating costs are variable with some measure(s) of the scale of the operation.

The value of the cost parameters can vary substantially according to the type of service being provided, the average route length, the efficiency of the public transport agency and the size of buses used.

An illustrative derivation of unit costs for a bus operation, based on the bus company's financial and operational statistics, is presented in Table 1.4.3.

- The first part of the table indicates total annual costs ($125 million overall) and their breakdown into major cost categories. It also shows the resource items with which each cost category is judged to vary e.g. for fuel and oil, 50 per cent of costs are variable with vehicle-hours, 50 per cent with vehicle-kilometres. (Many operators and authorities assume that fuel costs are fully variable with vehicle-kilometres, but the assumption made in the table is probably more accurate for typical urban bus operations.) The table also shows administrative overheads as being 50 per cent variable with vehicle-hours and 50 per cent with the number of peak vehicles (both of which are useful measures of the scale of the operation). While such overhead costs are often treated as fixed (i.e. independent of the scale of the operation), this is unlikely to be the case, except perhaps in the short-term: over the medium- to long-term, organisations generally should be able to adjust their overhead costs to match the scale of their operation.
- The second part of the table indicates the total annual resource statistics for the bus operation.
- The third part of the table derives unit costs by dividing the annual cost figures by the relevant resource measure. For example, for fuel and oil, the unit cost is estimated as $3.89 per vehicle-hour + $0.175 per vehicle-kilometre.

The costs in Table 1.4.3 include only the operating costs involved in the provision of bus services. The capital costs of vehicles (including major, non-routine overhauls) should be considered separately in an economic or financial appraisal. For economic appraisals, the actual capital costs of buses should be shown in the year in which the vehicles are acquired. For financial appraisals, the actual expenditures should be shown as the cash outlays would occur (e.g. in the case of a lease arrangement, the lease payments should be shown on a monthly or annual basis over the lease term).

Table 1.4.3: Approach to deriving bus operating unit costs

		ALLOCATED TO:			
	TOTAL COST ($ MILLION)	VEHICLE-HOURS	VEHICLE-KMS	PEAK VEHICLES	ROAD-KM OF ROUTE
TOTAL ANNUAL COST					
Crew					
Drivers	57.0	100%			
Ticket inspectors	4.0	100%			
Operations					
Fuel and oil	14.0	50%	50%		
Tyres	1.5		100%		
Vehicle repair and maintenance	16.0	50%	25%	25%	
Vehicle cleaning	4.0			100%	
Despatching	1.5	100%			
Bus stop maintenance & information	0.5				100%
Depot maintenance	3.0			100%	
Overhead					
Administration	23.5	50%		50%	
Total	125.0				
ANNUAL RESOURCES					
Unit		veh-hours pa	veh-kms pa	peak vehicles	road-km
Quantity		1 800 000	40 000 000	600	500
UNIT COST ($)					
Crew					
Drivers		31.67			
Ticket inspectors		2.22			
Operations					
Fuel and oil		3.89	0.175		
Tyres			0.038		
Vehicle repair and maintenance		4.44	0.100	6667	
Vehicle cleaning				6667	
Despatching		0.83			
Bus stop maintenance					1000
Depot maintenance				5000	
Overhead					
Administration		6.53		19 583	
Total		49.58	0.313	37 917	1000
Unit		/veh-hour	/veh-km	/peak bus	/road-km

Source: Based on a structure established by Ian Wallis. Values in the table are illustrative only, and do not reflect any particular enterprise.

Application of this approach requires information on the values of unit costs (C_{pv}, C_{bkm}, C_{bhr} and C_{rl}) for the local public transport agency, and values of operating statistics (N_{pv}, B_{km}, B_{hr} and RL) for the Base Case and the Project Case. Note that the unit costs would normally be the same in both the Base Case and the Project Case: any improvements in organisational efficiency should be achievable in both the Base Case and the Project Case. If this is the case, the effect should be excluded from the appraisal. Exceptions may exist; however, they need to be carefully considered and justified. For example, a project might allow an institutional reorganisation that would not be otherwise possible and that could result in reduced overhead costs. While this may be possible, it may simply reflect an easy way to make an institutional change that should be made on the grounds of cost efficiency in any event.

Some agencies may have their own, particular approaches to calculating the operating costs of public transport in the Base Case and the Project Case. The underlying objective is to determine the difference in the total annual cost of operating public transport between the Base Case and the Project Case; whatever means are available can be used, provided they are applied consistently. It is, however, good practice to calibrate the unit costs to the transport agency to demonstrate that the total operating costs, based on the unit costs, are the same as the total operating costs for the agency.

A change between the Base Case and the Project Case in the number of bus-kilometres travelled on the road system will result in a change in the amount of road wear (and the consequent need for road maintenance): this is a significant effect, given the relatively high axle loadings of buses. To a first approximation, the tax paid by bus operators on diesel fuel may be taken as a proxy for these road wear/maintenance costs. However, there is no comparable tax on CNG fuel. Therefore, where CNG buses are involved, an allowance needs to be added for the marginal road wear costs associated with bus operations. Typical marginal road wear costs of operating buses on urban arterial roads are around $0.10 per bus-kilometre in 2005/06 prices (updated from Bray and Wallis 1999, p. 258). In the case of diesel buses, such an estimate could be used to replace the tax component of fuel costs if desired.

Indicative unit operating costs for bus, tram/light rail and urban rail operations in Australia are given in Section 6.7, and vehicle capital costs for each mode are given in Section 6.8.

5 Infrastructure and associated investment costs

5.1 Introduction

Infrastructure costs can represent a large proportion of overall costs associated with public transport initiatives. This is especially the case with large, inner urban initiatives that involve tunnelling or other structures to separate public transport routes from surrounding development and traffic.

It is important, therefore, that infrastructure costs are estimated accurately and risks acknowledged when undertaking economic appraisals of proposed public transport investments. Experience around the world suggests that the costs of transport initiatives (both new roads and public transport) are often underestimated (Flyvbjerg, Bruzelius and Rothengatter 2003).

This section provides guidance on the capital costs of fixed infrastructure associated with major urban public transport initiatives. Capital costs for public transport rollingstock are addressed in Section 6.8.

5.2 Specification of the Base Case

A key first step in initiative definition and costing is the appropriate specification of the Base Case, against which the Project Case will be assessed. The Base Case typically represents the 'business-as-usual' situation and is sometimes referred to as the 'do-minimum' situation. General principles for specifying the Base Case are set out in Section 2.1.6 in Volume 3. The following provides brief additional comments of particular relevance to major urban public transport initiatives.

The Base Case should generally include capital and recurrent expenditures needed over the appraisal period in order to continue to provide either the existing services or a variant of these services that offers a similar service level and quality. For example, the existing service level of a specific mode may need to be expanded over time to cater for population growth in an area.

Where Base Case assets are likely to become technologically obsolescent, or to reach the end of their useful lives during the appraisal period, allowance should be made in the Base Case for their replacement by similar or enhanced assets. Railway signalling systems are an example of this type of asset.

It is important that major capital schemes, that are not already 'committed' but may affect the merits of the initiative being appraised, should not be included in the Base Case. (Committed in this context refers to schemes and expenditures where construction contracts have already been executed.) Where such a scheme (should it proceed) would provide a mutually exclusive alternative to the initiative being appraised, the initiative appraisal should consider three cases: Base Case, Alternative Scheme (plus Base Case) and Project (plus Base Case). Where such a scheme is complementary to the initiative being appraised, the appraisal should compare the Project Case and the Base Case, first with and then without the complementary scheme being included.

5.3 Specification of the Project Case and scope

Poor project specification and 'scope creep' are two of the primary reasons public transport initiatives cost more than originally forecast. Project specification is a particular problem when there is pressure to develop an initiative before all of its dimensions are considered. Project specification is a particular challenge in relation to public transport initiatives that have ramifications for the wider network that may not be readily apparent. The impacts may be felt some distance away from the location of the initiative itself such as the need to upgrade electricity supply or track capacity at particular junctions in a rail network.

Specification of the Project Case requires a range of assumptions to be made. There are two key points to consider: document the basis for any assumptions, and test the validity of key assumptions that are likely to drive the costs of the initiative.

5.3.1 Work breakdown structures

The infrastructure elements of public transport initiatives generally fall into one of the categories shown in Table 1.5.1.

Table 1.5.1: Public transport infrastructure categories

INFRASTRUCTURE CATEGORY	EXAMPLES
Systems infrastructure	Management centres such as network control centres, signalling, communications and rollingstock storage facilities.
Network infrastructure	Rail networks, bus lanes.
Nodal infrastructure	Stations, interchanges, parking stations.

Initiative costs should be itemised, or broken down, in a structured way. This is necessary for three reasons:

- Different assets have different lives and therefore different residual values at the end of the appraisal period.
- The operational and maintenance costs associated with different elements of infrastructure are likely to vary.
- A more detailed breakdown allows the make-up of infrastructure costs to be better understood. In particular, it:
  - minimises the risk that costs are forgotten
  - enables attention to be focused on areas of greatest significance to the total cost of the initiative, and
  - permits closer attention to be paid to areas where there are uncertainties and risks in estimating the costs of an initiative.

Where possible, work breakdown structures should follow a similar architecture and format to those used in the asset management systems of the organisation that will take ownership of the infrastructure. This has a number of advantages. It enables the appraisal to use maintenance schedules and costs that are consistent with those used elsewhere in the organisation (provided, of course, that these are reasonable). If the initiative proceeds, the organisation will find it easier to incorporate it into its asset management system as there is a greater ability to 'bed' the initiative into the organisation.

5.4 Cost estimation and other considerations

5.4.1 *Accuracy of cost estimates*

Given the uncertainty around initiative costs, it is vital that a range of cost estimates is incorporated into any initiative appraisal. Judgment should be exercised when establishing initiative costs.

The contingency applied to cost estimates should be adjusted at various stages of the appraisal as it proceeds from rapid appraisal through detailed appraisal to the Business Case. Larger contingencies are usually used at earlier stages in the initiative life cycle.

Table 1.5.2 gives, as an example, the default contingency allowances used for road schemes in New Zealand at various stages in the project development process.19 It should be noted that wider contingency ranges would generally be appropriate for major public transport initiatives, as these are more of a one-off nature and thus involve greater uncertainty.

Table 1.5.2: Example of default contingency allowances for New Zealand road schemes

PHASE	EARTHWORKS COMPONENT	OTHER WORKS
Initiative Feasibility Report	10%	20%
Scheme Assessment	25%	15%
Design	20%	10%
Contract	10%	5%

Source: Land Transport New Zealand (2006).

5.4.2 *Land and property costs*

Where land has to be acquired for initiative development, the costs should be assumed to equate to market value for purposes of appraising the initiative. Similarly, any land available for sale as part of the initiative should be included as a cost saving.

Where land required for an initiative is already owned by the public authority, its market value should be included in the analysis. Land should not be treated as a 'sunk cost', as the option of alternative use nearly always exists. Market value should be assessed on the basis that the land is available indefinitely for other uses. Indeed, land valuation and compensation legislation in various jurisdictions requires valuations to be determined on the basis of market value.

5.4.3 *Public transport rollingstock*

Changes in rollingstock requirements between the Base Case and the Project Case should be determined. Make allowances for sufficient spare rollingstock for vehicles needed for scheduled maintenance, for unexpected breakdowns and to meet unexpected demand. Typical unit costs for rollingstock are presented in Section 6.8

19 Note that the inclusion of contingencies in the estimated cost of projects differs from the concept of examining the effect of cost variations as part of sensitivity testing in an economic appraisal (as described in Section 2.11 in Volume 3).

5.4.4 *Environmental and related costs*

Costs associated with the amelioration of an initiative's environmental impacts should generally be regarded as part the infrastructure costs, on the basis that the mitigation of environmental impacts is an intrinsic part of the initiative. The extent of these costs is likely to vary widely from initiative to initiative. For example, the impacts themselves can vary between areas and the environmental standards that initiatives need to meet such as noise standards can also vary from jurisdiction to jurisdiction.

Environmental mitigation costs are likely to fall into the following major categories:

- noise mitigation
- remediation of contaminated land, and
- habitat protection.

Noise mitigation measures are one of the most common environmental mitigation costs associated with public transport initiatives. Noise mitigation measures include, for example, noise barriers at costs of up to $2 million per route kilometre. In the case of rail initiatives, various measures such as 'cologne eggs', floating track slabs and acoustic mats are also available to minimise regenerated noise.

No general guidance is given in the Guidelines on the cost of remediation of contaminated land. The cost will vary with the nature of the contaminants, the scale of the contamination and its location. However, these costs can be substantial.

Habitat protection is unlikely to be an issue in many public transport initiatives. By their nature, public transport initiatives tend to traverse urbanised areas where natural habitat is unlikely to remain. However, this issue has arisen on some initiatives in the relatively recent past, with environmental agencies requiring transport authorities to acquire compensatory habitat (where an initiative passes through natural habitat), or to meet the cost of rehabilitating disturbed habitat. Only general guidance can be provided in the Guidelines as the issue will be initiative-specific. If it is an issue, land acquisition costs should be benchmarked against other land sales in the area. Rehabilitation costs will vary depending on the scale of any disturbance and the scale of the initiative.

5.4.5 *Other costing aspects*

Service relocations and adjustments to road layouts and signalling can be significant cost drivers in public transport initiatives. The providers of utilities such as water, electricity, gas and telecommunications want to protect the integrity of their assets and maintain service assurance to their customers. However, utility authorities often have imperfect knowledge about the location of their assets, and usually try to transfer the cost of relocating or protecting their assets to the public transport initiative. In the case of 'trunk' services, where the implications of service disruptions can be significant, the cost of protecting or relocating the utilities can run into millions of dollars.

5.4.6 *Guideline costs*

As a very general guide, Table 1.5.3 provides broad costings for fixed infrastructure for major public transport infrastructure initiatives in large urban areas.

Table 1.5.3: Indicative infrastructure costs for major urban public transport initiatives

INFRASTRUCTURE TYPE	INDICATIVE COST ($2006)	COMMENT
Land	$0.5–4m per hectare (fringe) $3–15m per hectare (established areas)	Highly variable, depending on town/city, number of properties to be acquired, transaction costs and value of 'solatium' payment (i.e. incremental value paid for any forced sale of property).
SYSTEMS INFRASTRUCTURE		
Network control centres	See comment	Network control functions for new public transport initiatives are often incorporated in existing centres. Incremental costs e.g. software upgrades, display units and expansion of facilities, will vary.
NETWORK INFRASTRUCTURE		
Railway track and formation:		
Dual track—surface	$20–50m per kilometre	
Tunnels—dual track, twin bore	$100–150m per kilometre	Excludes land costs. Excludes station costs. Assumes reasonable ground conditions for tunnelling. Cost will be higher if ground conditions are poor, or if significant underpinning of existing buildings is required.
Light rail: dual track	$10–30m per kilometre	Includes stops and sub-stations. Cost at the lower end is for ideal locations, with minimal roadworks and service relocation. Cost at upper end in complex locations e.g. CBD, where roadworks, high quality 'stops' and service relocations will be required.
Essentially dedicated bus lanes	$3–10m per kilometre (excluding land costs)	Highly variable, depending on degree of separation from other traffic, extent of traffic-resignalling, quality of finishes at bus stops and extent of IT systems such as passenger information.
NODAL INFRASTRUCTURE		
Railway stations:		
Surface	$10–30m	Assumes relatively simple stations on new tracks.
Underground	$30–60m	Dependent on scale of station, depth of station, extent of access/egress (including emergencies) requirements.
Light rail stops	$0.1–1m	Highly variable, depending on extent and quality of facilities and urban design treatments. Upper end costs more common in established urban areas.
Commuter car parks	$10 000 per space (at grade) $30 000–$40 000 per space (multi-deck parking)	Dependent on site conditions.
Interchanges	$2–10m	Highly variable, dependent on size of interchange, features, etc. Large interchanges in established areas will cost more than the upper figure.
Wharves	$1–3m	Variable, depending on scale of facilities, range of vessels, need to accommodate variable maritime conditions.

5.5 Asset lives

Elements of public transport infrastructure have different economic lives. Table 1.5.4 provides a set of values that will generally be accepted by most parties. Various transport entities may adopt slightly different views.

Table 1.5.4: Typical economic lives for infrastructure assets

ASSET CLASS	ESTIMATED ECONOMIC LIFE (YEARS)[19]
Systems infrastructure	
Control centres (IT systems) excluding buildings	4
Rail signals and communications	10–20
Traffic lights	20–30
Navigation equipment	5–20
Network infrastructure	
Earthworks	100–150
Bridges	40 (timber), 120 (concrete)
Tunnels	100
Culverts	100–120
Rail	100
Turnouts	12
Ballast	60
Sleepers	20 (timber), 50 (concrete)
Road pavements	40–60
Nodal infrastructure	
Rail and light rail stations	50
Interchanges and commuter parking facilities	50
Bus stops	20
Wharves	40

5.6 Residual values of assets

Where infrastructure assets have a life that extends beyond the time horizon covered by the appraisal, any residual value in the asset (i.e. the discounted value of the asset beyond the appraisal horizon) should be recorded as an initiative benefit.

For purposes of calculating residual values, depreciation of infrastructure assets will normally be on a straight line basis over the economic life.

20 Derived from various sources, notably ARTC (2002). See also Independent Pricing and Regulatory Tribunal (April 1999) and Austroads (2000). In practice, assets such as tunnels (and some bridges) could have lives in excess of 100 years, provided they are well maintained.

6 Unit parameter values

6.1 Introduction

This section presents unit parameter values for items discussed in previous sections. It generally only addresses parameters specific to public transport appraisals. Unit values for the value of environmental externalities generated by public transport vehicles, and some road transport costs, are in Volume 3. Parameter values differing from the values given can be used where they are judged to be more appropriate to the appraisal of a particular initiative, but the basis for such values should be justified.

6.2 User cost function and unit values

Section 3.2.1 introduced the concept of the generalised perceived cost of travel and set out its formulation for travel by public transport. This section provides unit parameter values to use in this formulation, in the context of both demand assessment and initiative appraisal.

The perceived costs of public transport travel may be expressed in terms of either generalised cost or generalised time as follows[21]:

$$GC = F + V * [(T_A * W_A)+(T_W * W_W)+(T_R * W_R)+(T_I * W_I)+N_T * \{T_P + (T_{AT} * W_{AT})+(T_{WT} * W_{WT})\}]$$

$$GT = GC/V$$, with units of 'generalised minutes'

where

GC = total generalised cost (=perceived cost)

GT = total generalised time

F = fare ($)

V = standard value of time ($/min of, say, in-bus time or some other benchmark)

T_A = access time i.e. between an origin/final destination and the public transport facility (mins)

W_A = weighting on access time (to reflect its perceived valuation relative to in-bus travel time)

T_W = (expected) waiting time at a bus stop or train station for initial boarding (mins)

W_W = weighting on expected waiting time (to reflect its perceived valuation relative to in-bus travel time)

20 Identical formulas are provided in Section 3.2.1.

T_R = unexpected waiting or travel time (associated with service unreliability)

W_R = weighting on unexpected waiting or travel time

T_I = in-vehicle time (mins)

W_I = weighting on in-vehicle time to reflect quality attributes (relative to in-bus travel time)

N_T = number of transfers

T_P = transfer penalty to reflect the inconvenience associated with a transfer (in equivalent in-bus travel time (minutes)) where an interchange occurs

T_{AT} = access/walk time on transfer

W_{AT} = weighting on transfer access/walk time

T_{WT} = waiting time on transfer

W_{WT} = weighting on transfer waiting time.

This section provides appropriate default unit parameter values to apply in the generalised cost formula, for purposes of both demand assessment and economic appraisal. It is arranged in the following three sub-sections:

- Section 6.2.1—standard values of time. This sub-section provides standard values of time (V) by peak and off-peak periods and, where appropriate, by public transport mode.
- Section 6.2.2—other user unit cost values. This sub-section provides unit parameter values for all other components of the generalised cost formula, with each value expressed relative to the relevant standard value of time. Combined, the parameter values given in Sections 6.2.1 and 6.2.2 provide all the values required to assess the benefits of major initiatives during rapid appraisal.
- Section 6.2.3—values for infrastructure and vehicle features. This sub-section provides greater detail on unit parameter values, relative to the standard values of time, for specific features of vehicles and infrastructure. These more detailed values may be applied (replacing relevant modal and vehicle values from Section 6.2.2) at the more detailed appraisal stage, particularly for initiatives that involve enhancements to vehicles or station and stop infrastructure.

6.2.1 Standard values of time

The standard value of in-vehicle time for public transport users is a key input to the appraisal process. It also defines the ratio between generalised costs and generalised time i.e. it represents the factor that enables translation between the two sets of units.

The recommended default values in $2006 per hour are:

- Overall $10.00
- By time period peak $10.80, off-peak $9.20.

These values reflect the average incomes of public transport users as a whole, and the different mix of trip purposes at peak and off-peak periods. Appendix A sets out the basis on which the values were derived.[22]

Generally, it is recommended these values are used for all public transport. However, it is recognised that, on average, the incomes of bus users tend to be lower that those of train users, which are in turn lower than those of ferry users. Mode-specific values may therefore be used for particular initiatives, with the following default values:

22 The values quoted here have been derived from a considerable number of Australian studies, involving stated or revealed trade-offs by public transport users, mostly using stated preference methods. Therefore, these values may not be fully consistent with values used elsewhere in the Guidelines, for car and other road users, derived by other methods.

Bus	all $8.80	peak $9.35	off-peak $8.25
Rail/LRT	all $10.25	peak $11.20	off-peak $9.30
Ferry	all $11.80	peak $12.90	off-peak $10.70.

6.2.2 Other user cost unit values

Consistent with the generalised cost formulation, Table 1.6.1 provides recommended default values for all other unit cost parameters. These values are expressed in units of 'generalised time' and may be converted to units of generalised cost by multiplying by the standard values of in-vehicle time as given in Section 6.2.1.

These values are derived from an extensive review of Australian, New Zealand and international evidence, drawn from both stated preference and revealed preference studies. Further details of this review, sources and the range of values identified are provided in Appendix A.

6.2.3 Values for infrastructure and vehicle features

Two 'in-vehicle GT' terms in Table 1.6.1 account for user valuations of the generic or typical features of different modes:

- IVF (in-vehicle factor) represents typical differences between modes in terms of vehicle quality characteristics (e.g. appearance, comfort, ride quality), and
- MSC (mode-specific constant) represents typical differences in stop/station and infrastructure characteristics (e.g. station shelters, help points, real-time information).

At the rapid appraisal stage of modal options, it is normally appropriate to adopt the generic values for the features given in Table 1.6.1. However, at the subsequent, more detailed appraisal level of the most favoured options, it is useful to appraise the costs and benefits of particular modal or service features such as different stations or vehicle features. Typical user valuations of these features are given in Tables 1.6.2 and 1.6.3.

- All values are expressed in terms of generalised time (standard in-vehicle minutes). They may be converted to generalised costs by multiplying by the relevant standard value of time.
- The values are designed to replace the IVF and MSC terms in Table 1.6.1 and hence avoid any double-counting of vehicle or infrastructure features with modal factors: they should be applied as an adjustment term to the GC/GT formulation and expressed in in-vehicle (generalised) minutes per trip.
- All values represent the difference between a base situation and an improved situation.
- Further details on the sources for these values are given in Appendix A. Values have generally been drawn from stated preference studies in a variety of situations. They should be treated as indicative only and used with caution. In some circumstances, new stated preference surveys may be warranted for a particular initiative to derive situation-specific values.
- Experience with stated preference surveys indicates that the perceived benefits to the user of a number of individual features, together, are less than the sum of the individual benefits. This is the 'package effect' and is another reason for caution in the application of these values.[23]

23 In the absence of evidence to the contrary, when a 'package' of features is considered, the quoted values of individual attributes should be divided by two to adjust for any over-estimation (ATOC 2005).

Table 1.6.1: User perceived cost unit values

ITEM (1)	DEFAULT VALUES (GT MINUTES)	VARIATIONS, NOTES
Access GT		
Access time (T_A)	Actual access/egress time	
★		
Access weighting (W_A)	1.4 (normal)	1.2 for short walks (<5 mins). 1.8 for long walks (>20 mins).
Expected wait GT		
Expected wait time (T_W)	$0.72 * H^{0.75}$	H = average headway.
★		
Wait weighting (W_W)	1.4 (normal)	Up to 2.0 in highly congested conditions.
Unexpected wait/journey GT		
Unexpected wait/journey time (T_R)	Actual average lateness	Could apply weighting 6.0 to unexpected wait time at stop, 1.5 to unexpected in-vehicle time.
★		
Unexpected Wait/Journey Weighting (W_R)	3.0	
In-vehicle GT		
In-vehicle time (T_I)	T_i = Actual IVT– MSC (2)	MSC = 0 (on-street bus), 1.0 (on-street tram, old urban rail), 2.0 (busway, refurbished urban rail, LRT), 3.0 (new urban rail).
★		
In-vehicle weighting (W_I)	W_i = IVF (2) * VLF	IVF = 1.0 (on-street bus), 0.90 (busway, on-street tram, old urban rail), 0.85 (guided busway, LRT), 0.80 (refurbished urban rail), 0.75 (new urban rail). VLF (crowding factor): 1.0 (LF <70%); 1.1 seated, 1.4 standing (LF=100%); 1.3 seated, 2.0 standing (crush load).
Transfer GT		
No of transfers (N_T)	Actual number of transfers	
★		
[[Transfer penalty (T_P)	5–10 GT mins	Within mode: 5 for same facility, 7 for different facility. Between mode: 7 for same facility, 10 for different facility.
+ [Transfer walk time (T_{AT})	Actual walk time	
★		
Transfer walk weighting (W_{AT})]	2.0	Higher where gradients exist or congested conditions.
+ [Transfer wait time (T_{WT})	$0.72 * H^{0.75}$	H = average headway of second service.
★		
Transfer wait weighting (W_{WT})]]	1.2	Higher in congested conditions.

Notes: (1) GT = generalised time.

(2) MSC, IVF terms may be replaced by adjustments for specific vehicle or infrastructure features (see section 6.2.3).

Table 1.6.2: Vehicle features values

ATTRIBUTE	SUB-ATTRIBUTE	VALUATION (IVT MINUTES)	COMMENT
BUS			
Boarding	No steps	0.1	Difference between two steps up and no steps.
	No show pass	0.1	Two stream boarding, and no show pass relative to single file past driver.
Driver	Attitude	0.4	Very polite, helpful, cheerful, well-presented compared with businesslike and not very helpful.
	Ride	0.6	Very smooth ride (no jerkiness) compared with jerky ride causing anxiety and irritation.
Cleanliness	Litter	0.4	No litter compared with lots of litter.
	Windows	0.3	Clean windows with no etchings compared with dirty windows with etchings.
	Graffiti	0.2	No graffiti compared with lots of graffiti.
	Exterior	0.1	Very clean everywhere compared with some very dirty areas.
	Interior	0.3	Very clean everywhere compared with some very dirty areas.
Facilities	Clock	0.1	Clearly visible digital clock showing correct time compared with no clock.
	CCTV	0.7	CCTV, recorded, visible to driver, and driver panic alarm compared with no CCTV.
Information	External	0.2	Large route number and destination front/side/rear, plus line diagram on side relative to small route number of front/side/rear.
	Interior	0.2	Easy to read route number and diagram display compared with no information inside bus.
	Info of next stop	0.2	Electronic sign and announcements of next stop and interchange compared with no information of next stop.
Seating	Type/layout	0.1	Individual-shaped seats with headrests, all seats facing forward compared with basic, double-bench seats with some facing backwards.
	Tip-up	0.1	Tip-up seats in standing/wheelchair area compared with all standing area in central aisle.
Comfort	Legroom	0.2	Space for small luggage compared with restricted legroom and no space for small luggage.
	Ventilation	0.1	Push-opening windows giving more ventilation compared with slide-opening windows giving less ventilation.
		1.0	Air conditioning.
RAIL			
Driver/staff	Train attendant	1.6	
	Ride	1.2	Quiet and smooth.
Facilities	CCTV	2.0	
	Onboard toilets	0.6	
Information	Interior	1.1	Frequent and audible train announcements.
Seating	Comfortable	1.5	
	Layout	0.7	Facing travel direction.
	Maintained	1.2	Clean and well maintained.
Comfort	Ventilation	1.5	Air conditioning.

Note: For a package of changes, it would be expected that the total valuation would be lower than the sum of the individual components.

Table 1.6.3: Infrastructure features values

ATTRIBUTE	SUB-ATTRIBUTE	VALUATION (IVT MINUTES)	COMMENTS
BUS			
Stop/shelter	Condition	0.1	Excellent condition, looks like new compared with basic working order but parts worn and tatty.
	Size	0.1	Double-sized shelters compared with single-size.
	Seating	0.1	Seats plus shelter versus no shelter and seats.
	Cleanliness	0.1	Spotlessly clean compared with some dirty patches.
	Litter	0.2	No litter compared with lots of litter.
	Graffiti	0.1	No graffiti compared with lots of/offensive graffiti.
	Type	0.2	Glass cubicle giving good all-round protection compared with no shelter.
Ticketing	Roadside machines	0.1	Pay by cash (change given), credit/debit card compared with pay by coins (no change given).
	Availability of machines	0.2	At busiest stops compared with none.
	Sale of one-day pass	0.1	Sale on bus, same price as elsewhere compared with no sale of one-day pass.
	Cash fares	0.3	Cash fares on the bus, driver giving change compared with no cash fares on bus.
	Two-ticket transfer	2 * 1 ticket transfer	
Security	Security point	0.3	Two-way communication with staff compared with no security point.
	CCTV	0.3	Recorded and monitored by staff if alarm raised compared with no CCTV.
	Lighting	0.1	Very brightly lit compared with reasonably well lit.
Information	Terminals	0.1	Screen with real-time information for all buses from that stop compared with current timetable and map for route.
	Maps	0.2	Small map showing local streets and key locations versus no small map.
	Countdown signs/RTI	0.8	Up to the minute arrival times/disruptions, plus audio compared with no countdown sign.
	Clock	0.1	Digital clock telling correct time compared with no clock.
	Contact number	0.1	Free-phone number shown at stop compared with no number.
	Location of payphones	0.1	One payphone attached to shelter compared with no payphone.
	Simple timetable	0.4	Simpler more user-friendly.
Stations		Up to 3.0	Includes bright lighting, CCTV, cleaned frequently, customer service staff walking around and at info desk, central electronic sign giving departure times, snack bar, cash-point, newsagent, landscaping, block paving and photo-booths.

ATTRIBUTE	SUB-ATTRIBUTE	VALUATION (IVT MINUTES)	COMMENTS
RAIL			
Passenger facilities	Waiting room	0.2	
	Platform seating	0.3	
	Toilets	0.4	
	Weather protection	0.3	Canopies.
	Telephones	0.2	
	Platform lighting	0.3	
	CCTV	0.6	
	Cafe	0.3	
Cleanliness and appearance	Cleanliness	0.5	
	Litter-free	0.5	
	Graffiti-free	0.3	
	Modern	0.2	
Ticketing	Manned booths	0.3	
	Automatic machines	0.2	
Information	Helpful staff	0.5	
	Knowledgeable staff	0.5	
	PA system	0.4	
	Signage	0.3	
	Clocks	0.2	
	Information about next service	0.3	

Note: For a package of changes, it would be expected that the total valuation would be lower than the sum of the individual components.

6.3 Effect of initiatives on travel demand

6.3.1 *Overview*

As noted in Section 3.2.2, a range of methods is in common use for estimating the impacts of public transport initiatives on the demand for travel (by mode, location, time of day, etc.). Several of these methods make use of travel demand elasticity estimates in some form.

- Computerised public transport demand models may use an 'elasticised matrix' approach by which the public transport demand for each origin–destination movement varies in proportion to the change in the generalised cost of travel for this origin–destination pair. In this case, generalised cost elasticity values are used to define the constant of proportionality.
- Simple models for assessing changes in fares, travel times or frequencies on existing routes may use specific (component) elasticities relating to fares and travel times to estimate demand changes.

The following sub-sections outline:

- typical generalised cost, or generalised time, elasticities consistent with the generalised cost formulation provided in Section 6.1
- component elasticities relating to specific journey attributes, for use with simpler models or methods where public transport modes or route structures are not changed, and
- 'diversion rates' relating to the previous modes of the additional public transport passengers attracted by service quantity, service quality or fare changes.[24]

6.3.2 *Generalised cost elasticity of demand*[25]

The weight of Australian and international evidence indicates typical elasticities of urban public transport demand with respect to total generalised costs, or generalised time (as defined in Section 6.1) as:

- short-run (within 12 months of change)—peak -1.0; off-peak -1.5, and
- long-run (7–10 years after change)—approximately twice the short-run values.

Apart from the differences between peak and off-peak values, the weight of evidence suggests generalised cost elasticities are reasonably stable over a wide range of urban public transport situations across developed countries. However, it should be noted that:

- weekend elasticities are generally higher than weekday (off-peak) elasticities
- elasticities tend to be higher than average for short trips, where walking is a competitive alternative, and lower than average for medium and long-distance trips, and
- there is no evidence of systematic differences in generalised cost elasticities between different urban public transport modes, apart from the distance effect.

6.3.3 *Component elasticities of demand*

Table 1.6.4 presents a set of **short-run** default elasticity estimates for fares, service levels and in-vehicle time:

- These elasticities may be used for all urban public transport modes: there is insufficient evidence of any intrinsic differences between modes, other than those relating to trip lengths, service frequencies etc.

24 This part of Volume 4 addresses the impacts of changes in public transport travel (generalised) costs on car travel demand, but does not attempt to address the impacts of changes in car travel costs such as changes in fuel prices or parking charges on public transport demand. These impacts may be addressed through strategic transport models or by using cross-elasticity or similar methods.

25 This section and Section 6.3.3 draw heavily from Wallis (2004).

- The elasticity values are disaggregated by peak and off-peak periods as a proxy for strong differences between market segments, particularly work and commuting trips versus shopping, recreational and social trip purposes. Most evidence indicates that off-peak elasticities are around twice peak elasticities.
- Elasticity values also tend to vary with the contribution of the component to the total journey generalised cost, broadly consistent with the assumption of constant generalised cost elasticity. Thus, service level elasticities increase, more or less, proportionately with service headways, up to an hourly frequency.
- Fare elasticities should be applied to fare changes in real terms, that is, after adjustment for any inflationary effects.
- Table 1.6.4 does not include any elasticity values for service reliability. However, in the case of irregular services, the elasticity for the standard deviation of service arrival times may be around -0.7 to -0.8, approximately twice the elasticity for in-vehicle time.

Table 1.6.4 relates to short-run component elasticities. For the long-run, the best evidence is that elasticities are about twice the short-run values for all three variables.

Table 1.6.4: Short-run component elasticity estimates

ATTRIBUTE	BEST ESTIMATE (DEFAULT) VALUES			TYPICAL RANGES (ALL PERIODS)
	OVERALL	PEAK	OFF-PEAK	
Fares	-0.35	-0.25	-0.50	-0.2 to -0.6
Service levels (1)	+0.35	+0.25	+0.50	+0.2 to +0.5
In-vehicle time	-0.40	-0.30	-0.50	-0.1 to -0.7

Note: (1) Best estimates reflect medium-frequency (20–30 minutes headways) typical of suburban bus services.

Table 1.6.5 provides further evidence of how the Table 1.6.4 component short-run elasticity estimates vary across a range of market situations and trip characteristics. The following points should be noted in relation to this evidence:

- Strong systematic variations in elasticities exist between trip purposes and time periods (the two factors being strongly correlated) for all three variables. Weekday off-peak elasticities are around twice peak period elasticities and weekend elasticities are generally higher than weekday off-peak values.
- Elasticities vary in a complex way with trip distance: this can be explained, in part, by the availability of substitutes, with high elasticities for short trips having the alternative of walking, and, in part, by the importance of the component measure in the total trip generalised cost.
- Elasticities vary with city size, although the fare effect and the service level effect appear to be opposite. However, there is limited data relating to this issue.
- Both fare elasticity and service elasticity vary strongly, and more-or-less linearly, with the magnitude of the base fare or headway. This is particularly significant in regard to service headways: a typical service elasticity would be 0.1 to 0.2 at short headways (better than every 10 minutes) increasing to around 0.5 to 0.6 or more at longer headways (hourly or longer). These variations are broadly consistent with a constant generalised cost elasticity formulation.
- Most studies show no significant difference in elasticities between fare increases or decreases or between large or small fare changes. Very little evidence is available about any differences relating to the direction of change (increase or decrease) for either service levels or in-vehicle time.

Table 1.6.5: Summary of evidence on component elasticities for key variables

ASPECT	ELASTICITY VARIABLE		
	FARES	SERVICE LEVELS	IN-VEHICLE TIME
Time horizon	Long-run typically double (range 1.5 to 3.0) short-run.	Long run typically about double short-run.	Very limited evidence indicates long-run 1.5 to 2.0 times short-run.
Trip purpose/ time period	Off-peak/non-work typically twice peak/work; weekend most elastic.	Off-peak/non-work typically about twice peak/work; weekend most elastic (may be partly due to frequency differences).	Inconclusive re relative elasticities, although most evidence is that off-peak is more elastic than peak.
Mode	Bus elasticities typically somewhat greater than rail (but largely reflects shorter bus trip lengths).	No evidence of significant differences (apart from variations with headway).	Bus elasticities typically lower than rail (reflecting longer trips by rail with in-vehicle time a greater proportion of generalised costs).
Trip distance	Highest at very short distances (walk alternative), lowest at short/medium distances, some increase and then decrease for longest distances (beyond urban area).	Highest at short distances (walk alternative).	Limited evidence—longest trips more elastic than short/medium distance trips.
City size	Lower in larger cities (over 1 million population)—US evidence.	Higher in larger cities—EU evidence.	No evidence.
Base level of variable	Elasticities broadly proportional to the base fare level (based on recent UK study, otherwise limited evidence).	Elasticities increase with headways (broadly proportional up to 60 mins headway).	No firm evidence, although expect elasticities to increase with proportion of total trip (generalised costs) spent in-vehicle.
Magnitude of change	No significant variation in elasticities with magnitude of change (most studies).	No evidence.	No evidence.
Direction of change	No significant differences for fare increases and decreases (most studies).	No evidence.	No evidence.

6.3.4 Previous modes of 'new' public transport users[26]

Table 1.6.6 provides evidence from a range of Australian and international sources of the patronage impacts of major urban public transport initiatives in terms of the previous travel modes of their users. For each initiative it shows the breakdown, according to previous mode of travel, for:

- total patronage with the initiative, and
- 'new' public transport passengers only i.e. those who did not previously use public transport for the trip.

26 This section draws heavily from Booz Allen Hamilton (2000).

Table 1.6.6: Previous mode of travel by public transport users after the implementation of major public transport projects

PROJECT	PROPORTIONS OF MARKET BY PREVIOUS MODE (%) (1)							
	Car driver	Car passenger	Did not travel	Walk/ cycle	Other	Total new PT market	Existing PT users	Overall total
Australian Schemes								
Adelaide O-Bahn	13	6	9		4	33	67	100
	(40)	(17)	(27)		(15)	(100)		
Perth N Suburbs Railway	23	1	10		1	35	65	100
	(66)	(3)	(29)		(3)	(100)		
Bundoora (Melb) Tram extension	16		11	5		32	68	100
	(49)		(36)	(15)		(100)		
UK Heavy/Light Rail Schemes								
Birmingham (cross-city rail link)	11		26			37	63	100
	(30)		(70)			(100)		
Merseyside Rail (link/loop project)	20		24			44	56	100
	(45)		(55)			(100)		
West Yorkshire (new rail stations)	16		13		2	31	69	100
	(52)		(42)		(16)	(100)		
Manchester Metrolink	14		15			29	71	100
	(48)		(52)			(100)		
Glasgow Rail (cross-city rail link)	15		15			30	70	100
	(50)		(50)			(100)		
London Underground	20		19			39	61	100
	(51)		(49)			(100)		
European Light Rail Schemes								
Grenoble LRT	5		4	3		12	88	100
	(42)		(33)	(25)		(100)		
Nantes LRT	10		16		7	33	67	100
	(30)		(48)		(21)	(100)		
Nieuwegein LRT	8		10			23	77	100
	(35)		(23)			(100)		
USA Rail Schemes								
San Diego Trolley	30				4	44	56	100
	(68)				(9)	(100)		

Note: (1) Unbracketed figures show the proportions of passengers using the new service broken down by their previous mode of travel. Bracketed figures show the proportions of new public transport passengers (resulting from the initiative) broken down by their previous mode of travel.

Of most relevance to the appraisal of initiatives is the proportion of new public transport users that previously made their trip as car drivers.[27] The conclusions on this, in the context of urban public transport schemes in Australia, may be summarised as follows:

- For major public transport schemes, typically 35–40 per cent of new public transport users would have made the trip as car drivers.
- For those public transport initiatives particularly oriented to motorists, higher car driver proportions are appropriate. This includes initiatives such as park-and-ride facilities and express bus services, each with ‘diversion rates’ from car drivers of over 50 per cent and in some cases as high as 70–80 per cent.
- For those public transport initiatives with a more ‘social’ focus, lower diversion rates would be appropriate. These include off-peak fare schemes and suburban bus route enhancements. For these schemes, the diversion rates may be as low as 20–30 per cent.

6.4 Benefit of reduced car ownership

As noted in Section 3.4.2, the unit saving due to a reduced need for car ownership should be equal to half the benefit accruing to a former car driver who is able to avoid owning a car when they shift to public transport. This section estimates the unit savings associated with former car drivers.

While car trips avoided are likely to be made by cars of a variety of ages, it is more likely that the car given up is a second or subsequent vehicle, and hence will be older than the average age of the total vehicle fleet. Given a typical vehicle life of 15 years, it is recommended that the average age of cars whose ownership is avoided should be taken as ten years. Cars lose value more rapidly in early years, and the disposal value for a car two-thirds of the way through a 15-year life is about 15 per cent of the cost of the vehicle when new. Given a new car resource cost of $22 400 (Austroads 2004) in June 2002 and a 7.8 per cent reduction in car costs since that time (ABS Cat. No. 6401.0), the disposal value of cars that are no longer needed averages about $3100.

However, about half of vehicle depreciation is linked to the distance travelled by the vehicle (Bennett and Dunn 1990), and is recorded in the resource cost of car use; the other half of vehicle depreciation is related to time or the age of the vehicle. Hence, the additional resource benefit from the reduced need for car ownership is about $1550 per vehicle saved. This benefit should be included in the year in which the mode shift occurs. As indicated in Section 3.4.2, the average benefit per potential car saved is taken to be half of this value (i.e. $775 per car driver who shifts to public transport) to allow for some car ownership not being avoided. Reduced car ownership also avoids fixed charges such as vehicle registration and insurance; however, these are charges for resources such as road supply and crash costs respectively that are considered in other components of the appraisal, and hence should be ignored when assessing the direct benefit associated with avoided car ownership.

6.5 Benefit of avoided car parking

The benefit of avoided car parking varies substantially according to circumstances, as indicated in Section 3.4.2. The resource cost of providing a car park also varies substantially, being affected, for example, by the value of land and the type of parking involved. Based on data from a number of sources, a recommended default value for the cost of a car park in a multi-storey building is $20 000 per space excluding land, plus a further cost of about $1000 per annum per space for

27 The approach used here, based on ‘diversion rates’ (i.e. the proportions of new public transport users ‘diverted’ from the various alternative modes), is considered preferable to an approach based on cross-elasticities of car use with respect to public transport travel costs. The evidence indicates that cross-elasticity values are sensitive to base mode shares and are not readily transferable between situations.

maintenance and operation of the car park. The recommended default capital cost of at-grade car parks will generally be about $4000 per space excluding land, with maintenance costs of about $100 per space per annum. Operating costs for at-grade spaces will vary substantially according to the size and circumstance of the car park, and need to be estimated.[28]

Examples of subsidies for the development and operation of car parking are the provision of free land by the government or provision of the car park infrastructure to an operator at a price below its cost. Note that this is a separate matter to the price that is charged (or not charged, as may be the case) to users of the car parks because the price may be unrelated to the cost of the resources used to develop and operate the car park.

6.6 Decongestion benefits of reduced road traffic

Section 3.5 sets out several methods for estimating the decongestion benefits for remaining motorists as a result of some car users switching to public transport. One approach is to multiply the reduction in vehicle-kilometres (vkt) of car travel by some generalised value of unit decongestion benefits per vkt change.

Two sources of generalised unit decongestion benefit values are given in the following tables:

- Table 1.6.7 shows default values as recommended by the Department of Infrastructure, Victoria. These values range from 17¢ to 90¢ per vkt change. These values cover both time and vehicle operating cost changes, and allow for any 'induced traffic' effects resulting from reduced car travel demand.
- Table 1.6.8 shows default values recommended by Land Transport New Zealand for the appraisal of public transport and travel demand management (TDM) initiatives. These values allow for both time and vehicle operating cost changes and are explicitly adjusted for induced traffic effects. These adjusted values range from zero to NZ64¢ per vkt change.

The two sets of estimates are broadly comparable in magnitude[29], although the New Zealand set recognises that decongestion effects may be zero in many situations.

If such default values are used, choose values within the ranges given and use sensitivity testing to assess the impacts of plausible variations.

Table 1.6.7: Default decongestion benefit rates, Victoria

TIME PERIOD	CONGESTION LEVEL	BENEFIT RATE ¢/VKT CHANGE (JUNE 2004 PRICES)
Peak	Heavy	90
	Moderate	64
	Light	17
Off-peak	All	17

Source: Department of Infrastructure, Victoria (2005)

28 Cost estimates given are based on information provided by George Brown of Western Australian Department of Planning and Infrastructure (personal communication 15 September 2006).

29 Noting that, at October 2006, NZ$1 was equal to approximately A$0.88.

Table 1.6.8: Default decongestion benefit rates, New Zealand

TIME PERIOD	CITY	BENEFIT RATE ¢/VKT CHANGE (1) (NZ¢ 2002) 'BASE' (2)	'ADJUSTED' (2)
Peak	Auckland (average)	127	63.5
	Wellington (average)	98	49.0
	Christchurch (average)	9	4.5
	Other areas	Zero	Zero
Off-peak	All areas	Zero	Zero

Source: Land Transport New Zealand (2005)

Notes: (1) Rates cover travel time and vehicle operating cost savings (any accident and environmental benefits need to be allowed for separately).

(2) The 'base' figure is before allowing for any 'secondary' responses to changes in road traffic demand; the 'adjusted' figure is after allowing for 'secondary' responses, including 'induced' traffic effects. The adjusted figure is more appropriate for appraisal purposes (see Section 3.5.2).

6.7 Public transport operating costs

Section 4.2 provides a methodology for deriving unit costs for any specific urban public transport operation, and applying these unit costs to estimate the incremental operating costs for a defined change in services (frequencies, routes, hours of operation, vehicle types, etc.). Such a methodology should be used at the detailed appraisal stage. It may also be appropriate at the initial, rapid appraisal stage, depending on the type of options being assessed and the availability of appropriate data. It is expected that major operators would maintain a set of unit variable costs for their own purposes.

In other situations, unit variable costs for the options being appraised may not be readily available at the rapid appraisal stage, particularly when new public transport modes are under consideration. In these cases, estimates for unit costs of public transport operations typical of Australian metropolitan or urban conditions are provided. Table 1.6.9 provides relevant cost estimates for:

- bus—standard size buses (typically 40–45 seats)
- light rail or tram—based on average rates for Melbourne operations, and
- heavy (suburban) rail—three-car electric units (similar to Melbourne or Brisbane rollingstock).

Table 1.6.9: Operating cost summary—bus, tram & train (2005/2006 prices)

COST CATEGORY	UNITS	BUS	TRAM	TRAIN
On-vehicle crew costs	$/train or bus-hour	33	60	220
Vehicle (direct operating) costs	$/unit or bus-km	0.90	1.50	2.80
Infrastructure operations and maintenance costs	$ 000 pa/track-km		65	115
Overhead (operating) costs	% on other op costs	21.0	17.5	14.0
Profit margin	% on tot op costs	6.0	4.0	4.0

Notes:
Bus: standard size bus (approximately 40 seats).
Tram: typical tram (e.g. average of Melbourne fleet).
Train: three-car unit, typically operating as two units per train (e.g. similar to Melbourne, Brisbane operations).

For situations in which alternative bus capacities or types are being considered, Table 1.6.10 shows cost variations with bus capacity (based on diesel bus operations).

Table 1.6.10 Operating cost summary—buses, by size (2005/2006 prices)

COST CATEGORY	UNITS	ARTIC.	3-AXLE	STANDARD (39–49 SEAT)	MIDI (30–38 SEAT)	MINI
On-vehicle crew costs	$/bus-hour	33	33	33	33	33
Vehicle (direct operating) costs	$/bus-km	1.13	0.99	0.90	0.77	0.62
Overhead (operating) costs	% on other op costs	21.0	21.0	21.0	21.0	21.0
Profit margin	% on tot op costs	6.0	6.0	6.0	6.0	6.0

Notes: Based on diesel-powered buses.

The operating costs in Tables 1.6.9 and 1.6.10 are divided into four categories.

1. **On-vehicle crew costs.** These cover all direct costs for on-vehicle staff (drivers, guards, etc.), including both wage costs and direct on-costs (payroll tax, superannuation, etc.). They are expressed per vehicle hour or per set hour (trains).
2. **Vehicle (direct operating) costs.** These principally cover vehicle fuel and power, vehicle maintenance (labour, parts, outside services) and tyres.[30] They are expressed per vehicle-kilometre or unit-kilometre.
3. **Infrastructure operations and maintenance costs.** These cover all costs relating to operations and maintenance of the infrastructure operations and maintenance for track, right-of-way, signalling, power supply and communications systems. For simplicity, these costs are expressed per track-kilometre (although in practice some of these costs may vary with measures of system usage).
4. **Overhead (operating) costs.** This category covers all other operating costs not included in the other three categories. These include operations overheads (scheduling, rostering, driver supervision, depot-related costs); vehicle maintenance overheads (engineering technology services, etc.); head office costs (higher management functions, etc.); and general labour and non-labour overheads (information technology, human resources, insurance, etc.). While overhead cost functions may be expressed in various ways, Tables 6.9 and 6.10 treat them, for simplicity, as a percentage mark-up on all other operating costs.

In addition to operating costs, Tables 1.6.9 and 1.6.10 also include a **profit margin** term, expressed as a percentage mark-up on total operating costs. This item represents the amount a commercial operator expects to be paid to compensate for the risks of being in the business; it is additional to all operating costs plus the full economic costs of vehicle ownership (see Section 6.8 below). The percentage rates given are based on considerable evidence from the Australian (and international) bus sector, but on less evidence for the train and tram sectors.

The unit costs in Tables 1.6.9 and 1.6.10 should be applied in an **additive** manner i.e. (for trains):

Total cost = [(train-hours * $/train-hour) + (unit kms * $/unit-km)
+ (track-kms * $/track-km)] * (1 + overhead cost %) * (1 + profit margin %).

The total operating costs to provide a service are thus the sum product of the unit costs and the relevant operating resource requirements (train-hours, unit-kms, etc.). To establish these operating resource requirements, relationships need to be established between peak period service levels (e.g. services/hour) and peak passenger demand (as discussed in Section 4.1).

30 For buses, the figures given include an allowance for (incremental) road maintenance associated with the passage of buses. This allowance is about 8¢/bus-km (see Bray and Wallis 1999).

6.8 Rollingstock capital costs

This section provides estimates of typical capital costs of public transport vehicles for use in Australian urban conditions. Table 1.6.11 provides relevant estimates for:

- bus—ranging from mini-bus to articulated vehicles, mostly diesel-powered
- light rail/tram—articulated (five-module) vehicles (generally similar to Melbourne Combino rollingstock, and
- 'heavy' (suburban) rail—for both electric-powered and diesel-powered units, in both cases relating to three-car single-deck units (generally similar to Melbourne or Brisbane rollingstock).

In relation to the interpretation and application of the figures in Table 1.6.11, the following points should be noted.

- Costs are shown both on a capital basis, for discounted cash flow appraisals, and on an average annualised basis for annualised appraisals and at more strategic levels.
- Annualised costs are derived from capital costs on an annuity basis, using a seven per cent (real) discount rate.
- Effective vehicle lives are taken as 20 years for buses (except mini-buses) and 35 years for light and heavy rail vehicles. Authorities adopt different policies for vehicle lives, and the figures given represent lives between the extremes adopted by different Australian authorities.
- Given the vehicle lives assumed, the costs shown also allow for major ('half-life') rehabilitation once over the life of each vehicle (except the mini-buses). For rail vehicles, these rehabilitation costs are substantial as some elements of the vehicles such as the control system are likely to be technologically obsolescent by the time of rehabilitation, while other elements such as internal furnishings cannot be expected to have lives up to 35 years.
- The capital costs also allow for small residual values at disposal. In practice, these make little difference to the annualised cost estimates.
- The vehicle capital costs shown exclude the costs of procuring the rollingstock, including planning studies, development of specifications, tendering, contracting and supervision costs. These costs can range from 2–5 per cent of the cost of vehicles.
- Table 1.6.11 also shows effective vehicle passenger capacities and derives the annualised vehicle costs per unit of passenger capacity. The capacities are taken to represent practical capacities for service planning purposes in Australian conditions, averaged over a one-hour peak period (peak direction only) at the point of maximum loading along the route. Loading levels on individual services may exceed these one-hour averaged levels. For example, in Melbourne, heavy rail loadings of up to 550 passengers per three-car unit have been experienced on individual trains, compared with the one-hour standard of 400 passengers given in Table 1.6.11.
- In applying Table 1.6.11 costs, make an allowance for spare vehicles; that is, vehicles required in the fleet additional to the peak traffic requirement, to cover vehicle breakdowns and maintenance. Typical allowances for spare vehicles are usually in the range of 8–10 per cent of the peak vehicle requirement.

Table 1.6.11: Costs and capacities of public transport vehicles (2005/2006 prices)

	LENGTH (M)	PASSENGER CAPACITY PER VEHICLE			CAPITAL COST PER VEHICLE ($ 000)	AGE AT DISPOSAL (YEARS)	RESIDUAL VALUE AT DISPOSAL (%)	REHABILITATION [3]		EQUIVALENT ANNUAL CAPITAL COST ($ 000/YEAR) [5]			
		SEATS	SEATS + PRACTICAL STANDEES/ VEHICLE [1]	PRACTICAL PK-HOUR CAPACITY (PK DIRN) [2]				TIME FROM NEW (YEARS)	COST (% OF NEW VEH. COST)	INITIAL CAPITAL	REHAB-ILITATION	TOTAL	TOTAL COST/ PASSENGER CAPACITY [6]
Bus (diesel)													
Mini	8.0	19	19	19	115	10	0	0	0.0	15.8	0.0	15.8	0.83
Midi	10.0	29	40	34	280	20	5	12	10.0	25.2	2.0	27.2	0.80
Rigid standard	11.7	39	64	47	380	20	5	12	10.0	34.2	2.7	37.0	0.79
Rigid gas	11.7	39	64	47	430	20	5	12	11.5	38.8	3.6	42.3	0.90
Rigid long	14.5	47	81	57	400	20	5	12	10.0	36.1	2.9	38.9	0.68
Artic.	18.0	67	101	80	600	20	5	12	10.0	54.1	4.3	58.4	0.73
Light rail													
Artic.[4]	30.0	58	190	130	4500	35	2.5	20	12.0	335.4	14.8	350.2	2.69
Heavy rail [7]													
EMU 3-car set	72.0	265	750	400	8000	35	2.5	20	14.0	596.3	30.7	627.0	1.57
DMU 3-car set	72.0	265	750	400	8800	35	2.5	20	14.0	655.9	33.8	689.7	1.72

Notes:

(1) This is the maximum number of passengers that can be carried per vehicle—allowing for both seating and standing capacity.
(2) This represents the practical average loading/vehicle at the maximum load point spread over the peak one-hour, peak direction.
(3) Major rehabilitation/overhaul is assumed to occur once over the life of vehicles.
(4) Costs and capacity relate to five-module articulated trams, which cannot be coupled (based on Melbourne Combino vehicles).
(5) Based on annuity calculations, using a seven per cent per annum (real) discount rate.
(6) Need also to allow for spare vehicles, typically a 10 per cent addition to peak vehicle requirements.
(7) Costs and capacity relate to single-deck three-car sets (similar to Melbourne or Brisbane vehicles).

6.9 Expansion factors

Expansion factors are needed to derive annual benefits and costs from data that are likely to be available only for shorter periods such as estimates for a morning peak period or a weekday. Commonly used key periods are:

- morning or evening peak period—possibly the peak hour only, but 1.5-, two- and three-hour periods are sometimes used
- average daytime inter-peak hour—usually something like the average (per hour) for the period 9 or 10 am until 3 or 4 pm
- average working weekday—average for Monday to Friday, excluding public holidays
- average weekday—average for Monday to Friday, including public holidays
- annual—total for 365 days, and
- annual average day—annual divided by 365.

Where specific data are not available, the following factors are suggested.

6.9.1 Passenger demand and user benefits

It is usual for analyses of travel demand to consider only particular times of the day or a typical average weekday. Data are presented in Tables 1.6.12, 1.6.13 and 1.6.14 to enable benefits for these periods to be factored to allow an annual benefit to be estimated.[31]

Table 1.6.12: Distribution of weekday public transport demand

TIME PERIOD	SHARE OF DEMAND
00:00 to 06:59	2.6%
07:00 to 08:59	21.1%
09:00 to 11:59	17.9%
12:00 to 14:59	18.4%
15:00 to 15:59	11.2%
16:00 to 17:59	19.4%
18:00 to 21:59	8.0%
22:00 to 23:59	1.4%
Total	100.0%

Table 1.6.13: Distribution of working weekday public transport demand

TIME PERIOD	NUMBER PER ANNUM	SHARE OF DEMAND
Monday	47	17.8%
Tuesday	50	20.0%
Wednesday	52	20.6%
Thursday	51	20.9%
Friday	51	20.7%
Total	251	100.0%

31 These data are based on statistics for the Adelaide metropolitan public transport system for 2005/2006 as provided by Public Transport Division, SA Department for Transport Energy and Infrastructure.

Table 1.6.14: Distribution of annual public transport demand

TIME PERIOD	NUMBER PER ANNUM	SHARE OF DEMAND
Average working weekday	251	89.8%
Saturday	52	6.2%
Sunday	52	3.5%
Public holiday	10	0.5%
Total	365	100.0%

6.9.2 Public transport operating resources and costs

The quantity of public transport service provided is generally guided by demand during peak periods on working weekdays and by desired minimum service frequencies at other times of the day and week. Estimating the annual operating cost of public transport, based on the quantity of service required during a specific period for which planning has been undertaken, must take account of these factors. Default data that enable this are shown in Tables 1.6.15, 1.6.16 and 1.6.17. The data are drawn from bus schedules. Data more appropriate to particular circumstances may be substituted, where they are available.

Table 1.6.15: Distribution of weekday supply of public transport services

TIME PERIOD	SHARE OF VEHICLE-KILOMETRES	SHARE OF VEHICLE-HOURS
00:00 to 06:59	3.8%	3.4%
07:00 to 08:59	17.6%	18.4%
09:00 to 11:59	21.2%	21.0%
12:00 to 14:59	14.8%	14.7%
15:00 to 15:59	9.2%	9.3%
16:00 to 17:59	17.7%	18.5%
18:00 to 21:59	12.4%	11.6%
22:00 to 23:59	3.4%	3.0%
Total	100.0%	100.0%

Table 1.6.16: Distribution of working weekday public transport service supply

TIME PERIOD	NUMBER PER ANNUM	SHARE OF WEEKLY VEHICLE-KILOMETRES	SHARE OF WEEKLY VEHICLE-HOURS
Monday	47	20%	20%
Tuesday	50	20%	20%
Wednesday	52	20%	20%
Thursday	51	20%	20%
Friday	51	20%	20%
Total	251	100%	100%

Table 1.6.17: Distribution of annual public transport service supply

TIME PERIOD	NUMBER PER ANNUM	SHARE OF ANNUAL VEHICLE-KILOMETRES	SHARE OF ANNUAL VEHICLE-HOURS
Average working weekday	251	85.5%	85.5%
Saturday	52	8.5%	8.5%
Sunday	52	5.0%	5.0%
Public holiday	10	1.0%	1.0%
Total	365	100.0%	100.0%

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APPENDIX

A

Public transport appraisal guidelines—unit parameter values

A.1 Introduction

All valuations, apart from uncrowded in-vehicle time (IVT), are in equivalent uncrowded IVT minutes. IVT is given in Australian dollars with a 2006 price base. Values of IVT given for previous years are increased to an equivalent 2006 value, adjusting for inflation and a general increase in the values of time (VoT). Other attributes that are in minutes of equivalent IVT can be converted into a monetary value using the VoT.

Where attribute values are considered broadly consistent, the average and range in values are determined. The averages are unweighted and a 95 per cent confidence interval, where there is 95 per cent confidence the average lies within the interval, is also given. Most of the attribute valuations relate to stated preference data (what people say they do) rather than revealed preference data (what they actually do). There is significantly less revealed preference data for public transport attribute valuation, and little research on comparing stated and revealed behaviour. From the research available, it suggests that stated preference valuations are generally higher than revealed preference.

A.2 In-vehicle value of time

VoT are presented here as in uncrowded conditions (see Appendix A, Section 3 for crowded values). VoT are difficult to compare across studies because of differences in price bases and differences in the composition of market segments. Approaches used to calculate VoT can also differ, with some studies relating IVT to a public transport monetary component, typically a fare, and some studies relating IVT to car-based costs such as parking charges. It is also difficult to directly compare across countries, due to differences in exchange rates and average wages. As such, the direct analysis of IVT is undertaken for the Australian context only; however, the international research supports some of the Australian conclusions. For Australian VoT, the price base is adjusted by assuming average inflation between 2000 and 2005 of 2.3 per cent per annum and average increases in VoT assumed to be 0.5 per cent per annum, a total increase of 2.8 per cent per annum.

Table A.1 provides a summary of the Australian data.

Table A.1: IVT valuation summary ($2006/hour)

GEOGRAPHY	SUMMARY	COMMENTS
Australia	Mean: 9.97 Median: 9.64 Min: 5.51 Max: 15.22 Range: 9.71 95% Range: 9.06–10.87	Peak values are typically 8% higher than the average, and off-peak 8% lower. On average bus users the have lowest VoT at $8.78 (peak/off-peak ±6%), rail at $10.25 (±9%), ferry at $11.78 (±9%), and LRT at $12.63 (±12%). Note only one LRT observation.

References: 3, 13, 15, 16, 18, 20, 21, 26, 27, 28, 31, 32, 38, 44, 61, 63, 64, 65, 74, 86 and 87.

Note: Some valuations have been excluded due to being inappropriate. The mean is calculated as a straight average.

The following points summarise issues around VoT.

- International research suggests VoT differ by trip purpose, time period, distance and geographic locations where average incomes are highly disproportionate.
- Rail and metro users have similar VoT. Bus users typically have lower VoT due to, on average, the lower socio-economic status of bus users. VoT for in-work (business) travel purposes is significantly higher than for commuting or other (leisure, recreational etc) purposes.
- In Australia, the average VoT is $9.97 based on the studies reviewed, with a 95 per cent confidence interval range of $9.06–$10.87.
- Comparing peak and off-peak values, where these were available, indicates the peak as eight per cent above the average value and off-peak eight per cent below the average value. This means that the peak is around 18 per cent higher than off-peak.
- Australian studies also support the international research that bus users generally have the lowest VoT, with rail users 17 per cent higher, ferry users 34 per cent higher and LRT 44 per cent higher, with little variation in the peak/off-peak split between modes (bus ±6 per cent, rail and ferry ±8 per cent). Note, however, that the LRT VoT only relates to one study (BAH 2004).

There are a number of recommended typical values.

- An all-day public transport IVT valuation of $10.00/hour (2006 prices), with peak travel valued at $10.80 and off-peak at $9.20.
- Individual modal travel VoT could be used to represent differences in incomes of public transport users, typically defined by the geographic areas these modes cover. The studies examined suggest bus (peak/off-peak) valued at $8.80 ($9.35/$8.25), rail/LRT valued at $10.25 ($11.20/$9.30), and ferry at $11.80 ($12.90/$10.70); however, these values are context specific.
- For a transport context where only one mode is considered, the own mode VoT could be used. Where two modes are included, a VOT between the two modes could be used. For any more than two modes, the overall public transport valuation should be used. If more context-specific VoT are available for an initiative, they should be used.
- The recommended values exclude in-vehicle quality factors. Values of IVT could also be adjusted to reflect mode-specific quality factors. This is addressed in Appendix A, Section 9.

A.3 Crowding

Crowding, or crowded IVT, valuation reflects the discomfort passengers feel from not only standing on a service due to lack of seating, but also being seated while others are standing. For example, passengers may feel a level of guilt, or many feel they have their personal space invaded. As crowding levels increase to crush capacity, the valuation of crowding in IVT minutes should also increase. There is less research on crowding valuation than other public transport attributes, particularly in the Australian context. Internationally, most of the research is based on previous studies. Valuations are usually made on average load factors (LF) (demand/seats) in the case of heavy rail, where a higher proportion of capacity is seated, and the ratio of seated:standing load factors in the case of the metro Underground services where most capacity is standing room. Definitions of crush capacity also vary between studies. There is less research for crowding valuations on bus, but the available research does not suggest substantially different valuations.

The following summarises crowding valuation issues.

- Research on crowding valuation mostly comes from international sources, although the small amount of Australian research supports the international experience.
- Crowding valuations are different for sitting in crowded conditions and different for various levels of crowding while standing.
- International research suggests rail crowding IVT is equal to 1.0, relative to the uncrowded IVT for load factors (passengers:seats) less than 60 per cent. The 60 per cent load factor reflects that trains are often unevenly loaded, and that load factors are usually averages across a number of days or services.
  - Seated values average around 1.1 at 100 per cent occupation and around 1.3 at 140 per cent occupation based on the Passenger Demand Forecasting Handbook (PDFH) (ATOC 2005) with 140 per cent as the highest load factor valuation for non-commuting travel.
  - Standing values average around 2.4 for the first standee to 2.9 for crush-standing (140 per cent load factor).
  - An implied overall factor of 1.7–2.0 for all passengers (seated and standing) when standing room is full.
- Australian research suggests a similar value to international research for sitting (1.2 in Australia versus 1.1 internationally), a lower valuation for standing (1.3–1.8 in Australia versus 2.4 internationally) and a lower valuation for crush standing (2.0–2.5 for Australia versus 2.9 internationally) in crowded conditions for rail. Similar values are applied for standing on a bus in Australia at 1.8.
- New Zealand research also suggests a lower value of standing time at 1.4. This possibly reflects the lower levels of crowding on New Zealand public transport services.
- People travelling for work-related trips are generally more averse to travelling in crowded conditions than people travelling for leisure or social trips. Commuters are more tolerant than leisure users for travelling in crowded conditions.
- Less research is available on bus crowding, but what is available suggests values are similar to those derived for train travel.

Recommended typical values are:

- Seated time for rail and bus should be based on load factors relative to seats. When all seats are occupied (LF=100 per cent), seated time is valued at 110 per cent of IVT, increasing linearly to 130 per cent at crush capacity, which is typically six passengers per m^2.
- Standing time should be valued at 140 per cent of IVT when LF=100 per cent, increasing linearly to 200 per cent of IVT at crush capacity.
- For shorter journeys, these values should be reduced.

Table A.2: Crowded time recommended values

LOAD FACTOR (PAX:SEATS)	SEATED VALUATION	STANDING VALUATION
70%	1.0	N/A
100%	1.1	1.4
Crush capacity (6pax/m2)	1.3	2.0

References: 3, 14, 26, 31, 32, 44, 54, 80, 85, 86, 87 and 92.

A.4 Walking and access

There is extensive Australian and international research on the valuation of walking and access time. Walk time differs from access and egress time as walk time is a general valuation for walking in any condition, either access or egress. However, access and egress time is a valuation applied to going to or from public transport and it can include walk time, but it can also include other modes such as bicycles and cars. While walk time is fairly self-explanatory, many studies are not explicit about what access and egress valuations relate to. Sometimes access and egress is walk only, while in other cases it is a weighted average across all modes. As such, it is difficult to determine an appropriate valuation of access and egress times.

Survey research suggests that the valuation of walk time, based on equivalent IVT, increases with distance; this is supported by both Australian and international research. Further, walk time is valued more highly when undertaken in highly congested conditions, or when there is increased effort on the part of the traveller such as changes in gradient. Access to public transport via motorised modes is generally valued less than walk time, even when including the running costs of the car (but excluding parking costs). Egress from public transport modes to final destinations, usually undertaken by walking, is valued less than access. This may be due to the typically shorter egress distance than access distance for a CBD-bound trip. Transfer walking, say, within station or between stops, is detailed in Appendix A, Section 6.

Table A.3 gives a statistical summary of the sourced research. The valuation of walk and access time for Australian studies is around 75 per cent that of international studies. This may be due, in part, to:

- much of the international research relates to manuals that typically recommend a valuation of 2.0
- walk/access distances in Australia may be less than international distances
- Australian studies tend to focus more on access/egress rather than walk time, and therefore may have a lower valuation when other access modes are included, and
- there are possibly better and safer walking conditions in Australia compared with some international locations.

Table A.3: Walk/access valuation summary

GEOGRAPHY	SUMMARY	COMMENTS
Australia	Mean: 1.36 Median: 1.30 Min: 0.34 Max: 2.20 Range: 1.86 95% Range: 1.15–1.56	Australian studies suggest walk weightings of less than 2.0. Walking in highly crowded conditions has a higher valuation. Walking valuation increases as distance increases. Little difference between walk to/from different modes.
International	Mean: 1.79 Median: 1.90 Min: 0.70 Max: 2.80 Range: 2.10 95% Range: 1.64-1.93	Manuals typically recommend valuations of 1.5-2.0. Studies have fairly wide range of values, but typically range between 1.3 and 2.5. Clear relationship between distance and valuation. Access via motorised modes is valued less than walk.

References: 3, 8, 13, 14, 16, 18, 20, 21, 25, 26, 27, 31, 32, 36, 38, 46, 56, 61, 63, 64, 87, 89 and 92.

Note: Some valuations have been excluded due to being inappropriate. The mean is calculated as a straight average.

In summary:

- There are a number of Australian and international valuations of walk/access time.
- The evidence suggests a mean valuation of around 1.4 for Australian walk/access time and 1.8 for international walk/access times.
- Shorter walk/access distances have lower valuations than longer distances.
- Walking in congested situations or walking on gradients has a higher value. This is supported by both Australian and international research.
- International revealed preference studies suggest a somewhat lower valuation than stated preference studies.

Recommended typical values are:

- An average walk/access valuation of around 1.4 times IVT.
- Lower values of around 1.2 should be used for very short distance walk trips up to five minutes and higher values of around 1.8 for longer distance walk trips over 20 minutes.
- Interchange/transfer walk time should be valued higher (see Appendix A, Section 6).

A.5 Wait and frequency

Wait and frequency time (sometimes referred to as scheduled wait time to distinguish it from reliability) reflects the perceived disbenefit a passenger receives from having to wait for a service. Wait time and frequency (or service interval) are the same concept, with service interval valuations based on the ratio of the penalty to the service headway. Valuation of wait and frequency includes two components. The first component relates to the actual waiting time penalty. For more frequent services, this penalty reflects the average time a passenger spends waiting for a service. For less frequent services, the penalty includes an added component representing the disbenefit of passengers not being able to travel at the time they want to. The second component of wait time valuation involves the unit cost, expressed in equivalent IVT, associated with that penalty (or waiting at a stop), as generally passengers would rather be on the service moving towards their destination.

Service interval valuations are applied by taking the current headway of a given service and applying the valuation to give a wait time valuation. For example, a service running every half hour, with a service interval valuation of 0.5, implies a wait time penalty of 15 IVT minutes (30 * 0.5).

Table A.4: Service interval valuation summary

GEOGRAPHY	SUMMARY	COMMENTS
Australia	Mean: 0.46 Median: 0.46 Min: 0.20 Max: 1.05 Range: 0.85 95% Range: 0.35–0.58	Cannot directly compare across studies, as there is an implicit frequency assumed in each proportion that dominates the value variation.
International	Mean: 0.88 Median: 0.85 Min: 0.45 Max: 1.90 Range: 1.45 95% Range: 0.73–1.04	Cannot directly compare across studies, as there is an implicit frequency assumed in each proportion that dominates the value variation. Higher mean probably due to higher typical public transport frequencies in Europe.

References: 3, 4, 8, 13, 14, 15, 16, 18, 21, 25, 26, 27, 31, 32, 36, 38, 44, 57, 61, 63, 64, 65, 71, 86, 87, 89 and 92.

Note: Some valuations have been excluded due to being inappropriate. The mean is calculated as a straight average.

Most Australian research provides valuations of service interval, rather than unit wait times. The average service interval valuation from Australian studies is 0.46 (see Table A.4). However, the service interval proportion is a function of the service interval. For example, for a very frequent service (one every five minutes) a value of one might be expected—passengers arrive randomly and, on average, wait half the time. This time is usually weighted by two. For a more infrequent service (one every hour), a lower value of between 0.2–0.3 is given as passengers will tend to align their journeys more closely to the timetable rather than arriving randomly. As such, it is difficult to compare across studies.

The international research implies a higher service interval valuation of 0.88; however, typical frequencies in the European urban context are significantly higher than in the Australian context. Also, the valuation of waiting for one minute is higher in the international research, which will also increase the service interval valuation.

Other studies value the time spent waiting rather than the total disbenefit. Once the penalty associated with a particular frequency is determined, a valuation of that penalty (wait time in IVT minutes) can be applied.

Table A.5 Wait valuation summary

GEOGRAPHY	SUMMARY	COMMENTS
Australia	Mean: 1.41 Median: 1.44 Min: 1.13 Max: 1.62 Range: 0.49 95% Range: 1.04–1.77	Small count of only 4 values.
International	Mean: 2.00 Median: 2.00 Min: 1.17 Max: 2.88 Range: 1.71 95% Range: 1.76–2.23	

References: 3, 4, 8, 13, 14, 15, 16, 18, 21, 25, 26, 27, 31, 32, 36, 38, 44, 57, 61, 63, 64, 65, 71, 86, 87, 89 and 92.

Note: Some valuations have been excluded due to being inappropriate. The mean is calculated as a straight average.

The following points summarise this discussion.

- There are many Australian and international valuations of wait time and frequency.
- Most research suggests a wait time weight of between 1.1 and 2.5, with Australian research lower than international research—an average Australian weight of 1.4 versus 2.0 internationally. This may be due to better perceived waiting conditions in Australia, compared with internationally.
- Wait time weightings are lower for longer distance trips and for shorter wait times.
- Waiting in congestion conditions is valued higher, and waiting time on transfers is generally valued lower (see Appendix A, Section 6).
- Service interval valuation depends on service frequencies, with higher factors for more frequent services and shorter distance trips.
- The average service interval valuation for Australian studies is 0.46, which is consistent with an average of 25 minutes headways (see Table A.6). For international studies, the average service interval valuation of 0.88 is consistent with an average headway of eight minutes (assuming a higher wait time weight of two).
- For a typical urban situation, research suggests similar values by mode, with trip distance and peak/off-peak travel as distinguishing features and highly correlated with frequency.

Recommended typical values are:

- Scheduled wait time, as opposed to unexpected wait time (see Appendix A, Section 7), is represented through a wait time penalty (as shown in Table A.6). The service interval factor is calculated by dividing the penalty by the headway; however, use the wait time penalty to derive user benefits.
- Values are based on an average wait time valuation of 1.4; however, waiting in highly congested conditions could increase this up to 2.0 (a 40 per cent increase on the penalties listed).
- A wait time function of 0.72 * headway^0.75 is used to generate the unweighted wait time penalty (excluding the 1.4 weighting), based on an analysis of UK wait time penalty functions.

Table A.6: Wait time/frequency recommended values

HEADWAY (MINS)	WAIT TIME PENALTY (IVT MINS)	SERVICE INTERVAL FACTOR
1	1.0	1.01
2	1.7	0.85
3	2.3	0.77
4	2.9	0.71
5	3.4	0.67
6	3.9	0.64
7	4.3	0.62
8	4.8	0.60
9	5.2	0.58
10	5.7	0.57
15	7.7	0.51
20	9.5	0.48
25	11.3	0.45
30	12.9	0.43
40	16.0	0.40
50	19.0	0.38
60	21.7	0.36
70	24.4	0.35
80	27.0	0.34
90	29.5	0.33
120	36.5	0.30

Note: Wait time weight assumed to be 1.4 times IVT. Wait time penalty, excluding weight, is based on function 0.72 * headway^0.75.

A.6 Transfer and interchange

A transfer penalty is generally used to represent passengers' reluctance to change services. This reluctance may be due to uncertainty about reliability, the effort required to interchange or the quality of the facilities at the interchange point. As such, people's perception of interchanges includes aspects that may be captured in other public transport attributes such as walk/wait time (see Appendix A, Sections 4 and 5) or in the infrastructure valuation (see Appendix A, Section 10). There will be some overlap between the research given here, and research elsewhere in this Appendix.

In terms of interchange, three aspects are examined in the literature: the transfer penalty (people's reluctance to transfer), the value of interchange walk time (usually in more congested conditions than normal) and the value of interchange wait time. These aspects have been separated where possible, but the transfer penalty of some studies may include some walk/wait time aspects implicitly in the transfer penalty.

Table A.7: Transfer penalty valuation summary

GEOGRAPHY	SUMMARY
Australia	Mean: 7.45 Median: 6.50 Min: 1.50 Max: 20.00 Range: 18.50 95% Range: 5.61–9.28
International	Mean: 9.17 Median: 8.00 Min: 2.80 Max: 27.00 Range: 24.20 95% Range: 7.24–11.09

References: 3, 7, 8, 13, 14, 15, 16, 18, 21, 23, 25, 26, 31, 32, 50, 56, 61, 63, 65, 67, 75, 86, 87 and 90.

Note: Some valuations have been excluded due to being inappropriate. The mean is calculated as a straight average.

In summary:

- There is a lot of research on transfer/interchange valuations, but the valuations are context specific and can include different attributes that are not consistent. Valuation is also different depending on quality of the interchange, which includes attributes listed in stop/station valuations, so there may be some double-counting.
- Australian research suggests an average transfer penalty of 7.45 minutes (of IVT), and a 95 per cent range of 5.61–9.28. International studies suggest a higher penalty of 9.17.
- Penalties are generally lowest between enclosed rail services (e.g. metros) and highest for transfers between bus services. Within-mode transfers are generally lower than between-mode transfers.
- Work trips generally have higher penalties than non-work or leisure trips, and transfer penalties increase as travel time increases.
- The physical quality of the transfer will affect valuations (e.g. weather protection, need to negotiate steps). The reliability of the new service may also have a substantial effect (if it is not captured elsewhere).
- New Zealand suggests a simple within-mode planned interchange penalty of five minutes and a complicated, or mode change transfer, of up to 14 minutes. These values are broadly consistent with the UK market (London Underground transfer penalties have lower valuations, but services have a higher frequency).
- Guaranteed connections reduce the transfer penalty by up to 50 per cent, and changing stop, platform or station will increase this value by up to 10 minutes.
- Wait time during an interchange is typically valued lower than the initial wait time (1.1–1.2 instead of the typical 2.0), while walking time during interchange is usually valued higher than typical values due to walking in congested conditions or changing levels.

Recommended typical values are:

- An interchange penalty related to the type of interchange and whether within-mode or between-mode.
- A simple interchange that is within-mode (i.e. bus–bus, rail–rail) and usually at the same platform or stop, or a planned interchange, has a value of five minutes (IVT).

- An interchange that is either between-mode but at the same facility or within-mode and requires a facility change has a value of seven minutes.
- A complex interchange that is between-mode and requires a facility change has a value of 10 minutes.
- Any walk and wait time during the interchange is additional, with walk time valued at 2.0 (noting that any change in gradient or high-level congestion will increase this value) and wait time at 1.2 (noting that waiting in highly congested conditions will increase this value).

Table A.8: Interchange recommended values

FACILITY	MODE	VALUATION
Same	Within	5
Same	Between	7
Different	Within	7
Different	Between	10

Note: Additional wait time assumed to be 1.2 times IVT.

Additional walk time assumed to be 2.0 times IVT.

A.7 Reliability

Service reliability is consistently highly valued by passengers. Reliability covers many aspects of a passenger's journey, including:

- delay of service departure (longer than expected wait time)
- delay of service 'on-route' (longer than expected IVT)
- delay of service on arrival, which is generally the combined impact of departure and 'on-route' delay, and
- service cancellation.

Further, in terms of passengers' valuation of delay, some practitioners believe that the average delay over, say, a week of services is important, whereas others believe it is the variability of delay (measured as the standard deviation of delay) that is important. To address these issues, discussion of the research is separated into the following reliability attributes:

- unexpected wait time
- unexpected IVT
- late on arrival (combined impact of wait time and IVT), and
- cancellations.

Most of the research for reliability is based on international studies. Many of the studies are not explicit about which aspect of reliability they consider. Also, there are significant differences in the way reliability is presented, particularly in relation to probabilities. Table A.9 gives a summary of the valuations. Note, however, that valuations have been classified into the individual attributes for studies where the attribute is clearly apparent and into the general 'late on arrival' where it is not apparent.

Table A.9: Reliability valuation summary

ATTRIBUTE	SUMMARY	COMMENTS
Unexpected wait time (average)	Mean: 5.82 Median: 5.6 Min: 1.7 Max: 12.0 Range: 10.3 95% Range: 1.81–9.83	
Unexpected wait time (standard deviation)	Mean: 1.44 Median: 1.3 Min: 0.48 Max: 2.5 Range: 2.02 95% Range: 0.46–2.41	
Unexpected IVT (average)	Around 1.2 for an average 4 minute delay.	For London Underground, valuation of IVT lateness is 1 up to 3 minutes, and then increases to a value of 3 for 9 or more minutes.
Unexpected IVT (standard deviation)	Mean: 0.98 Median: 0.8 Min: 0.1 Max: 2.3 Range: 2.2 95% Range: 0.43–1.53	
Late on arrival (average)	Mean: 3.31 Median: 2.95 Min: 1.5 Max: 9.7 Range: 8.2 95% Range: 1.61–5.00	
Late on arrival (standard deviation)	0.51–0.63	Based on two observations.

References: 2, 3, 5, 7, 14, 16, 22, 24, 31, 32, 36, 44, 46, 49, 52, 61, 70, 71, 72, 80, 86, 87, 94.

Note: Some valuations have been excluded due to being inappropriate. The mean is calculated as a straight average.

For average unexpected wait time, the mean weighting determined from the studies is approximately 5.8 or around 3–4 times normal wait time. For average unexpected IVT, there is less research, but parameters used on the London Underground suggest for delays less than four minutes there is no increase in IVT valuation (i.e. IVT factor of one), increasing to a value of three for delays of nine minutes or more. This assumes an average delay of four minutes gives a weighting for IVT delay of around 1.2. Average lateness on arrival is weighted as (on average) 3.3 and is caused by a combination of unexpected wait time and unexpected IVT. Assuming that half the delay is caused by each gives a total impact of around 3.5 (50 per cent of 5.8 + 50 per cent of 1.2), which suggests that all valuations are broadly internally consistent.

Valuations of variation in wait time indicate an average valuation of 1.44 on the standard deviation of wait time. For variation in IVT, the valuation is lower and is approximately equal to one.

The following summarises this discussion.

- Average lateness is typically valued at around three, and is a combination of unexpected wait time (which has an average valuation of around six) and unexpected IVT (which has an average valuation of less than three).
- Variation (measured by the standard deviation) in wait time and IVT can also be used to represent reliability, with wait time variability having a higher weight (1.44) than IVT variability (around 1.0).
- Valuations differ depending on rigidity of destination time e.g. services serving airports have a higher valuation than general commuter services. Similarly, longer distance, high-speed services where people are using the service for business or to be picked up has a higher valuation.
- For commuter or shorter distance services, valuation is generally less than average.
- Bus reliability valuations are generally higher than rail (6–7), and ferry valuations are generally lower, possibly due to passengers being able to see the ferry coming from a longer distance.
- There is little research to suggest a difference between peak and off-peak valuations.

Recommended typical values are:

- Valuation of an average one minute of service lateness should be three.
- This could be broken down as a six-times weighting on unexpected wait time, and a lower weighting of approximately 1.5 on unexpected IVT.
- Variation in wait time could also be used, with a weighting of around 1.5 on the standard deviation of wait time.
- Variation of IVT time (standard deviation) should take a lower value of around one.
- These valuations should apply across all modes and time periods.

A.8 Mode-specific factors

Mode-specific factors (MSF) are used to represent perceptions about one mode over another mode when other factors such as journey time, fare and frequency have been excluded. These factors can be included in two ways. Firstly, as a mode-specific constant (MSC), a fixed penalty is associated with accessing the system, including boarding service (independent of a transfer valuation). It is not distance-related and covers the station/stop facilities and the more qualitative aspects of boarding a service (such as negotiating steps, having to pay a driver, etc.). Secondly, as an IVT factor, the penalty associated with a mode is distance or time-based and relates to the quality of the in-vehicle travel such as comfort and air conditioning.

Mode-specific factors are used when detailed attribute valuations are not available or required; they generally approximate the valuations as given in Appendix A, Section 9. In a stated preference study, these factors are a fair representation of people's attitudes to a mode, since the other cost-based attributes are presented in an accurate way. Mode-specific factors can also be determined using revealed preference data. This approach is used most often in mode-split transport models. However, mode-specific factors are likely to include an additional term relating to biases within the model such as an under-representation of short distance trips. This means that the quality of the modelling is important in determining the preference for a particular mode. In a modelling context, mode-specific differences should be applied as a relative difference rather than as an absolute value.

The following summarises this discussion.

- In general, passengers perceive rail, LRT and trams, and ferries as 'better' modes of transport than on-street buses, due to better station/stop facilities offered, improved ease of boarding/alighting the service, and a better in-vehicle experience (smooth, less jerky ride, CCTV, on-board information systems, etc.).
- Research suggests that, on average, an unguided bus on a busway is valued better than a standard bus, and a guided bus on a busway is valued even higher. This is due primarily to better stop facilities offered on the busway and a better in-vehicle experience (ride quality).
- A dedicated LRT system is valued at a similar level as a guided busway, whilst tram services operating generally on-street are valued lower due to poorer stop and in-vehicle experience.
- Heavy rail is generally valued higher than bus and tram/LRT-based modes, due to better station facilities, ease of boarding, and an improved in-vehicle experience.
- Ferries typically are valued substantially higher than other modes. New Zealand evidence suggests ferries are valued at around 25–30 minutes better than buses; however, this valuation is based on calibration of a model and so may include model-based biases.
- There is no research to suggest any differences between time periods.

Recommended typical values are given in Table A.10, in all cases expressed relative to on-street buses.

Table A.10: Mode-specific factors recommended values

MODE		MSC (MINUTES)	IVT	TOTAL MSF (MINUTES)[1]	COMMENT
Bus	On-street	0	1.0	0	Reference Case.
	Busway	-2	0.9	-4	Better quality of stop facilities, and better in-vehicle experience than on-street bus.
	Guided busway	-2	0.85	-5	Same quality of stops as busway, but slightly better ride quality due to guiding of bus.
Tram/LRT	Tram	-1	0.9	-3	Same in-vehicle experience as busway, but poorer quality of stops.
	LRT	-2	0.85	-5	Station quality and in-vehicle experience similar to busway.
Heavy Rail	Old DMU/EMU	-1	0.9	-3	Older station facilities and older vehicles (in-vehicle quality similar to tram).
	Refurbished DMU/EMU	-2	0.8	-6	Improved station facilities and in-vehicle experience.
	New DMU/EMU	-3	0.75	-8	Best quality station and in-vehicle experience.
Ferry[2]		-20	0.7	-26	Generally have a better in-vehicle experience than other modes; however, these should be used with extreme caution.

References: 8, 13, 23, 25, 64, 81, 82 and 83.

Notes: Values are generally based on work undertaken in Auckland, which included review of international evidence.
1: Total mode-specific factor based on average in-vehicle time of 20 minutes (provided for information purposes only).
2: Ferry MSC values should be used with extreme caution as they are highly context specific and include modelling biases.

A.9 Vehicle factors

Valuation of vehicle factors relates to the perceived quality of the journey experience given an improvement in the facilities, cleanliness, information, driver attitude and comfort of the journey. Extensive information for bus attributes exist from the Business Case Development Manual (Transport for London), which is extremely detailed on the benefits of changing aspects of the service, particularly in the London context. It is difficult to compare detailed sources like this with the other research because the cases attributes are defined more generally in the majority of the research. In most of the research, it is not clear what is included in the attributes and how people have interpreted the options given. For example, an option may include defining a valuation for a 10 per cent improvement in cleanliness. For rail, the research is predominately Australian and more general than bus. There is limited information relating to ferries, with a study of Sydney ferries giving a total valuation for in-vehicle attributes of 1.13 minutes per boarding

Table A.11 summarises typical valuations for bus and rail attributes. The valuation is the maximum benefit that could be gained. For example, a litter value of 0.41 minutes is the maximum valuation that could be placed on a bus service with no litter. Averages are determined where there is more than one valuation on a consistent attribute. Note that a package of improvements is likely to be valued lower than the sum of the individual improvements up to a maximum valuation. There is little research to suggest what this maximum is.

Table A.11: Vehicle factor values

ATTRIBUTE	SUB-ATTRIBUTE	VALUATION (IVT MINUTES)	COMMENT
Bus			
Boarding	No steps	0.1	Difference between two steps up and no steps.
	No show pass	0.1	Two-stream boarding and no show pass relative to single file past driver.
Driver	Attitude	0.4	Very polite, helpful, cheerful, well-presented compared with businesslike and not very helpful.
	Ride	0.6	Very smooth ride (no jerkiness) compared with jerky ride causing anxiety and irritation.
Cleanliness	Litter	0.4	No litter compared with lots of litter.
	Windows	0.3	Clean windows with no etchings compared with dirty windows with etchings.
	Graffiti	0.2	No graffiti compared with lots of graffiti.
	Exterior	0.1	Very clean everywhere compared with some very dirty areas.
	Interior	0.3	Very clean everywhere compared with some very dirty areas.
Facilities	Clock	0.1	Clearly visible digital clock showing correct time compared with no clock.
	CCTV	0.7	CCTV, recorded, visible to driver, and driver panic alarm compared with no CCTV.

ATTRIBUTE	SUB-ATTRIBUTE	VALUATION (IVT MINUTES)	COMMENT
Information	External	0.2	Large route number and destination front/side/rear, plus line diagram on side relative to small route number of front/side/rear.
	Interior	0.2	Easy to read route number and diagram display compared with no information inside bus.
	Info of next stop	0.2	Electronic sign and announcements of next stop and interchange compared with no information of next stop.
Seating	Type/layout	0.1	Individual-shaped seats with headrests, all seats facing forward compared with basic, double-bench seats with some facing backwards.
	Tip-up	0.1	Tip-up seats in standing/wheelchair area compared with all standing area in central aisle.
Comfort	Legroom	0.2	Space for small luggage compared with restricted legroom and no space for small luggage.
	Ventilation	0.1	Push-opening windows giving more ventilation compared with slide-opening windows giving less ventilation.
		1.0	Air conditioning.
Rail			
Driver/Staff	Train Attendant	1.6	
	Ride	1.2	Quiet and smooth.
Facilities	CCTV	2.0	
	Onboard toilets	0.6	
Information	Interior	1.1	Frequent and audible train announcements.
Seating	Comfortable	1.5	
	Layout	0.7	Facing travel direction.
	Maintained	1.2	Clean and well maintained.
Comfort	Ventilation	1.5	Air conditioning.

References: 3, 14, 16, 17, 31, 32, 44, 46, 62 and 87.

Note: For a package of changes the total valuation is expected to be lower than the sum of the individual components.

A.10 Infrastructure factors

Valuation of infrastructure factors relate to the perceived quality of the waiting or transfer environment. In the context of urban travel, this primarily relates to the facilities located at stops, platforms and stations, as well as the condition of these facilities.

For bus stops and rail platforms, the major components of quality relate to the stop or shelter type and condition, facilities in the case of rail platforms, the inclusion of ticketing machines, security measures and the information provided to users. As with the vehicles factors, extensive information is available for bus stop and station attributes from the Business Case Development Manual (Transport for London) with rail-focused research predominately Australian-based and more general than bus.

Table A.12 summarises typical valuations for bus and rail stop and station attributes. Averages have been determined where there is more than one valuation of a consistent attribute. Note that a package of improvements is likely to be valued lower than the sum of the individual improvements up to a maximum valuation. There is little research to suggest what this maximum is.

Table A.12: Infrastructure factor values

ATTRIBUTE	SUB-ATTRIBUTE	VALUATION (IVT MINUTES)	COMMENTS
Bus			
Stop/shelter	Condition	0.1	Excellent condition looks like new compared with basic working order but parts worn and tatty.
	Size	0.1	Double-sized shelters compared with single-size.
	Seating	0.1	Seats plus shelter versus no shelter and seats.
	Cleanliness	0.1	Spotlessly clean compared with some dirty patches.
	Litter	0.2	No litter compared with lots of litter.
	Graffiti	0.1	No graffiti compared with lots of/ offensive graffiti.
	Type	0.2	Glass cubicle giving good all-round protection compared with no shelter.
Ticketing	Roadside machines	0.1	Pay by cash (change given), credit/ debit card compared with pay by coins (no change given).
	Availability of machines	0.2	At busiest stops compared with none.
	Sale of one-day pass	0.1	Sale on bus, same price as elsewhere compared with no sale of one-day pass.
	Cash fares	0.3	Cash fares on the bus, driver giving change compared with no cash fares on bus.
	Two-ticket transfer	2 * 1 ticket transfer	
Security	Security point	0.3	Two-way communication with staff compared with no security point.
	CCTV	0.3	Recorded and monitored by staff if alarm raised compared with no CCTV.
	Lighting	0.1	Very brightly lit compared with reasonably well lit.

ATTRIBUTE	SUB-ATTRIBUTE	VALUATION (IVT MINUTES)	COMMENTS
Information	Terminals	0.1	Screen with real-time information for all buses from that stop compared with current timetable and map for your route.
	Maps	0.2	Small map showing local streets and key locations versus no small map.
	Countdown signs/RTI	0.8	Up to the minute arrival times/ disruptions, plus audio compared with no countdown sign.
	Clock	0.1	Digital clock telling correct time compared with no clock.
	Contact number	0.1	Free phone number shown at stop compared with no number.
	Location of payphones	0.1	One payphone attached to shelter compared with no payphone.
	Simple timetable	0.4	Simpler, more user-friendly.
Stations		Up to 3.0	Includes bright lighting, CCTV, cleaned frequently, customer service staff walking around and at info desk, central electronic sign giving departure times, snack bar, cash point, newsagent, landscaping, block paving, and photo booths.
Rail			
Passenger facilities	Waiting room	0.2	
	Platform seating	0.3	
	Toilets	0.4	
	Weather protection	0.3	Canopies.
	Telephones	0.2	
	Platform lighting	0.3	
	CCTV	0.6	
	Cafe	0.3	
Cleanliness and appearance	Cleanliness	0.5	
	Litter-free	0.5	
	Graffiti-free	0.3	
	Modern	0.2	
Ticketing	Manned booths	0.3	
	Automatic machines	0.2	
Information	Helpful staff	0.5	
	Knowledgeable staff	0.5	
	PA System	0.4	
	Signage	0.3	
	Clocks	0.2	
	Information about next service	0.3	

References: 3, 14, 16, 17, 31, 32, 44, 46, 50, 57, 61, 62 and 87.

Note: For a package of changes, the total valuation is expected to be lower than the sum of the individual components.

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PART

2 Urban transport modelling guidelines

1 Introduction to Part 2

Volume 4, Part 2 provides guidance in the development and application of highway and public transport models in the appraisal of major transport initiatives. It covers aspects of model structure, model form, model calibration and validation and forecasts.

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 to develop transport infrastructure options, examine and assess these options and identify how the transport system is likely to perform at some point in the future.

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

- provide an analytical framework to assess existing demands on the transport system and to project demands into the future, to systematically test the impact of transport and land use options, and
- enable quantitative measures to be generated to act as key indicators in the appraisal process.

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

At the most fundamental level, transport models are comprised of the following:

- demand model (trip generation, trip distribution and mode choice)
- highway assignment model, and
- public transport assignment model.

Volume 4, Part 2 is not intended to be a detailed technical treatise on the development of the 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 is available in transport modelling references, some of which are detailed in the bibliography to Volume 4, Part 2.

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 that there is a consistent understanding in the application of transport modelling, and
- provide a better understanding of the transport modelling process.

2 Transport model development

Any transport model is a tool for understanding and assessing the likely impacts of changes in the drivers of transport e.g. transport supply, demographics or land use. In this context, transport modelling can assist the decision-making processes as it relates to the future development and management of the urban transport and land use system.

Generally, the development of a transport modelling system requires:

- a Statement of Requirements
- a Functional Specification of the transport model, and
- a Technical Specification the transport model.

2.1 Statement of Requirements

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

2.1.1 Objectives of the modelling system

The overall objectives for a transport modelling system refer to what the system is required to do, and this may include:

- providing the technical means for on-going 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 statewide model, and
- extending the modelling system to test the impacts of transport strategies on the location and intensity of land use development.

2.1.2 Interfacing with other modelling systems

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

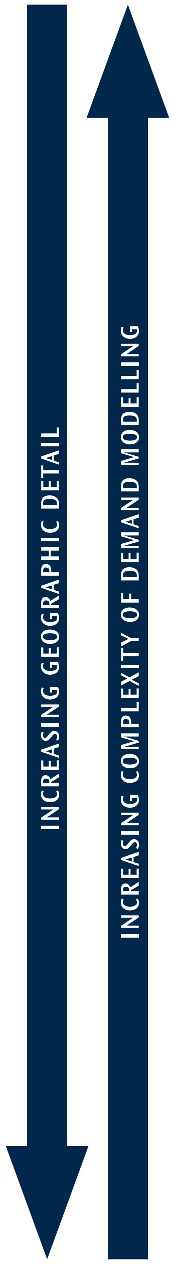
The key interface attributes are that model systems share common information and data sources and provide consistency within the hierarchy of transport modelling (see Table 2.2.1).

2.1.3 Hierarchy of transport modelling applications

Transport modelling development and applications generally fall into the five broad categories shown in Table 2.2.1.

Table 2.2.1: Hierarchy of transport modelling

Land use and transport interaction modelling	› Examines and evaluates the impacts of transport policy and land use changes on urban form and transport.
Strategic modelling	› Examines 'what if?' questions in policy development and the definition of strategies. › Identifies and assesses broad metropolitan-wide impacts of 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 2.2.1, some specific examples of model applications 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, and
- the interaction between freight, private vehicles and public transport.

2.1.4 Transport model attributes

Desired transport model attributes may include:

- an integrated multi-modal model that can be easily and readily updated
- sensitivity to changes in demographics, individual travel decision-making, social behaviour, land use

- accessible and quick response, state-owned, developed and maintained transport model
- an ability to model motorised (including freight) and non-motorised travel, and
- techniques and transferable parameters that can be used to undertake the 'what if?' analyses.

2.1.5 Transport model outputs

Examples of model outputs could include:

- road and traffic levels and public transport patronage estimates
- transport network performance (e.g. vehicle-hours and kilometres of travel, congestion indicators) and accessibility measures (e.g. to services, employment)
- forecasts of aggregate travel costs and benefits, and
- input to externalities modelling (e.g. quantum of emissions).

2.2 Functional Specifications

The purpose of the Functional Specification is to describe the functions that should be included in a transport model, based on the scope of the transport model as derived from the Statement of Requirements. It outlines the model structure, 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 sources.

2.2.1 Transport model scope

The scope of the transport model is defined by the policy issues the model system is to address, and these may be:

- land use–transport interaction
- pricing (toll roads, parking)
- 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 (nominated freight routes, impacts of congestion, location of freight centres)
- public transport networks (extensions, service provision, fares, cross-town routes), and
- non-motorised travel (cycling, walking).

Establishing a suitable model scope and structure for transport modelling and analysis is not a simple process. There is a whole range of modelling approaches, spanning between the options of using no formal transport models through to the most complex microsimulation models. The choice of transport model structure and scope is driven by the requirements of the specific transport study and the requirements of the appraisal process.

2.2.2 Transport model structure

A broad transport model structure will include:

- a database populated by data from surveys of travel across the region being modelled, together with traffic volumes across the road network and patronage levels on the public transport network, including current and projected land use data and demographics (population and employment)
- the inputs to the modelling process e.g. parking supply, land use distribution, fares, car travel costs, traffic management measures, road and public transport infrastructure

- a travel demand model to derive the quantum of travel across the region, comprising trip generation, trip distribution and mode choice modules and would include factors such as travel purposes and the quantum of commercial vehicle travel
- a transport supply model covering the road and public transport networks, which would cover 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, and
- the required outputs e.g. network performance indicators such as vehicle-hours and kilometres of travel, passenger-hours and kilometres, congestion indicators, tonnages of emissions (NOx, CO, CO_2), traffic volumes, trip lengths, trip costs and benefits and accessibility measures.

2.3 Technical Specification

The Technical Specification usually follows the choice of modelling approach and includes the methodologies and processes developed to meet the Functional Specification. It involves details on, among other issues, the input data, model calibration and validation parameters and the format of the required outputs.

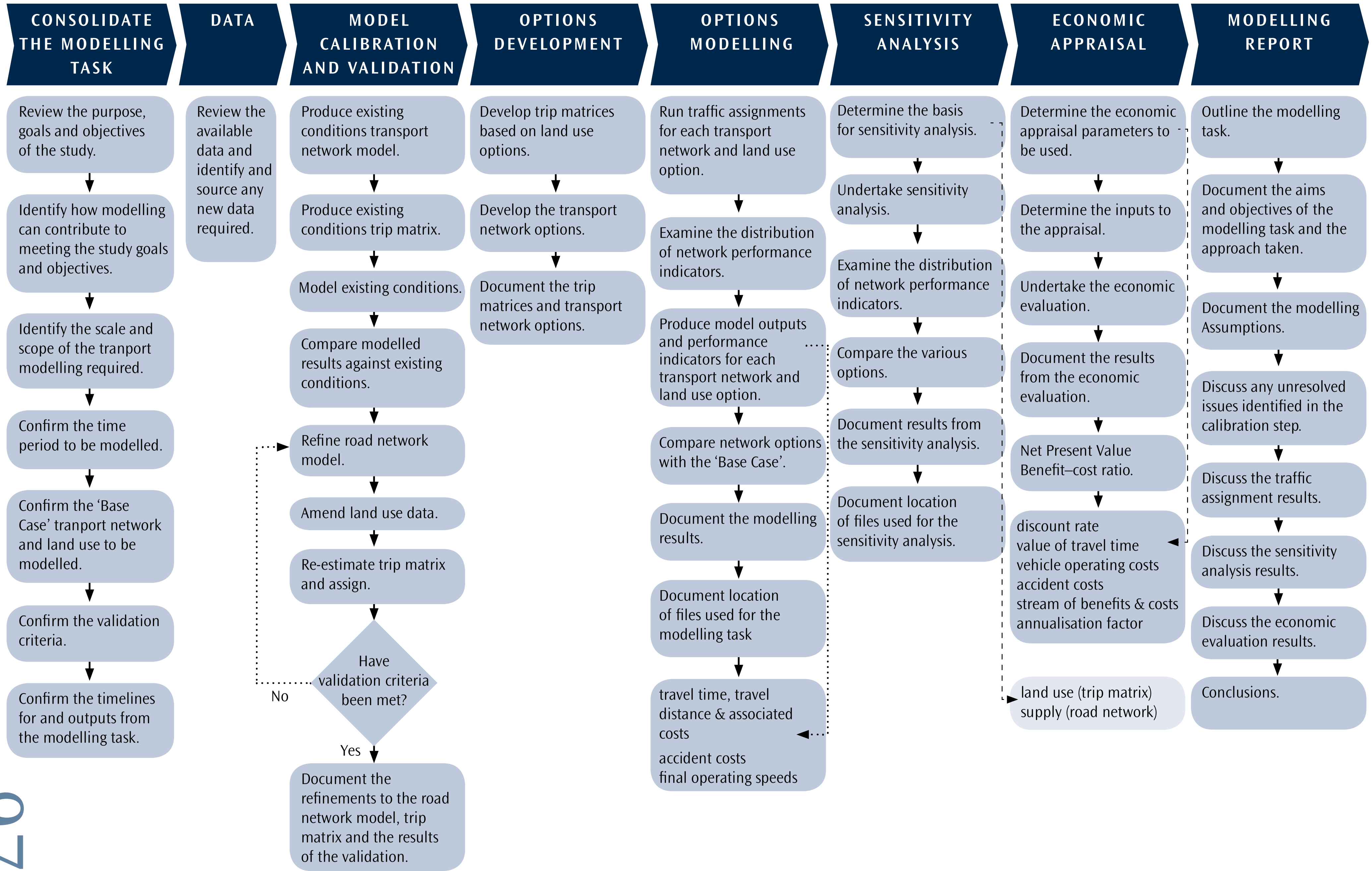
2.4 Transport Modelling Process

The Transport Modelling Process is shown in Figure 2.2.1 and is comprised of a number of components.

- Consolidating the modelling task. This involves identifying the key transport, socio-economic and land use issues and problems that are to be modelled. This step is also informed by the definition of goals, objectives and appraisal criteria to be adopted.
- Data collection. This is a critical component of the transport modelling process and may include highway and public transport patronage data, census information and targeted or area-wide travel surveys.
- Model calibration and validation. This is required to develop the relationships used in the modelling process and to gauge the performance of the transport model.
- Options development. This usually includes variations of transport network options, land use options or combinations of both.
- Options modelling. An outcome of this stage may be further refinement and development of options, together with more detailed design and appraisal. This stage usually involves an iterative process covering options development and modelling through to appraisal.
- Sensitivity analysis. This stage varies input data and model parameter values to identify the robustness of the model relationships and the associated forecasts.
- Economic appraisal. The results of the modelling are used as input to the appraisal process to assess the performance of the options against the specified goals, objectives and criteria.
- Modelling report. This is the full documentation of each of the steps detailed above, including the transport model details.

Further detail on the Transport Modelling Process is provided in Appendix B.

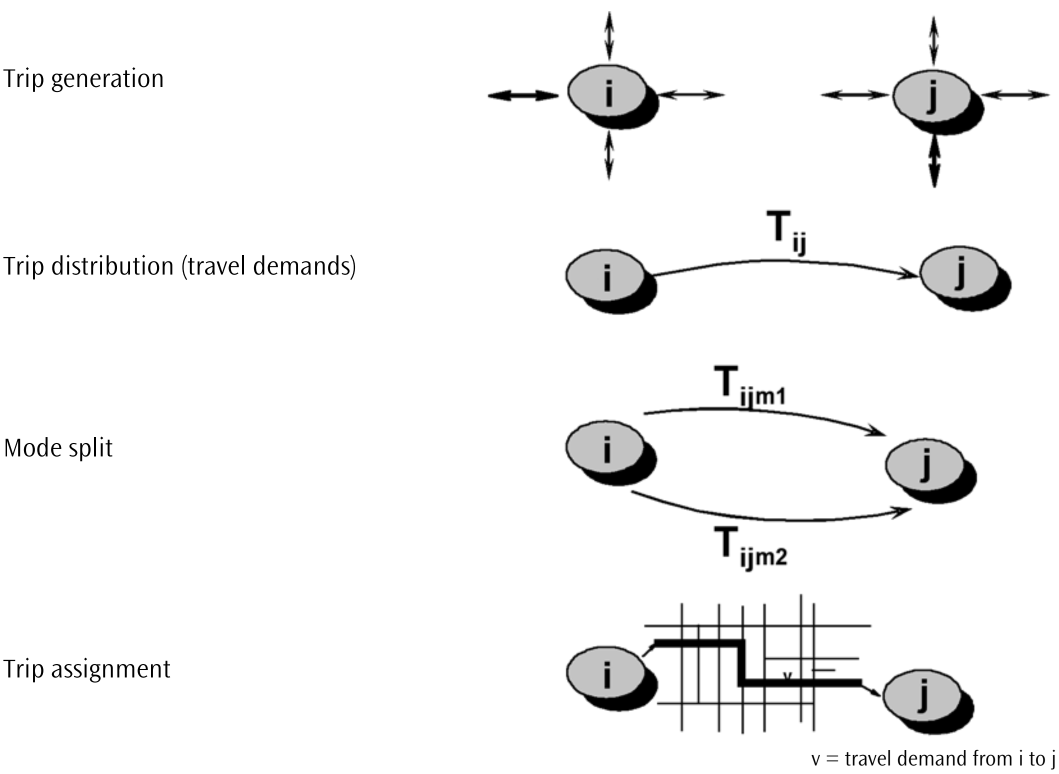
Figure 2.2.1: Transport modelling process



3 The four-step transport modelling process

A commonly used model structure is the 'four-step' transport modelling process. The component steps in this process are shown in Figure 2.3.1 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 that there is a balance between the final trip pattern and the costs by which it is derived.

Figure 2.3.1: The four-step transport modelling process



3.1 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 i.e. work trips that begin or end at home
- home-based shopping trips
- home-based education trips i.e. 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)
- truck trips, and
- other non home-based trips.

The productions and attractions developed in the trip generation step are usually termed 'trip ends'.

The Table 2.3.1 provides examples of the type of data that would be used in this step.

Table 2.3.1: Demographic and land use variables used in urban transport modelling

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

3.2 Step 2—Trip distribution

The trip distribution step determines where the trip ends, developed in trip generation, will go. These trip ends are linked together 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 (employment, shopping, recreation, etc.) than to a more distant zone with a low level of activity.

The most commonly used procedure for trip distribution is the 'gravity model'.[1] The gravity model takes the trips produced at one 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 several ways. The simplest way is to use either actual travel distance (km) or travel times (mins) 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[2]' can be used as the 'impedance'.

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.

3.3 Step 3—Mode choice

The mode choice step allocates the origin–destination trips derived from the trip distribution step 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, etc.), the trip itself (trip purpose, the origin and destination, etc.) and the characteristics of the travel mode (fares, vehicle operating costs, travel time, parking availability and cost, reliability, etc.). 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 (e.g. from survey data), the characteristics of people undertaking the travel (e.g. age, employment status, currently studying and at what level, if they hold a licence, etc.) and the characteristics of the travel modes (e.g. availability, frequency, fare levels, reliability, etc.).

Travel modes may include:

- walking
- bicycle
- car
- bus
- tram
- train.

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.

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.[3]

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 i.e. ease of access to each mode and the ability, or inclination, to use a 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. A typical formulation of the logit model for mode choice is shown below. The horizontal offset accounts for measures of cost difference that are not included in the logit model.

Figure 2.3.2: A typical formulation of a logit model for mode choice

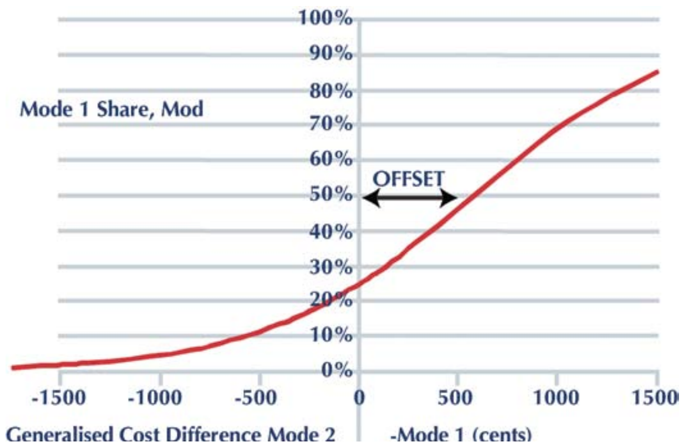
$$P_2=1/(1+e^{N(C_2-C_1+\text{Offset})})$$

where:

P_2 = Probability of choosing Mode 2

C_1, C_2 = Generalised cost for Modes 1 and 2

Offset = Horizontal offset



3.4 Step 4—Trip assignment

The trip assignment step assigns the various mode-specific trip matrices, by trip purpose, to the alternative routes or paths available across the transport network. Typically, public transport trips are assigned to the public transport network, where path choice includes all public transport modes, and car trips 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, and
- provide inputs to economic appraisal.

3 Ortúzar and Willumsen (1994) *Modelling Transport.*

3.4.1 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 i.e. congestion increases.[4]

There are a number of specific techniques available for undertaking a capacity restrained assignment (e.g. all-or-nothing, equilibrium, stochastic, volume-averaging, incremental), and detailed information on these techniques is provided in the available literature.

In general, the capacity restrained assignment begins by estimating the shortest path from each origin to all destinations (expressed in terms of the minimum generalised cost and based on travel time and travel distance). 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.

3.4.2 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 listed below.

- 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 walking 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.

One of the main outputs from the public transport assignment is public transport patronage and line or service loadings, boardings and alightings at stops and network-wide indicators such as passenger-hours of travel and passenger-kilometres of travel.

4 Defined by the volume-to-capacity ratio.

4 Modelling issues

4.1 Transport zoning system

One of the main issues 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 (i.e. solely residential, industrial, commercial, parking lots) and they should not cross significant barriers to travel (e.g. rivers, freeways, 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 e.g. airports, ports, universities, shopping centres.

Generally, the accuracy of a transport model increases 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 that all trips from all transport zones are able to 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. Centroid connectors should not be connected to intersections but, more appropriately, be connected to mid-block points in the modelled transport network.

4.2 Transport model networks

Generally, transport network models 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 (road section) attributes:

- distance
- free speed on the link or travel time
- capacity, as related to the number of lanes
- direction indicator (i.e. one-way or two-way link), and
- speed-flow curve identifier.

The transport network model should be sufficiently refined to support the adopted model zoning system and, as a minimum, it 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, and
- local roads (the extent to which these are included is at the discretion of the modeller and the requirements of the particular study).

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. Any network errors identified and rectified prior to the calibration stage will improve the calibration results.

Some techniques that can be used to check the coding of transport network models are:

- visual checking of the network in the study area, supplemented with site visits to confirm the link data being used
- checking connection points of centroid connectors (see Section 4.1)
- building paths to or from selected zones (on the basis of minimum distance, time or generalised cost)—one of the best ways of checking the network coding; the path building process will ensure that the paths built by the model are logical and that any errors in the coding are identified and corrected, thereby eliminating any illogical paths during the assignment stage
- comparing actual travel times along key links with those from the network model
- comparing link distances from the model with actual distances, and
- checking the frequency and stopping patterns of public transport routes.

4.3 Travel demands

Reference (Base) Year travel demands for both highway and public transport 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 both the calibration and validation of the transport models.

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

- origin and destination purpose
- rigin and destination location
- car availability and use for travel purpose
- public transport mode used
- cost of travel
- duration of travel
- time of day of travel, and
- age, gender, income and employment status of the traveller.

4.4 Model convergence

It is necessary to assess the stability of the trip assignment process referred to in Section 4.1 before the results of the assignment process are used either to influence decisions or for input to economic appraisal, or both. The iterative[5] 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 2.4.1).

Table 2.4.1: Example of model convergence output

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

ITERATION	DELTA		AAD	RAAD	%FLOW	
41	1.03119	%	4.53441	0.0029626	0.18298	%
42	0.68327	%	9.86224	0.0080850	2.70688	%
43	0.93032	%	6.95290	0.0047448	0.63728	%

Source: Melbourne Integrated Transport Model.

4.5 Peak periods

Specific peak period (am, inter-peak and pm) 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 peak period factors, by trip purpose, to generate the time period matrices for subsequent use in the assignment process. The peak 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 modelling, the peak period trip matrices may be for either a one-hour or two-hour time period, depending on the requirements of the analysis.

5 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.

4.6 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 and 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
- identification of special generator and external trips input to trip generation
- summary of trip generation results
- description of the trip distribution model
- 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 peak period models
- description of the trip assignment model
- description of the impedance measures used in the trip assignment
- 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, delay and average speed), and
- identification of model validation tests and results for each model stage.

5 Travel demands

5.1 Background

It is important that government funds be spent in areas that provide the greatest return. Capital investment in transport infrastructure projects must be underpinned by good information on travel demand patterns (i.e. 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, which are 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 (i.e. currency, coverage, robustness, reliability) of available data should be ascertained early in any model development and application undertaking.

5.2 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 out to a household and is mailed back to the survey firm or agencies 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 Activity and Travel Survey (VATS) is an example of a mail out/mail back survey.

The household personal interview survey involves a face-to-face personal interview 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. In general, household personal interview surveys have high response rates (in the order of 70–80 per cent) 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 of the critical issues to be addressed in designing a travel demand survey is the survey sample size. In general, the more detailed the travel demand model, the larger the survey sample size that is 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 may be to conduct relatively small annual travel demand surveys that will accumulate to increasing sample sizes over the ensuing years, making it possible to develop a travel demand model that becomes more detailed over time.

5.3 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, and
- reason for not travelling on the travel day.

5.4 Other data sources

Other data sources may include:

- Up-to-date traffic counts covering, 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 reliably identifying trips involving interchanging, and
    - 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.

5.5 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 (Section 3).

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 that 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.

6 Model calibration and validation

6.1 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 that the modelled travel patterns, traffic volumes and patronage estimates replicate observed survey data. Calibration of transport models is, in part, predicated 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 5) and census journey-to-work data can provide more detailed information for model calibration.

The validation process attempts to quantify how accurately a transport model reproduces a set of Reference (Base) Year conditions (i.e. traffic volumes, patronage estimates), and is used to define the transport model's degree of 'fit-for-purpose'.

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 C.

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, and
- reporting on the validation outcomes for a Reference (Base) Year.

6.2 Vehicle operating costs and the value of time

As noted throughout Volume 3, Austroads produces estimates of various road use unit costs (value of time, crash costs, vehicle operating costs, etc.) for Australia, and these are suitable for using in appraisal and as input parameter values of time and vehicle operating cost in the transport modelling process. Part 1 of this volume provides a detailed coverage of parameter values for public transport appraisal.

6.3 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.

6.4 Transport network validation

In general terms, transport network validation will usually include:

- comparing observed modelled travel times with observed travel times
- 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, and
- checking public transport routes in terms of stopping patterns, timetables and frequency.

6.5 Assignment validation

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

- validation should be against independent data (e.g. traffic counts, screenline volumes, 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 C, and
- 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 C, provides 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. However, there is increasing interest in identifying not only how models perform globally against observed data, but also how changing the inputs changes the model outputs.

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 (e.g. increase fares by 10 per cent 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, and
- modifying the zonal trip generation (employment and population levels) and noting the change in vehicle-kilometres of travel on the highway network.

7 Forecasts

A forecast year model is used to derive forecasts of transport network system use for input into the economic appraisal process. A forecast year model is usually comprised of:

- demographic data for the forecast years to develop travel demands
- 'do-minimum' and 'do-something' network models for the forecast year, and
- forecast year highway and public transport assignments.

7.1 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.

7.2 Networks

The 'do-minimum' network should be based on the validated Reference (Base) Year network and should include all the supply-side proposals (i.e. committed highway and public transport infrastructure) and operational proposals that are expected to be implemented by the forecast year.

The 'do-something' network should be based on the 'do-minimum' 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 'do-minimum' network.

7.3 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 'do-minimum' network and assigning the 'do-minimum' demand to the Option Case network. Appendix D 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.

7.4 Sensitivity tests

Sensitivity tests around a 'Do-Minimum' 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, and
- an assessment of complementary schemes.

8 Transport model audit

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, and
- 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 (inventory surveys, timetables, etc.), and
  - description of demographic and employment data (sources, summary statistics, etc.).
- A document reporting on model specification and model estimation:
  - model structures, variables and coefficients
  - outputs of statistical estimation procedures, and
  - model fit to data.
- Evidence of validation:
  - fit to independent data
  - comparison with other models, and
  - sensitivity tests and elasticities.

- Description of the forecast year inputs (networks, demographic data, economic assumptions, etc.):
  - sources of data, and
  - 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, etc.):
  - comparison with other forecasts, where available
  - comparison with historic trends, if relevant, and
  - reasoned explanations of the forecasts (the sources of the diverted traffic, the reasons for diversion—size of time saving, etc.).
- A record of model applications.

Appendix E provides a Model Audit Checklist.

APPENDIX

B The transport modelling process

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

B.1 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 study.
- Identify how transport modelling can contribute to informing the study goals and objectives.
- 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, and
  - transport network performance indicators e.g. vehicle-hours, vehicle-distance, passenger-kilometres, levels of congestion, average speeds and travel times.

B.2 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), and
- stated preference data.

B.3 Model calibration and validation

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

B.4 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.

B.5 Options modelling

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

- total vehicle-kilometres and vehicle-hours of travel
- total network travel time
- vehicle operating and travel time costs, and
- emissions—CO_2, CO, NO_x, CH_4, HC, PM10, PM2.5.

The modelled options should be compared to the calibrated and validated Base Case model on the basis of:

- traffic volumes, and
- network performance indicators.

B.6 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, and
- an assessment of complementary schemes.

B.7 Economic appraisal

Volume 3 and Part 1 of this volume provide a detailed coverage of economic appraisal.

B.8 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 the following:

- 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, and
- documentation of the economic appraisal.

APPENDIX

C Reference (Base) model validation criteria

The following criteria should be used 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, then 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.

C.1 Link flows

(a) 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.

(b) Scatter plot of modelled and observed flows

- Produce an XY scatter plot of modelled versus observed flows for:
  - all individual links
  - freeway links, and
  - screenlines.
- Superimpose the y=x line on each plot. Report on the R^2 for each plot.

(c) GEH statistic

- The GEH statistic is a form of Chi-squared statistic, which 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).

(d) Percentage root mean square error (RMSE)

- The RMSE applies to the entire network and has the following formulation:

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

where:

V_1 = modelled flow (in vehicles/hour)

V_2 = observed flow (in vehicles/hour)

C = number of count locations in set.

C.2 Travel times

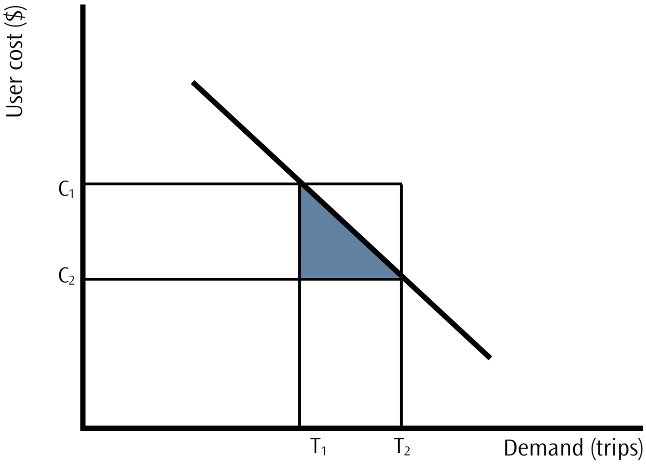
- Provide a comparison of modelled and observed travel times as an XY scatter plot for each time period modelled. The scatter plot should also include the 95 per cent confidence limits for the modelled data.

C.3 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 per cent, and
  - normalised gap δ; 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 one per cent between successive assignment iterations.

APPENDIX

D Induced benefits calculation



Benefits due to 'do-minimum' demand (T_1)	$C_1T_1 - C_2T_2$	1
Benefits due to generated/induced demand	$\dfrac{C_1T_2 - C_1T_1 - C_2T_2 + C_2T_1}{2}$	2
Total benefits	$C_1T_1 - C_2T_2 + \dfrac{C_1T_2 - C_1T_1 - C_2T_2 + C_2T_1}{2}$	3

where:

T_1 = the number of trips in the 'Do-Minimum' Case

T_2 = the number of trips in the Option Case

C_1 = the cost of travel in the 'Do-Minimum' Case

C_2 = 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 whilst keeping the paths and link speeds unchanged (i.e. 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 whilst keeping the paths and link speeds unchanged (i.e. 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).

	‘DO MINIMUM’ DEMAND T_1	OPTION CASE DEMAND T_2
‘Do-minimum’ cost – C_1	C_1T_1	C_1T_2
Option Case cost – C_2	C_2T_1	C_2T_2

APPENDIX

E

Model audit checklist

E.1 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 (public transport and highway) included and their details
- the time periods modelled
- the vehicle types modelled, and
- how the external trips are modelled.

E.2 Data sources

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

- transport network data (eg. link lengths, link types, free flow speeds, capacities, number of lanes)
- travel data and collection methods (traffic counts, origin–destination surveys), and
- other.

E.3 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, and
- the basis for the development of a commercial vehicle matrix.

E.4 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), and
- any intersection modelling being undertaken and the basis it is being undertaken on.

E.5 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, and
- comparisons with other forecasts (if any).

APPENDIX

F

Abbreviations

AAD	Average Absolute Difference
ABS	Australian Bureau of Statistics
AON	All-or-nothing
AST	Appraisal Summary Table
ATC	Australian Transport Council
BAH	Booz Allen Hamilton
BCA	Benefit–cost analysis
BCR	Benefit–cost ratio
BTCE	Bureau of Transport and Communications Economics
CATI	Computer aided telephone interview
CCD	Census Collection District
CNG	Compressed Natural Gas
COAG	Council of Australian Governments
DMU	Diesel Multiple Unit
EMU	Electric Multiple Unit
GC	Generalised cost
GEH	GEH formula
GST	Goods and Services Tax
GT	Generalised time
IVF	In-vehicle factor
LF	Loaf factors
MSC	Mode-specific constant
MSF	Mode-specific factors
NPV	Net present value
NZ	New Zealand

O–D	Origin–destination
PCIE	Pacific Consulting Infrastructure Economists
PDFH	Passenger Demand Forecasting Handbook
PVR	Peak vehicle requirement
RAAD	Relative Average Absolute Difference
RAC	Road-agency cost
RMSE	Root mean square error
RTT	Round trip time
SA	South Australia
SCOT	Standing Committee on Transport
TDM	Travel demand management
UK	United Kingdom
VATS	The Victorian Activity and Travel Survey
VOC	Vehicle operating cost
VoT	Values of time
Vkt	Vehicle-kilometres
WTP	Willingness-to-pay

APPENDIX

G Glossary

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

Accessibility	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.
Aggregate data	Data that relates to a mass or group of people, vehicles or area. The collective properties of the variable are of interest.
AON assignment	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.
Capacity restraint	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.
Centroid connector	Imaginary links that represent the street network within a zone. They 'connect' trips from a zone to the modelled network.
Destination	The point or area of termination of a trip.
Disaggregate data	Data at the level of individual persons, households, etc.
Employment	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.
External trip	A trip that has either an origin or destination, but not both, in the study area.
Equilibrium assignment	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.
Generalised cost	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.
Gravity model	A model that distributes the number of trips between all trip-producing zones and trip-attracting zones.
Home	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.
Home-based trip	A trip that has its origin or destination at the home end. It may be a person trip, vehicle trip, walk trip, bicycle trip or public transport trip.
Household	A person or persons living in the one home.

Incremental assignment	The process by which flows between all zone pairs are loaded onto the network in pre-specified steps.
Internal trip	A trip that has both its origin and destination in the study area.
Link	A section of a highway or public transport network defined by a node at each end.
Logit model	Also known as the 'mulitnomial logit model', it calculates the proportion of trips that will select a specific mode or activity.
Minimum path	The route between a zone pair that has the least cost (time, distance, generalised) in comparison to all other possible routes.
Minimum path tree	All the minimum paths between zone pairs that emanate from an origin zone.
Modal split	The division of trips between different modes of travel (private transport, public transport).
Node	A numbered point on a network representing a centroid or a junction of two or more links.
Non home-based trip	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.
Origin	The point or zone at which a trip begins.
Person trip	Any trip made by a person.
Screenline	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.
Travel time	The time taken to travel between two points.
Trip	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.
Trip assignment	The process by which the flows between zones derived from the trip distribution process are allocated to the minimum path routes through a network.
Trip attraction	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.
Trip distribution	The process by which the total numbers of trips originating in each zone are distributed among all the possible destination zones.
Trip end	Either a trip origin or trip destination.
Trip generation	The process by which the total number of trips beginning, or ending, in a zone are determined, based on demographic, socio-economic and land use characteristics.
Trip matrix	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.
Trip production	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.
Trip purpose	This can be defined as work trips, school trips, recreational or social trips and shopping trips.
Zone	A portion of the study area with homogenous land use, socio-economic and demographic characteristics.
Zone centroid	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.

APPENDIX

H

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